

Contents	
General Validations	1
Obesity	3
Paediatric & Children	4
Ethnic Groups	5
Athlete Groups	7
Literature Reviews	7

#### Useful Links

COSMED Homepage

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BOD POD Page

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## BOD POD

### General Validations

#### Reliability of BOD POD Measurements Remain High Following a Short Duration Low-Carbohydrate Diet.

*Greer BK, Edsall KM, Greer AE. Int J Sport Nutr Exerc Metab. 2015 Sep 24*

**PURPOSE:** The purpose of the present study was to determine whether expected changes in body weight via a three day low-carbohydrate (CHO) diet will disrupt the reliability of air displacement plethysmography measurements via BOD POD.

**METHODOLOGY:** Twenty-four subjects recorded their typical diets for three days prior to BOD POD and seven-site skinfold analyses. Subjects were matched for lean body mass and divided into low-CHO (LC) and control (CON) groups. The LC group was given instruction intended to prevent over 50 grams/day of carbohydrate consumption for three consecutive days, while the CON group replicated their previously recorded diet. Body composition measurements were repeated post-dietary intervention.

**RESULTS:** Test-retest reliability measures were significant ( $p < 0.01$ ) and high for body fat percentage in both the LC and CON groups ( $r = 0.993, 0.965$ , respectively). Likewise, skinfold analysis for body fat percentage reliability was high in both groups ( $r = 0.996, 0.997$ , respectively). There were significant differences between first and second BOD POD measurements for body mass ( $72.9 \pm 13.3$  vs.  $72.1 \pm 13.0$  kg) and body volume ( $69.0 \pm 12.7$  to  $68.1 \pm 12.2$  L) in the LC group ( $p < 0.05$ ). However, there were no differences ( $p > 0.05$ ) in BOD POD-determined body fat percentage, lean body mass, or fat mass between the first and second trial in either groups.

**CONCLUSIONS:** Body composition measures via BOD POD and seven-site skinfolds remain reliable after three days of a LC diet despite significant decreases in body mass.

#### Test-retest reliability of the Bod Pod: the effect of multiple assessments.

*Tucker LA, Lecheminant JD, Bailey BW. Percept Mot Skills. 2014 Apr;118(2):563-70.*

**PURPOSE:** The Bod Pod uses air-displacement plethysmography to estimate body fat percentage (BF%). This study was designed to assess the test-retest reliability of the Bod Pod.

**METHODOLOGY:** The study included 283 women (M age = 41.0 yr., SD = 3.0). Each participant was tested at least twice in the Bod Pod. Results showed no significant mean difference between the test and the retest. The intraclass correlation coefficient (ICC) was .991. However, the absolute value of the initial trial differences (absolute mean difference) was .96 (SD = .90). A third assessment of BF% was taken when the initial trial difference was greater than 1 percentage point, and the two closest values were compared.

**RESULTS:** This strategy resulted in a significant decrease in the absolute mean difference, from .96 to .55 percentage point, and ICC increased to .998.

**CONCLUSIONS:** The Bod Pod appears to measure body fat percentage reliably; however, findings suggest that multiple trials may be necessary to detect small treatment effects.

#### Reliability of air displacement plethysmography.

*Anderson DE. J Strength Cond Res. 2007 Feb;21(1):169-72.*

**PURPOSE:** 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.

**METHODOLOGY:** 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 x m(-2), and percentage body fats (BF) of 7.9-43.1%. Two estimates of BF were performed on 3 days.

**RESULTS:** 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.

**CONCLUSIONS:** 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.

### **Reliability of air displacement plethysmography in a large, heterogeneous sample.**

*Noreen EE, Lemon PW. Med Sci Sports Exerc. 2006 Aug;38(8):1505-9.*

**PURPOSE:** Several studies have assessed the validity of air displacement plethysmography (ADP), but few have assessed the reliability of ADP using a large, heterogeneous sample. This study was conducted to determine the reliability of ADP using the Bod Pod in a large, heterogeneous sample.

**METHODOLOGY:** A total of 980 healthy men and women (30 +/- 15 yr, mean +/- SD) completed two body composition assessments separated by 15-30 min. All testing was done in accordance with the manufacturer's instructions.

**RESULTS:** A significant correlation ( $r = 0.992, P = 0.001$ ) was found between body density (BD) 1 (1.046 +/- 0.001 kg.L(-1); mean +/- SEM) and BD 2 (1.046 +/- 0.001 kg.L(-1)). A paired t-test revealed no significant difference between BD 1 and 2 ( $P = 0.935$ ). The coefficient of variation (CV) for BD was 0.15%. A significant intraclass correlation coefficient (ICC) was found for BD (ICC = 0.996,  $P = 0.001$ ), and the standard error of measurement (SEM) was 0.001 kg.L(-1). Body mass (BM) 1 and 2 were correlated significantly ( $r = 0.999, P = 0.001$ ); however, a significant ( $P = 0.001$ ) decrease was seen from BM 1 (75.510 +/- 0.461 kg) to BM 2 (75.497 +/- 0.461 kg). Body volume (BV) tended to decrease ( $P = 0.08$ ) from BV 1 (69.900 +/- 0.449 L) to BV 2 (69.884 +/- 0.449 L).

