CHAPTER 4

RESULTS

*Changes in Thoracic Gas Volume with Air Displacement Plethysmography after a Weight Loss Program in Overweight and Obese Women

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Running Title: **Changes in V_{TG} with ADP after weight loss**.

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ABSTRACT

Objective: This study was designed to study the impact of a 16-month weight loss program on measured and predicted thoracic gas volume (V_{TG}) measurements employed by air displacement plethysmography (ADP).

Design: Intervention study.

Setting: Outpatient University Laboratory, Lisbon, Portugal.

Subjects: Subjects were 85 overweight and obese women (39.0±5.7 y; 76.6±10.1 kg; 159.8±5.6 cm; 30.0±3.5 kg/m^2).

Methods: Subjects participated in a 16-month university-based weight-loss program. Body weight, body volume (Vb), body density (Bd), fat mass (FM), percent fat mass (%FM), fat-free mass (FFM) were assessed by ADP at baseline and at post-intervention (16 months). ADP requires the assessment of the V_{TG}, thus V_{TG} was measured directly and predicted utilizing ADP software. To obtain a measure of central adiposity, waist circumference was measured (WC). Additionally, dual-energy x-ray absorptiometry (Hologic QDR 1500) was also used for body composition assessement.

Results: Significant differences between the baseline and post-weight loss intervention were observed for body weight and composition (Vb, Db, %FM, FM, FFM) and measures of V_{TG} (measured: Δ= 0.2 L, $p<0.001$; predicted: Δ= 0.01 L, $p<0.010$) variables. Measured V_{TG} change was negatively associated with the change in the WC ($p=0.008$). Linear regression analysis results indicated that %FM using the measured and predicted V_{TG} explained 72% and 76% of the variance in %FM changes using DXA.

Conclusion: In conclusion, after weight loss, measured V_{TG} increased significantly between baseline and post weight-loss intervention. This was partially attributed to

changes is the WC, which is an indicator central adiposity. Consequently, measured and predicted V_{TG} should not be used interchangeably in body composition changes assessment.

Key words: Waist circumference; Weight loss; Body composition; Air Displacement Plethysmography; Thoracic Gas Volume.

INTRODUCTION

Weight loss intervention programs typically emphasize a loss in body weight as the primary outcome, just as important though, is a loss in fat mass. Therefore, the need for accurate techniques in the assessment of body composition in weight loss clinical programs is important.

There are several body composition instruments that can be applied in a clinical setting (1). Recently, air-displacement plethysmography (ADP) has been used for measuring human body composition (i.e. BOD POD; Life Measurement Incorporated, Concord, CA), in part because of its wide applicability to many diverse populations and its relative ease both on the subject and tester as compared to more traditional techniques. This equipment has been widely validated against reference methods in healthy children, adolescents, adults, and elderly (2-11). Furthermore, test-retest reliability, between-day variability, within-subject variability, and between instrument variability appear to be good to excellent (12-14). Other studies have also assessed the importance of selected methodological issues associated with ADP such as the effects of clothing, hair, and skin surface area to measure Vb with adequate accuracy (13, 15).

Air-displacement plethysmography utilizes the inverse relationship between pressure and volume (Boyle's law) to measure body volume (Vb) as described by Dempster and Aitkens (16). Interestingly Vb determined by Boyle's law is underestimated by 40% of the thoracic gas volume (V_{TG}) partly because the air in the lungs is isothermic is 40% more compressible than adiabatic air. Thus, failure to correct for this phenomenon will result in an overestimation of total body density (Db) and, consequently, an underestimation of percent fat mass (%FM), therefore measurement of V_{TG} by the BOD POD is incorporated into the testing procedure (17). Alternatively, the BOD POD provides the use of a predicted V_{TG} ($V_{TGPredicted}$) (18). The validity of using the $V_{TGPredicted}$ in place of the measured V_{TG} ($V_{TGMeasured}$) to determine %FM was studied in a few cross-sectional studies with mixed results (19, 20). Accordingly, no differences were found between measured vs. predicted V_{TG} in different age groups.