**CONCLUSION:** ADP using the Bod Pod appears to assess BD reliably; however, the observed CV suggests that multiple trials are necessary to detect small treatment effects.

### **Interdevice variability in percent fat estimates using the BOD POD.**

*Ball SD. Eur J Clin Nutr. 2005 Sep;59(9):996-1001.*

**PURPOSE:** To evaluate interdevice reliability in body density (Db) and percent body fat (%BF) using air-displacement plethysmography, the BOD POD (BP) body composition system.

**METHODOLOGY:** Duplicate body composition tests were performed in immediate succession on 50 adults (26 M, 24 F; 21-53 y) using two BP units located in the same body composition laboratory.

**RESULTS:** Mean Db and %BF between BP1 and BP2 did not differ significantly for men (DeltaDb = 0.0003 +/- 0.0008 g/ml,  $P = 0.632$ ; Delta%BF = 0.1 +/- 1.3,  $P = 0.665$ ), while for women, there were small but significant differences in Db and %BF between BP1 and BP2 (DeltaDb = 0.0018 +/- 0.0003 g/ml,  $P = 0.001$ ; Delta%BF = 0.8 +/- 1.1,  $P = 0.001$ ). The regression between %BF by BP1 and BP2 did not deviate significantly from the line of identity for both men and women ( $R^2 = 0.95$ , standard error of estimate (s.e.e.) = 1.23 %BF for men;  $R^2 = 0.97$ , s.e.e. = 1.13 %BF for women). Individual variations in %BF estimates between the two BP units were within acceptable ranges (95% limits of agreement = -2.5-2.7 %BF for men; -1.4-3.0 %BF for women), and there was no trend in individual differences as %BF varied ( $r = -0.19, P = 0.359$  for men;  $r = 0.09, P = 0.677$  for women). Other subject characteristics, including age, body mass, height, and body mass index, did not significantly contribute to the differences in %BF estimates by the two BP units.

**CONCLUSIONS:** No clinically significant differences in Db and %BF estimates exist between the BP units, and the interdevice variability of the BP has minimal impact on %BF estimates. Further, test-to-test reliability between BP units appears to be as good as within one unit.

### **Precision of measurement and body size in whole-body air-displacement plethysmography.**

*Wells JC, Fuller NJ. Int J Obes Relat Metab Disord. 2001 Aug;25(8):1161-7.*

**PURPOSE:** To investigate methodological and biological precision for air-displacement plethysmography (ADP) across a wide range of body size.

**METHODOLOGY:** Repeated measurements of body volume (BV) and body weight (WT), and derived estimates of density (BD) and indices of fat mass (FM) and fat-free mass (FFM). Sixteen men, aged 22-48 y; 12 women, aged 24-42 y; 13 boys, aged 5-14 y; 17 girls, aged 5-16 y. BV and WT were measured using the Bodpod ADP system from which estimates of BD, FM and FFM were derived. FM and FFM were further adjusted for height to give fat mass index (FMI) and fat-free mass index (FFMI).

**RESULTS:** ADP is very precise for measuring both BV and BD (between 0.16 and 0.44% of the mean). After removing two outliers from the database, and converting BD to body composition, precision of FMI was <6% in adults and within 8% in children, while precision of FFMI was within 1.5% for both age groups.

**CONCLUSION:** ADP shows good precision for BV and BD across a wide range of body size, subject to biological artefacts. If aberrant values can be identified and rejected, precision of body composition is also good. Aberrant values can be identified by using pairs of ADP procedures, allowing the rejection of data where successive BD values differed by >0.007 kg/l. Precision of FMI obtained using pairs of procedures improves to <4.5% in adults and <5.5% in children.

### **Body composition in children and adults by air displacement plethysmography.**

*Nuñez C, Kovera AJ, Pietrobelli A, Heshka S, Horlick M, Kehayias JJ, Wang Z, Heymsfield SB. Eur J Clin Nutr. 1999 May;53(5):382-7.*

**PURPOSES:** Air displacement plethysmography (ADP) may provide a partial alternative to body density (Bd) and therefore body composition measurement compared to conventional hydrodensitometry (Hd) in children. As there are no evaluation studies of ADP in children, this study had a two-fold objective: to compare Bd estimates by ADP and Hd; and to compare fat estimates by both ADP and Hd to fat estimates by another reference method, dual energy X-ray absorptiometry (DXA).

**METHODOLOGY:** One hundred and twenty subjects (66 females/54 males) who ranged in age from 6-86 y and in body mass index (BMI, kg/m<sup>2</sup>) from 14.1-40.0 kg/m<sup>2</sup> met study entry criteria. Cross-sectional study of healthy children (age < or = 19 y) and adult group for comparison to earlier studies. Each subject completed ADP, Hd, and DXA studies on the same day. Only subjects with subjectively-judged successful Hd studies were entered into the study cohort.