Changes in body weight and composition (commonly seen in a weight loss program) may result in functional alterations in the V_{TG}. Refsum et al (21) has reported a change in lung function (i.e. increased filling of the lungs, improved dynamic function, reduced ventilation disturbances) following weight loss. Moreover, Wannamethee et al. (21-23) concluded that total body fat and central adiposity measured by waist circumference is inversely associated with lung function in non-obese and obese elderly men after adjusting for confounders such as age and height. Hence, functional changes in the measured V_{TG} may be an important methodological issue that needs to be addressed within the scope of the BOD POD in general and weight loss programs specifically. Therefore, the purpose of this study was two-fold: to compare changes between the measured and predicted V_{TG} following a 16-month weight loss intervention program and to understand the effect of confounders (e.g. waist circumference) on the measured V_{TG} in overweight and obese and women.

METHODS

Subjects

Subjects were recruited from the Lisbon community for a sixteen month weight management program through newspaper ads, the internet, and flyers. Eligibility into the study required subjects: 1) > 24 years, 2) pre-menopausal, 3) currently not pregnant nor trying to become pregnant, 4) body mass index (BMI) between $\geq$25 kg/m^2 and <40 kg/m^2, and 5) free of major diseases. After several orientation sessions, 152 women enrolled into the program. During the run-in phase, four women decided not to participate (reporting time and scheduling conflicts), four did not comply with testing requirements and were excluded, three women were pregnant or were trying to become pregnant, and one subject was found ineligible due to medical reasons (untreated hyperthyroidism), leaving a total of 140 women who started the intervention. An initial visit with the study physician ensured that subjects met all the medical inclusion criteria. All participants agreed to refrain from participating in any other weight loss program and gave written informed consent prior to participation in the study. The research *design of the 16-month weight loss program is described in detail elsewhere* (24). Briefly, the program included educational content and practical application classroom exercises in the areas of physical activity and exercise, diet and eating behaviour, and behaviour modification. Sixteen months after the intervention, 93 women were evaluated but only 85 women performed all the body composition methods and had successful thoracic gas volume measured. The Institutional Review Board of the Faculty of Human Movement approved the study,

Surface morphology

Subjects were weighed wearing a swimming suit without shoes on using an electronic scale connected to the plethysmograph computer (BOD POD©, Life Measurement Instruments, Concord, CA, USA) to the nearest 0.01 kg. Height was measured to the nearest 0.1 cm with a stadiometer (Seca, Hamburg, Germany).

A trained researcher measured waist circumference (WC) above the iliac crest according to the procedures of Lohman (25). For data analysis, the averages of the three measurements were considered. The technical error of measurement (TEM) and the intraclass coefficient of correlation (ICC) for WC in ten subjects in our laboratory is 0.41 and 1.00, respectively.

ADP testing

The subjects Vb was assessed via air-displacement plethysmography using the BOD POD® software version 1.68 (Life Measurement Incorporated, Concord, CA, USA) according to manufacturer testing recommendations and guidelines. Details regarding the physical concepts and operational principles of the ADP are reported elsewhere (16, 26) . Briefly, each subject wore a swimsuit and cap provided by the laboratory while body mass was measured to the nearest 100 g by an electronic scale connected to the BOD POD® computer. Next, the measured V_{TG} was calculated where:

$$V_{TG} = \text{functional residual capacity} + 0.5 \text{ tidal volume}$$

Alternatively, the BOD POD offers the ability to predict the V_{TG} in cases where a measured thoracic gas volume is impossible. The predicted V_{TG} was calculated where:

V_{TG} = functional residual capacity + 0.5 tidal volume

The predicted V_{TG} equation is calculated from Crapo et al. (18) equation and is based upon a functional residual capacity that is derived by the following equation developed for women:

Functional residual capacity (L) = 0.0472 x H + 0.009 x age – 5.290

where H is height in centimeters and the ADP software calculates the tidal volume by using a constant of 0.7 L for women. The Crapo et al. (18) prediction V_{TG} equations were developed from healthy adult male and female subjects between the ages of 17-91 years, by using single breath helium dilution techniques .

After the V_{TG} was measured the corrected Vb was calculated and the subsequent total body density (Db), with %FM calculated utilizing the Siri equation (27). The TEM and the coefficient of variation (CV) for body volume in our laboratory in ten subjects is 0.20 L and 0.5 %, respectively.

Dual Energy X-ray Absorptiometry

To estimate total fat mass (FM) and fat-free mass (FFM), dual energy X-ray absorptiometry (DXA) was used (QDR-1500, Hologic, Waltham, USA, pencil beam mode, software version 5.67 enhanced whole-body analyses). Following the protocol for DXA described by the manufacturer, a step phantom with six fields of acrylic and aluminium of varying thickness and known absorptive properties was scanned alongside each subject to serve as an external standard for the analysis of different tissue composition. The same lab technician positioned the subjects, performed the scans and executed the analysis according to the operator's manual using the standard analysis protocol. The CV for FM in our laboratory in ten subjects is 2.9%.

Maximal oxygen uptake (VO_2 max)

Balke's (28) modified cardiopulmonary exercise testing protocol was used to asses cardiovascular fitness using a Quinton 645 treadmill. VO_2 max was measured using a breath-by-breath system with a zircon O_2 gas analyser coupled to measurement pulmonary flow (MedGraphics® MN, USA), with an accuracy ±3% and ±0.1%, respectively.

Statistical analyses

All data are reported as the mean ± standard deviation (SD). Differences between predicted and measured mean variables were evaluated by a paired sample t-test. Multiple regression analysis was applied to investigate changes in the measured V_{TG} with recognized influencing factors, such as waist circumference, VO_2 max, and age. Statistical significance was set at $p \leq 0.05$ and data were analyzed using SPSS (version 14.0; SPSS Inc. Chicago, IL).

RESULTS

Subject descriptive characteristics at baseline and post-weight loss intervention are reported in **Table 1**. Significant differences between the baseline and post-weight loss intervention were observed for body weight and composition (Vb, Db, %FM, FM, FFM) and measures of V_{TG} (measured and predicted) variables.

Table 1. Subjects characteristic and body composition variables (Mean ± SD) in all completers (N=85).

Variable	Baseline	Post-Intervention	Δ	Significance
Age	39.0 ± 5.7			
Height (cm)	159.8 ± 5.6			
Weight (kg)	76.6 ± 10.1	73.1 ± 10.6	-3.5 ± 5.5	<0.001
BMI (kg/cm^2)	30.0 ± 3.5	28.6 ± 3.9	-1.4 ± 2.1	<0.001
Measured V_{TG} (L)	2.92 ± 0.55	3.12 ± 0.61	0.20 ± 0.36	<0.001
Predicted V_{TG} (L)	3.12 ± 0.20	3.13 ± 0.20	0.01 ± 0.02	<0.010
Measured BV (L)	76.2 ± 10.6	72.2 ± 11.1	-4.0 ± 6.0	<0.001
Predicted BV (L)	76.3 ± 10.6	72.2 ± 11.2	-4.1 ± 6.0	<0.001
Measured Db (cm^2)	1.006 ± 0.01	1.013 ± 0.01	0.007 ± 0.01	<0.001
Predicted Db (cm^2)	1.005 ± 0.01	1.013 ± 0.01	0.008 ± 0.01	<0.001
%FM using the measured V_{TG}	42.0 ± 5.3	38.5 ± 6.1	-3.5 ± 4.4	<0.001
%FM using the predicted V_{TG}	42.5 ± 5.7	38.5 ± 6.9	-4.0 ± 4.6	<0.001
FM (kg) using the measured V_{TG}	32.5 ± 7.6	28.6 ± 8.1	-3.9 ± 5.2	<0.001
FM (kg) using the predicted V_{TG}	32.9 ± 7.9	28.6 ± 8.6	-4.3 ± 5.4	<0.001
FFM (kg) using the measured V_{TG}	44.1 ± 4.6	44.5 ± 4.5	0.4 ± 1.5	<0.050
FFM (kg) using the predicted V_{TG}	43.7 ± 4.7	44.4 ± 4.7	0.7 ± 1.3	<0.001
DXA %FM	46.2 ± 5.2	42.3 ± 6.5	-3.9 ± 4.5	<0.001
DXA FM (kg)	35.4 ± 7.8	31.1 ± 8.6	-4.3 ± 5.5	<0.001
WC (cm)	90.5 ± 8.1	86.3 ± 9.1	-4.2 ± 4.4	<0.001
VO_2 max (mL/kg/min)	24.5 ± 4.4	27.7 ± 5.7	3.2 ± 5.2	<0.001

SD, Standard Deviation; BMI, Body Mass Index; V_{TG}, Gas Thoracic Volume; BV, Body Volume; Db, Body Density; %, Percentage; FM, Fat Mass, FFM, Fat Free Mass, DXA, Dual Energy X-ray absorptiometry; WC, Waist Circumference; VO2max, maximal oxygen uptake; Δ is the change between baseline and post-weight loss intervention program.