**RESULTS:** There was a high correlation between Bd by ADP and Hd ( $Bd = 0.11 + 0.896 \times Hd$ ;  $r = 0.93$ ,  $SEE = 0.008 \text{ g/cm}^3$ ,  $P < 0.0001$ ), although the regression line slope and intercept differed significantly from 1 and 0, respectively. Additional analyses localized a small-magnitude Bd bias in the child ( $n = 48$ ) subgroup. Both ADP and Hd %fat estimates were highly correlated ( $r > 0.9$ ,  $P < 0.0001$ ) with %fat by DXA in child and adult subgroups. Bland-Altman analyses revealed no significant %fat bias by either ADP or Hd vs DXA in either children or adults, although a bias trend ( $P = 0.11$ ) was detected in the child subgroup.

**CONCLUSION:** With additional refinements, the air displacement plethysmography system has the potential of providing an accurate and practical method of quantifying body fat in children as it now does in adults.

### **Evaluation of a new air displacement plethysmograph for measuring human body composition.**

*McCrary MA, Gomez TD, Bernauer EM, Molé PA. Med Sci Sports Exerc. 1995 Dec;27(12):1686-91.*

**PURPOSE:** A new air displacement plethysmograph, the BOD POD (BP), was evaluated in comparison to hydrostatic weighing (HW).

**METHODOLOGY:** Sixty-eight adult subjects (26 F, 42 M) varying widely in age (range 20-56 yr), ethnicity, and fatness participated in this study. Same-day test-retest reliability was assessed in a subsample of 16 subjects (9 F, 7 M) and validity was assessed in all subjects ( $N = 68$ ).

**RESULTS:** The test-retest coefficients of variation (CV) for %FAT measured by BP (%FATBP) and HW (%FATHW) were not significantly different (1.7% +/- 1.1% and 2.3% +/- 1.9% for BP and HW, respectively (mean +/- SD)), indicating excellent reliability for both methods. Validity of percent fat measured by the BP (%FATBP) was also excellent. The mean difference in %FAT (BP - HW) was -0.3 +/- 0.2 (SEM), with a 95% confidence interval of -0.6 to 0 %FAT. The regression equation ( $\%FATHW = 1.86 + 0.94 \times \%FATBP$ ;  $r^2 = 0.93$ ,  $SEE = 1.81$ ) was not significantly different from the line of identity ( $\%FATHW = \%FATBP$ ), and did not differ by gender.

**CONCLUSIONS:** These findings indicate that the BOD POD is a highly reliable and valid method for determining %FAT in adult humans in comparison to HW. This new method has several advantages over HW in that it is quick, relatively simple to operate and may be able to accommodate special populations such as the obese, elderly, and disabled.

### **A new air displacement method for the determination of human body composition.**

*Dempster P, Aitkens S. Med Sci Sports Exerc. 1995 Dec;27(12):1692-7.*

**PURPOSE:** A new device based on the plethysmographic measurement of body volume has been developed for the purpose of estimating human body composition. The device, the BOD POD Body Composition System, uses the relationship between pressure and volume to derive the body volume of a subject seated inside a fiberglass chamber. Derivation of body volume, together with measurement of body mass, permits calculation of body density and subsequent estimation of percent fat and fat-free mass. Critical issues which have hampered prior plethysmographic approaches are discussed.

**METHODOLOGY:** The present system's ability to measure the volume of inanimate objects was evaluated for accuracy, reliability, and linearity.

**RESULTS:** Twenty successive tests of a known volume (50,039 ml) on two separate days produced values of 50,037 +/- 12.7 ml and 50,030 +/- 13.5 ml (mean +/- SD) for each day, respectively. The CV for these series were 0.025% and 0.027%. Further testing across a wide range of volumes approximating human size (25-150 l) produced the following regression equation where  $y =$  measured volume (l) and  $x =$  actual volume (l):  $y = 0.9998x - 0.0274$ ,  $r^2 = 1.0$ ,  $SEE = 0.004 \text{ l}$ .

**CONCLUSIONS:** The resultant device is likely to enhance opportunities for the quick, simple and noninvasive measurement of body composition for both research and clinical applications.

## Obesity

### **Body composition assessment in overweight women: validation of air displacement plethysmography.**

*Wingfield HL, Smith-Ryan AE, Woessner MN, Melvin MN, Fultz SN, Graff RM. Clin Physiol Funct Imaging. 2014 Jan;34(1):72-6. doi: 10.1111/cpf.12067. Epub 2013 Jul 15.*

**PURPOSE:** The purpose of this study was to evaluate the validity and reliability of air displacement plethysmography (ADP) compared to a dual energy x-ray absorptiometry (DXA) criterion for body composition measurement in overweight and obese women ( $BMI \geq 25.0 \text{ kg m}^2$ ).