Linear regression analysis was performed to compare %FM changes using the measured and predicted V_{TG} and %FM changes from DXA with the results presented in **Table 2**. Similar regression parameters were found between %FM changes obtained from both the measured and predicted V_{TG} with %FM changes from DXA. The results indicate that %FM using the measured and predicted V_{TG} explained 72% and 76% of the variance in %FM changes using DXA with similar standard error of estimations of 2.2% and 2.4%, respectively. In addition, no significant mean bias was observed between %FM changes using the measured and predicted V_{TG} with %FM changes from DXA (Bias ± SD: 0.44 % ± 2.5, p=0.105; - 0.04 % ± 2.3, p= 0.877) respectively.

Table 2. Regression between %FM changes from measured and predicted V_{TG} and %FM from DXA.

Independent Variable	%FM changes (measured V_{TG})			%FM changes (predicted V_{TG})		
	R^2	SEE	Bias	R^2	SEE	Bias
%FM from DXA	0.72	2.41	0.877	0.76	2.23	0.105

%, Percentage; FM, Fat Mass; V_{TG}, Gas Thoracic Volume; R^2, Coefficient of Determination; SEE, Standard Error of Estimation.

Multiple regression analysis was performed to explain the significant difference in the measured V_{TG} between the baseline and 16 month post-weight loss program. The change in the measured V_{TG} observed were significantly and negatively associated/influenced by waist circumference and this significant influence was observed even after controlling for VO_2 max and age (**Table 3**).

Table 3. β Coefficients from multiple regression analysis examining the effect of potential variables on V_{TG} changes.

Independent Variables	V_{TG} changes		
	β	SE	p
Waist Circumference	-0.023	0.009	0.008
Waist Circumference	-0.030	0.011	0.008
VO_2max	-0.005	0.009	0.581
Waist Circumference	-0.030	0.011	0.007
VO_2max	-0.006	0.009	0.511
Age	-0.007	0.007	0.331

β, Beta coefficient ; SE, Standard Error; p, Pearson significance.

DISCUSSION

To our knowledge, this is the first study that has investigated the impact of a weight loss intervention program on V_{TG} and the subsequent impact on body composition variables. The findings from this study showed that the V_{TG} was significantly overestimated by ~0.2 L when utilizing the predicted V_{TG} equations vs. measuring the V_{TG}.

In order to appreciate the impact that the V_{TG} plays on the estimation of %FM and absolute FM it is important to consider how V_{TG} is used to calculate total BV and subsequently Db and %FM. The ADP software calculates body volume with the following equation:

$$BV = BV_{raw} + 0.40\ V_{TG} - SAA$$

Where BV is the body volume, V_{TG} is the thoracic gas volume, SAA is the surface area artifact, and the BV_{raw} is the body volume prior to correcting for the V_{TG} and SAA.

For example, if the BV_{raw} and SAA remain unchanged (78.7 L and -0.9, respectively) with an observed V_{TG} change of 1.2 L the final effect on a 90 kg women would have resulted in a final BV change of 0.5 L, thus impacting the estimation in body composition by 2.6% FM units (i.e. 2.3 kg of absolute FM). Considering that the mean % FM change in this sample was ~3.5% and the change in the measured V_{TG} was ~0.2 L it would be plausible to suggest that some of the loss in FM observed could be directly contributed to the change in the V_{TG}.

To better understand the effect of using a measured or predicted V_{TG} on estimates of %FM, an independent method of body composition (i.e. DXA) was used to further explore and refine these relationships. The findings suggest a strong relationship between the effects of both V_{TG} methods on %FM changes with %FM changes using DXA, which explained 72 to 76% of the total variance in %FM changes from DXA. Therefore, it seems that for group comparisons the observed differences in %FM estimation using either the measured or predicted V_{TG}, though significantly different, provided similar finding utilizing an independent technique (i.e. DXA). However, one should not use interchangeable the measured and predicted V_{TG}, particularly to assess body composition changes in a weight loss program.

In order to explain the discrepant results between the measured V_{TG} before and after the intervention we hypothesized that body composition changes observed after the intervention, namely central body fat distribution would significantly impact V_{TG}. Our findings presented a 4.2 cm reduction in the waist circumference (ΔWC, $p<0.001$) which indicated a significant decrease in central body fat distribution. Lung function was not obtained in the present study, however, VO_2 max was obtained and a significant increase was seen ($p<0.001$). In addition, a significant and inverse correlation ($p<0.001$) was found between waist circumference changes and the change in VO_2 max ($r = -0.423$) (data not shown).