**METHODOLOGY:** Twenty-four overweight and obese women (Mean  $\pm$  SD; Age:  $36.6 \pm 12.0$  years; Height:  $166.4 \pm 5.8$  cm; Weight:  $86.5 \pm 14.2$  kg; Body Fat:  $38.5 \pm 3.7\%$ ; BMI:  $31.3 \pm 5.5 \text{ kg m}^2$ ) were tested after an 8-h fast. Fat mass (FM), fat-free mass (FFM) and percent body fat (%BF) were measured by ADP and compared to values determined by the DXA criterion. FFM from DXA was calculated as lean mass plus bone mineral content. A paired samples t-test was used to test for significant differences in the body composition variables between methods. A one-way ANOVA along with intraclass correlation coefficient (ICC), SEM, %SEM and MD was used to represent reliability.

**RESULTS:** Validity data comparing ADP and DXA demonstrated no significant difference in FM (ADP-DXA FM =  $0.99 \text{ kg}$ ;  $P = 0.113$ ), FFM ( $0.98 \text{ kg}$ ;  $P = 0.115$ ) and %BF ( $1.56\%$ ;  $P = 0.540$ ). Reliability data for ADP between the first and second trials showed no significant difference in FM ( $P = 0.168$ ; ICC =  $0.994$ ; SEM =  $0.668$ ), FFM ( $P = 0.058$ ; ICC =  $0.973$ ; SEM =  $0.892$ ) or %BF ( $P = 0.121$ ; ICC =  $0.971$ ; SEM =  $0.813$ ).

**CONCLUSIONS:** For overweight and obese women, ADP was found to be a valid measure of FM, FFM and %BF when compared with DXA. The reliability of ADP was supported for all body composition variables.

### **Air displacement plethysmography: validation in overweight and obese subjects.**

*Ginde SR, Geliebter A, Rubiano F, Silva AM, Wang J, Heshka S, Heymsfield SB. Obes Res. 2005 Jul;13(7):1232-7.*

**PURPOSE:** Patients with moderate and severe obesity, because of their physical size, often cannot be evaluated with conventional body composition measurement systems. The BOD POD air displacement plethysmography (ADP) system can accommodate a large body volume and may provide an opportunity for measuring body density (D(b)) in obese subjects. D(b) can be used in two- or three-compartment body composition models for estimating total body fat in patients with severe obesity. The purpose of this study was to compare D(b) measured by ADP to D(b) measured by underwater weighing (UWW) in subjects ranging from normal weight to severely obese.

**METHODOLOGY:** D(b) was measured with UWW and BOD POD in 123 subjects (89 men and 34 women; age,  $46.5 \pm 16.9$  years; BMI,  $31.5 \pm 7.3 \text{ kg/m}^2$ ); 15, 70, and 10 subjects were overweight ( $25 < \text{or} = \text{BMI} < 30 \text{ kg/m}^2$ ), obese ( $30 < \text{or} = \text{BMI} < 40 \text{ kg/m}^2$ ), and severely obese ( $\text{BMI} \geq 40 \text{ kg/m}^2$ ), respectively.

**RESULTS:** There was a strong correlation between D(b) (kilograms per liter) measured by UWW and ADP ( $r = 0.94$ , standard error of the estimate =  $0.0073 \text{ kg/L}$ ,  $p < 0.001$ ). Similarly, percent fat estimates from UWW and ADP using the two-compartment Siri equation were highly correlated ( $r = 0.94$ , standard error of the estimate =  $3.58\%$ ,  $p < 0.001$ ). Bland-Altman analysis showed no significant bias between D(b) measured by UWW and ADP. After controlling for D(b) measured by ADP, no additional between-subject variation in D(b) by UWW was accounted for by subject age, sex, or BMI.

**CONCLUSIONS:** Body density, an important physical property used in human body composition models, can be accurately measured by ADP in overweight and obese subjects.

### **Body composition measurement in severe obesity.**

*Das SK. Curr Opin Clin Nutr Metab Care. 2005 Nov;8(6):602-6.*

**PURPOSE:** Severe obesity is accompanied by large increases in fat mass and alterations in the composition of fat free mass, in particular total body water and its extracellular compartment. The physical size limitations imposed by severe obesity, and variations in body composition from that of normal weight, pose tremendous challenges to the measurement of body composition.

**METHODOLOGY:** This review focuses on some of the methodological and practical issues associated with the use of common body composition methods, and identifies available published information on feasible methods for use in the severely obese.

**RESULTS:** There is little published research regarding what body composition methods can be used with confidence in the severely obese populations. A simple three-compartment model combining measurements of body density by air displacement plethysmography and total body water by bio-electrical impedance can provide measurements of percentage body fat in the severely obese that are comparable with a traditional, highly technical three-compartment model requiring facilities such as isotope ratio mass spectrometry along with a substantial technical expertise.

**CONCLUSIONS:** This review highlights some of the basic challenges faced by researchers and clinicians when conducting body composition assessments in severely obese patients. A simple three-compartment model that is accurate and easy to perform appears to be promising for use in this population. Further research is needed, however, on this and other feasible methods of body composition assessment in a diverse group of severely obese people.