The relationship between WC and the changes in the measured V_{TG} was performed to explain the change between the measured V_{TG} between baseline and post weight loss intervention. The change in the measured V_{TG} was significantly and negatively associated with the change in the WC ($p=0.008$), even after controlling for VO_2 max and age. These results indicate that a reduction in the WC and consequently central adiposity contributes significantly to the higher measured V_{TG} values, independently of VO_2 max and age. These findings extend the results of previous studies which reported inverse associations between lung function and measurements of central adiposity such as the WC (29-33). Lazarus et al. indicated a negatively association between FVC and WC in 1,235 adults of both genders. Additionally, Canoy et al (29) using a large sample of 9,674 men and 11,876 women aged 45-79 years concluded that abdominal fat deposition may play a role in the impairment of respiratory function among the abdominally obese.

This association between WC changes and measured V_{TG} changes might be explained by a variety of mechanisms. Abdominal fat deposition may directly impede the descent of the diaphragm into the abdominal cavity, whereas fat deposition in the chest wall may diminish rib cage movement and thoracic compliance, both of which lead to restrictive respiration impairment (34). Other mechanisms have been suggested, including the possibility that abdominal fat deposition leads to a redistribution of blood to the thoracic compartment that reduces vital capacity (32). In addition, high amounts of FM may be related to a greater degree of airway narrowing than would be expected on the basis of reduced lung volume alone, although the mechanisms remain uncertain (35). However, obesity is a complex disorder and the effects of excess adipose tissue on pulmonary function may be influenced by the location of excess fat deposits as well as by their extent.

CONCLUSION

Air-displacement plethysmography was used to assess changes in body composition following a 16-month weight loss program. Taking into account the fact that the subject's "raw" BV is corrected according to the V_{TG}, the present study underscores the impact of using the predicted vs. measured V_{TG}. This is to say the %FM change using the measured V_{TG} resulted in a decrease of 3.5 %FM vs. using the predicted V_{TG} which resulted in a decrease of 4.0 %FM over the course of the 16 month program. Therefore, this study indicates that the measured and predicted V_{TG} should not be used interchangeably. An important predictor of the change in the measured V_{TG} could be attributed to changes in the WC, which is an indicator of central adiposity.

However, the underlying mechanisms of the role of central adiposity is unclear and worthy of future investigation.

REFERENCES

1. Heymsfield, S., Allison, D., Wang, Z., Baumgartner, R. & Ross, R. (1998) Evaluation of total and regional body composition, in: James, W. (Ed.) Handbook of obesity, pp. 41-77 (New York, Marcell Dekker).
2. Bosy-Westphal, A., Mast, M., Eichhorn, C. et al. (2003) Validation of air-displacement plethysmography for estimation of body fat mass in healthy elderly subjects, Eur J Nutr, 42, 207-16.
3. Collins, M. A., Millard-Stafford, M. L., Sparling, P. B. et al. (1999) Evaluation of the BOD POD for assessing body fat in collegiate football players, Med Sci Sports Exerc, 31, 1350-6.
4. Fields, D. A., Wilson, G. D., Gladden, L. B. et al. (2001) Comparison of the BOD POD with the four-compartment model in adult females, Med Sci Sports Exerc, 33, 1605-10.
5. Levenhagen, D. K., Borel, M. J., Welch, D. C. et al. (1999) A comparison of air displacement plethysmography with three other techniques to determine body fat in healthy adults, JPEN J Parenter Enteral Nutr, 23, 293-9.
6. Millard-Stafford, M. L., Collins, M. A., Evans, E. M. et al. (2001) Use of air displacement plethysmography for estimating body fat in a four-component model, Med Sci Sports Exerc, 33, 1311-7.
7. Miyatake, N., Nonaka, K. & Fujii, M. (1999) A new air displacement plethysmograph for the determination of Japanese body composition, Diabetes Obes Metab, 1, 347-51.
8. Nunez, C., Kovera, A. J., Pietrobelli, A. et al. (1999) Body composition in children and adults by air displacement plethysmography, Eur J Clin Nutr, 53, 382-7.
9. Sardinha, L. B., Lohman, T. G., Teixeira, P. J., Guedes, D. P. & Going, S. B. (1998) Comparison of air displacement plethysmography with dual-energy X-ray absorptiometry and 3 field methods for estimating body composition in middle-aged men, Am J Clin Nutr, 68, 786-93.
10. Silva, A. M., Minderico, C. S., Teixeira, P. J., Pietrobelli, A. & Sardinha, L. B. (2006) Body fat measurement in adolescent athletes: multicompartment molecular model comparison, Eur J Clin Nutr.
11. Wagner, D. R., Heyward, V. H. & Gibson, A. L. (2000) Validation of air displacement plethysmography for assessing body composition, Med Sci Sports Exerc, 32, 1339-44.
12. Going, S. B. (2005) Hydrodebsitometry and Air Displacement Plethysmography, in: Heymsfield, S. B., Lohman, T. G., Wang, Z. M. & Going, S. B. (Eds.) Human body composition, pp. 17-33 (Champaign, IL, Human Kinetics Publishers).
13. Fields, D. A., Goran, M. I. & McCrory, M. A. (2002) Body-composition assessment via air-displacement plethysmography in adults and children: a review, Am J Clin Nutr, 75, 453-67.
14. Ball, S. D. (2005) Interdevice variability in percent fat estimates using the BOD POD, Eur J Clin Nutr, 59, 996-1001.
15. Fields, D. A., Hunter, G. R. & Goran, M. I. (2000) Validation of the BOD POD with hydrostatic weighing: influence of body clothing, Int J Obes Relat Metab Disord, 24, 200-5.