## Paediatric & Children

### **Air-displacement plethysmography pediatric option in 2-6 years old using the four-compartment model as a criterion method.**

*Fields DA, Allison DB. Obesity (Silver Spring). 2012 Aug;20(8):1732-7. doi: 10.1038/oby.2012.28. Epub 2012 Mar 15.*

**PURPOSE:** The objective of this study was to determine the accuracy, precision, bias, and reliability of percent fat (%fat) determined by air-displacement plethysmography (ADP) with the pediatric option against the four-compartment model in 31 children ( $4.1 \pm 1.2$  years,  $103.3 \pm 10.2$  cm,  $17.5 \pm 3.4$  kg).

**METHODOLOGY:** %Fat was determined by (BOD POD Body Composition System; COSMED USA, Concord, CA) with the pediatric option. Total body water (TBW) was determined by isotope dilution ( $(2)H(2)O$ ; 0.2 g/kg) while bone mineral was determined by dual-energy X-ray absorptiometry (DXA) (Lunar iDXA v13.31; GE, Fairfield, CT and analyzed using enCore 2010 software). The four-compartment model by Lohman was used as the criterion measure of %fat.

**RESULTS:** The regression for %fat by ADP vs. %fat by the four-compartment model did not deviate from the line of identity where:  $y = 0.849(x) + 4.291$ . ADP explained 75.2% of the variance in %fat by the four-compartment model while the standard error of the estimate (SEE) was 2.09 %fat. The Bland-Altman analysis showed %fat by ADP did not exhibit any bias across the range of fatness ( $r = 0.04$ ;  $P = 0.81$ ). The reliability of ADP was assessed by the coefficient of variation (CV), within-subject SD, and Cronbach's. The CV was 3.5%, within-subject SD was 0.9%, and Cronbach's was 0.95.

**CONCLUSIONS:** In conclusion, ADP with the pediatric option is accurate, precise, reliable, and without bias in estimating %fat in children 2-6 years old.

### **Comparison of body composition methods in overweight and obese children.**

*Gately PJ, Radley D, Cooke CB, Carroll S, Oldroyd B, Truscott JG, Coward WA, Wright A. J Appl Physiol (1985). 2003 Nov;95(5):2039-46.*

**PURPOSE:** The objective of the present study was to investigate the accuracy of percent body fat (%fat) estimates from dual-energy X-ray absorptiometry, air-displacement plethysmography (ADP), and total body water (TBW) against a criterion four-compartment (4C) model in overweight and obese children.

**METHODOLOGY:** A volunteer sample of 30 children (18 male and 12 female), age of (mean +/- SD)  $14.10 \pm 1.83$  yr, body mass index of  $31.6 \pm 5.5$  kg/m<sup>2</sup>, and %fat (4C model) of  $41.2 \pm 8.2\%$ , was assessed. Body density measurements were converted to %fat estimates by using the general equation of Siri (ADPSiri) (Siri WE. Techniques for Measuring Body Composition. 1961) and the age- and gender-specific constants of Lohman (ADPLoh) (Lohman TG. Exercise and Sport Sciences Reviews. 1986). TBW measurements were converted to %fat estimates by assuming that water accounts for 73% of fat-free mass (TBW73) and by utilizing the age- and gender-specific water contents of Lohman (TBWLoh).

**RESULTS:** All estimates of %fat were highly correlated with those of the 4C model ( $r > \text{or} = 0.95$ ,  $P < 0.001$ ;  $SE < \text{or} = 2.14$ ). For %fat, the total error and mean difference +/- 95% limits of agreement compared with the 4C model were 2.50,  $1.8 \pm 3.5$  (ADPSiri); 1.82,  $-0.04 \pm 3.6$  (ADPLoh); 2.86,  $-2.0 \pm 4.1$  (TBW73); 1.90,  $-0.3 \pm 3.8$  (TBWLoh); and 2.74,  $1.9 \pm 4.0$  DXA (dual-energy X-ray absorptiometry), respectively.

**CONCLUSIONS:** In conclusion, in overweight and obese children, ADPLoh and TBWLoh were the most accurate methods of measuring %fat compared with a 4C model. However, all methods under consideration produced similar limits of agreement.

### **Body composition techniques and the four-compartment model in children.**

*Fields DA, Goran MI. J Appl Physiol (1985). 2000 Aug;89(2):613-20.*

**PURPOSE:** The purpose of this study was to compare the accuracy, precision, and bias of fat mass (FM) as assessed by dual-energy X-ray absorptiometry (DXA), hydrostatic weighing (HW), air-displacement plethysmography (PM) using the BOD POD body composition system and total body water (TBW) against the four-compartment (4C) model in 25 children ( $11.4 \pm 1.4$  yr).



**RESULTS:** The regression between FM by the 4C model and by DXA deviated significantly from the line of identity (FM by 4C model =  $0.84 \times \text{FM by DXA} + 0.95 \text{ kg}$ ;  $R(2) = 0.95$ ), as did the regression between FM by 4C model and by TBW (FM by 4C model =  $0.85 \times \text{FM by TBW} - 0.89 \text{ kg}$ ;  $R(2) = 0.98$ ). The regression between FM by the 4C model and by HW did not significantly deviate from the line of identity (FM by 4C model =  $1.09 \times \text{FM by HW} + 0.94 \text{ kg}$ ;  $R(2) = 0.95$ ) and neither did the regression between FM by 4C (using density assessed by PM) and by PM (FM by 4C model =  $1.03 \times \text{FM by PM} + 0.88$ ;  $R(2) = 0.97$ ). DXA, HW, and TBW all showed a bias in the estimate of FM, but there was no bias for PM.

**CONCLUSIONS.** In conclusion, PM was the only technique that could accurately, precisely, and without bias estimate FM in 9- to 14-yr-old children.

## Ethnic Groups

### **A 4-compartment model based validation of air displacement plethysmography, dual energy X-ray absorptiometry, skinfold technique & bioelectrical impedance for measuring body fat in Indian adults**

*Rebecca Kuriyan, Tinku Thomas, Sangeetha Ashok, Jayakumar J, and Anura V. Kurpad. Indian J Med Res. May 2014 139(5): 700–707. PMID: PMC4140034*

**PURPOSE:** Many methods are available for measuring body fat of an individual, each having its own advantages and limitations. The primary objective of the present study was to validate body fat estimates from individual methods using the 4-compartment (4C) model as reference. The second objective was to obtain estimates of hydration of fat free mass (FFM) using the 4C model.

**METHODOLOGY:** The body fat of 39 adults (19 men and 20 women) aged 20–40 yr was estimated using air displacement plethysmography (ADP), dual energy X-ray absorptiometry (DEXA), 4-skinfold technique and bioelectrical impedance (BIA). Total body water was estimated using isotope dilution method.

**RESULTS:** All the methods underestimated body fat when compared to 4C model, except for DEXA and the mean difference from the reference was lowest for DEXA and ADP. The precision of the fat mass estimated from 4C model using the propagation of error was 0.25 kg, while the mean hydration factor obtained by the 4C model was found to be  $0.74 \pm 0.02$  in the whole group of men and women.

**CONCLUSIONS:** The results of the present study suggest that DEXA and ADP methods can provide reasonably accurate estimates of body fat, while skinfold and bioelectrical impedance methods require the use of population specific equations.

### **Body composition by the four-compartment model: validity of the BOD POD for assessing body fat in Mexican elderly.**

*Alemán-Mateo H, Huerta RH, Esparza-Romero J, Méndez RO, Urquidez R, Valencia ME. Eur J Clin Nutr. 2007 Jul;61(7):830-6. Epub 2007 Jan 17.*

**PURPOSE:** The aims of this study were to validate BOD POD in a wide sample of healthy and independent Mexican elderly men and women subjects using the 4-compartment (4C) model as the reference method, and to evaluate the assumptions of the densitometric two-compartment (2C) model.

**METHODOLOGY:** Cross-sectional study designed to assess body composition and validation of a method based on 2C model (BOD POD). Two hundred and two free-living subjects  $\geq 60$  years old were completed in this study. Body density and body fat were measured by the BOD POD, total body water by deuterium dilution and total body bone ash by dual energy X-ray absorptiometry. Body composition was determined using Baumgartner's equation.

**RESULTS:** Percent body fat by the 4C model was 31.2 and 42.5% in men and women, respectively ( $P < 0.001$ ). Group mean accuracy of body fat by BOD POD against that of the 4C model showed an effect of sex ( $P < 0.001$ ), but not the method ( $P = 0.27$ ). Results of individual accuracy showed no significant difference with the identity line and the slope was significantly different from zero or a slope similar to one. Precision assessed by model  $R(2)$  was high for all subjects and for men and women by separate. The standard error of the estimate was low for all and for men and women by separate. Bland and Altman analysis showed no significant bias.

**CONCLUSION:** The BOD POD technique is a valid and reliable method compared to the 4C model and it could be applied in subjects with similar physical and anthropometric characteristics to subjects of this study.

### **Clinical evaluation of body fat percentage in 11,833 Japanese measured by air displacement plethysmograph.**

*Miyatake N, Takenami S, Kawasaki Y, Kunihashi Y, Nishikawa H, Numata T. Intern Med. 2005 Jul;44(7):702-5.*

**PURPOSE:** Body fat percentage is commonly used for assessing body composition. We investigated the body fat percentage in Japanese subjects measured by air displacement plethysmograph (ADP) termed BOD POD.

**METHODOLOGY:** Cross-sectional clinical investigation study. We used data of 11,833 Japanese subjects aged 20–79 years [body mass index (BMI):  $23.2 \pm 3.7 \text{ kg/m}^2$ ]. Body fat percentage was evaluated by BOD POD. Anthropometric parameters such as height, weight, BMI, waist circumference and hip circumference were also measured.

RESULTS: Mean values of body fat percentage measured by BOD POD were 24.5+/-6.6% in men and 31.1+/-7.1% in women, mean values were also calculated as classified into aged groups in normal weight subjects. Body fat percentage was significantly correlated with BMI and 25.1% of men and 34.6% of women corresponded to 25 kg/m<sup>2</sup> in BMI.

CONCLUSION: Mean value of body fat percentage in normal weight Japanese subjects was revealed. In addition, the level of 25% in men and 35% in women corresponded to 25 kg/m<sup>2</sup> of BMI.

#### **Body composition predicted from skinfolds in African women: a cross-validation study using air-displacement plethysmography and a black-specific equation.**

*Dioum A, Gartner A, Maire B, Delpeuch F, Wade S. Br J Nutr. 2005 Jun;93(6):973-9.*

PURPOSE: Skinfold thickness (SF) measurements are commonly used for the indirect assessment of body composition. It is necessary to know how large the bias is when using Caucasian SF-based prediction equations Africans, as no specific equations exist. Our first aim was to test the validity of the equation of Durnin & Womersley for predicting body density from SF in Africans. The second aim was to determine the effect of calculating percentage body fat (%BF) from body density using a black-specific formula rather than the Siri equation, thus taking into account the higher fat-free mass (FFM) density in blacks than in whites.

METHODOLOGY: A total of 196 African women volunteered. Mean age was 29.5 (sd 8.7) years and mean BMI was 22.5 (sd 4.6) kg/m<sup>2</sup>. We compared body density values predicted from SF with those measured by air-displacement plethysmography, and %BF values obtained from body density using the Siri equation or the black-specific calculation.

RESULTS: The bias (reference minus prediction) was 0.0100 kg/cm<sup>3</sup> in body density ( $P < 10^{-4}$ ) and 6.5 % BF ( $P < 10^{-4}$ ), and the error (sd of the bias) 0.0097 kg/l and 4.5 % BF. With the black-specific equation, the bias was reduced by 1.9 % BF, while error remained similar. As the %BF prediction required an SF-based equation followed by a body density-based calculation, the lack of validity we observed in Africans may be due to known differences between blacks and whites in the distribution of subcutaneous adipose tissue and, as demonstrated, in the FFM density. Equations thus need to be established using SF values specific to Africans.

### **Athlete Groups**

#### **Body size and composition of National Football League players.**

*Kraemer WJ, Torine JC, Silvestre R, French DN, Ratamess NA, Spiering BA, Hatfield DL, Vingren JL, Volek JS. J Strength Cond Res. 2005 Aug;19(3):485-9.*

PURPOSE: The purpose of this study was to present a profile of body size and composition of National Football League (NFL) players prior to the start of the regular season.

METHODOLOGY: Fifty-three members of the Indianapolis Colts professional football team were measured for height, body mass, and percentage body fat using the BOD POD air-displacement plethysmography system during summer camp of the 2003 football season. These data were categorized by position for comparison with previous studies of NFL football players.

RESULTS: The relationships observed were as follows (= represents nonsignificant; > represents  $p < 0.05$ ): Height: Offensive Line = Defensive Line = Quarterbacks/Kickers/Punters = Tight Ends > Linebackers > Running Backs = Wide Receivers = Defensive Backs. Body Mass: Offensive Line = Defensive Line > Tight Ends = Linebackers > Running Backs = Quarterbacks/ Kickers/Punters > Wide Receivers = Defensive Backs. Percentage Body Fat: Offensive Line > Defensive Line > Quarterbacks/ Kickers/Punters = Linebackers = Tight Ends > Running Backs = Wide Receivers = Defensive Backs. Comparisons to teams in the 1970s indicate that body mass has increased only for offensive and defensive linemen; however, height and body fat among player positions have not dramatically changed. Furthermore, the body mass index is not an accurate measure or representation of body fat or obesity in NFL players.

CONCLUSIONS: These data provide a basic template for size profiles and differences among various positions and allow comparisons with other studies for changes in the NFL over the past 3 decades.

#### **Evaluation of air displacement for assessing body composition of collegiate wrestlers.**

*Utter AC, Goss FL, Swan PD, Harris GS, Robertson RJ, Trone GA. Med Sci Sports Exerc. 2003 Mar;35(3):500-5.*

PURPOSE: To evaluate the accuracy of air displacement plethysmography (ADP) by using the BOD POD in comparison with hydrostatic weighing (HW) in a collegiate wrestling population in hydrated and acutely dehydrated states.

METHODOLOGY: Body composition was determined by ADP, HW, and three-site skinfolds (SK) in 66 NCAA Division I collegiate wrestlers before and after acute dehydration (2.6% reduction in body mass). For all methods, body density (D(b)) was converted to percent body fat (%BF) by using the Brozek equation for Euro-Americans and the Schutte equation for African-Americans.

**RESULTS:** There were no significant differences between ADP and HW for D(b), %BF, and fat-free mass (FFM) in either the hydrated or dehydrated states. The standard errors of the estimate for %BF estimated from ADP with HW as the reference method were 2.12% (hydrated) and 2.16% (dehydrated); prediction errors were 2.35% (hydrated) and 2.49% (dehydrated). Bland-Altman plots of D(b) and %BF showed no systematic bias, and 64 out of 66 subjects fell within the 95% limits of agreement (mean difference  $\pm$  2 SD) for both variables. For SK, %BF was significantly higher than HW in both the hydrated and dehydrated state. All methods (ADP, HW, and SK) showed a significant decrease in FFM from the hydrated to the dehydrated state.

**CONCLUSIONS:** This study demonstrates that the BOD POD air displacement method provides similar estimates of D(b), %BF, and FFM when compared with HW in a heterogeneous collegiate wrestling population during hydrated and acutely dehydrated states. Pretest guidelines to ensure normal hydration status before body composition assessment using any method must be followed to minimize measurement error in %BF.

## Literature Reviews

### **Air Displacement Plethysmography: Cradle to Grave.**

*Fields DA, Gunatilake R, Kalaitzoglou E. Nutr Clin Pract. 2015 Mar 11. pii: 0884533615572443. [Epub ahead of print]*

**PURPOSE:** Differences in body composition are associated with increased disease risk in various stages of life. Despite numerous available methods in assessing body composition (air displacement plethysmography, dual-energy X-ray absorptiometry, bioelectrical impedance, hydrometry, and magnetic resonance imaging), due to innate technical limitations, the ability for one singular method to track body composition over the life span (ie, infancy to adulthood) is challenging and imperfect. The primary goal of this review is to determine if there are body composition methods that can accurately track body composition from infancy into adulthood.

**CONCLUSIONS:** After careful consideration and taking into account the best available scientific evidence, we feel air displacement plethysmography is the best instrument at this time for tracking body composition, starting in infancy and forward into adulthood, partly because it is the only "practical" clinical tool currently available for use during infancy.

### **Air-displacement plethysmography: here to stay**

*Fields DA, Higgins PB, Radley D. Current Opinion in Clinical Nutrition and Metabolic Care, 8(6):624-629, 2005.*

**PURPOSE:** Air-displacement plethysmography holds promise as an alternative to more traditional body composition techniques, although our understanding of air-displacement plethysmography is less than complete. Specifically, factors that influence its validity and application in certain populations, for example children, the obese, and athletes, must be better understood. This review will summarize recent findings on the validity and precision of air-displacement plethysmography and will focus primarily on papers published since 2004, with particular attention on its use in infants.

**RESULTS:** The most significant recent findings in the air-displacement plethysmography literature are mechanistic in nature specifically dealing with measurement issues such as heat, moisture, clothing, and recently, inter-device variability. It is important to recognize that air-displacement plethysmography can be a practical instrument in the evaluation of body composition in a wide range of populations.

**CONCLUSIONS:** Therefore, based on the body of literature that has emerged, air-displacement plethysmography appears to be a suitable and reliable instrument in the assessment of body composition. Of particular interest is its use in pediatric and obese individuals, areas requiring further study. Research is also needed to help us better understand sources of measurement error.

### **Body-composition assessment via air-displacement plethysmography in adults and children: a review.**

*Fields DA, Goran MI, McCrory MA. Am J Clin Nutr. 2002 Mar;75(3):453-67.*

**PURPOSE:** Laboratory-based body-composition techniques include hydrostatic weighing (HW), dual-energy X-ray absorptiometry (DXA), measurement of total body water (TBW) by isotope dilution, measurement of total body potassium, and multicompartiment models. Although these reference methods are used routinely, each has inherent practical limitations. Whole-body air-displacement plethysmography is a new practical alternative to these more traditional body-composition methods.



RESULTS: We reviewed the principal findings from studies published between December 1995 and August 2001 that compared the BOD POD method (Life Measurement, Inc, Concord, CA) with reference methods and summarized factors contributing to the different study findings. The average of the study means indicates that the BOD POD and HW agree within 1% body fat (BF) for adults and children, whereas the BOD POD and DXA agree within 1% BF for adults and 2% BF for children. Few studies have compared the BOD POD with multicompartiment models; those that have suggest a similar average underestimation of approximate 2-3% BF by both the BOD POD and HW. Individual variations between 2-compartment models compared with DXA and 4 -compartment models are partly attributable to deviations from the assumed chemical composition of the body. Wide variations among study means, -4.0% to 1.9% BF for BOD POD - HW and -3.0% to 1.7% BF for BOD POD - DXA, are likely due in part to differences in laboratory equipment, study design, and subject characteristics and in some cases to failure to follow the manufacturer's recommended protocol. Wide intersubject variations between methods are partly attributed to technical precision and biological error but to a large extent remain unexplained. On the basis of this review, future research goals are suggested.