16. Dempster, P. & Aitkens, S. (1995) A new air displacement method for the determination of human body composition, Medicine and Science in Sports and Exercise, 27, 1692-1697.
17. Dubois, A. B., Botelho, S. Y., Bedell, G. N., Marshall, R. & Comroe, J. H., Jr. (1956) A rapid plethysmographic method for measuring thoracic gas volume: a comparison with a nitrogen washout method for measuring functional residual capacity in normal subjects, J Clin Invest, 35, 322-6.
18. Crapo, R. O., Morris, A. H., Clayton, P. D. & Nixon, C. R. (1982) Lung volumes in healthy nonsmoking adults, Bull Eur Physiopathol Respir, 18, 419-25.
19. Demerath, E. W., Guo, S. S., Chumlea, W. C. et al. (2002) Comparison of percent body fat estimates using air displacement plethysmography and hydrodensitometry in adults and children, Int J Obes Relat Metab Disord, 26, 389-97.
20. McCrory, M. A., Mole, P. A., Gomez, T. D., Dewey, K. G. & Bernauer, E. M. (1998) Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes, J Appl Physiol, 84, 1475-9.
21. Refsum, H. E., Holter, P. H., Lovig, T., Haffner, J. F. & Stadaas, J. O. (1990) Pulmonary function and energy expenditure after marked weight loss in obese women: observations before and one year after gastric banding, Int J Obes, 14, 175-83.
22. Teixeira, P. J., Palmeira, A. L., Branco, T. L. et al. (2004) Who will lose weight? A reexamination of predictors of weight loss in women, Int J Behav Nutr Phys Act, 1, 12.
23. Wannamethee, S. G., Shaper, A. G. & Whincup, P. H. (2005) Body fat distribution, body composition, and respiratory function in elderly men, Am J Clin Nutr, 82, 996-1003.
24. Teixeira, P. J., Going, S. B., Houtkooper, L. B. et al. (2004) Pretreatment predictors of attrition and successful weight management in women, Int J Obes Relat Metab Disord, 28, 1124-33.
25. Lohman, T. G., Roche, A. F. & Martorell, R. (1988) Anthropometric standardization reference manual (Champaign, IL, Human Kinetics Publishers).
26. McCrory, M. A., Gomez, T. D., Bernauer, E. M. & Molé, P. A. (1995) Evaluation of a new air displacement plethysmograph for measuring human body composition, Medicine and Science in Sports and Exercise, 27, 1686-1691.
27. Siri, W. E. (1961) Body composition from fluid spaces and density: Analysis of method, in: Henschel, A. (Ed.) Techniques for measuring body composition, pp. 223-244 (Washington, DC, National Academy of Sciences).
28. Balke, B. & Ware, R. W. (1959) An experimental study of physical fitness of Air Force personnel, U S Armed Forces Med J, 10, 875-88.
29. Canoy, D., Luben, R., Welch, A. et al. (2004) Abdominal obesity and respiratory function in men and women in the EPIC-Norfolk Study, United Kingdom, Am J Epidemiol, 159, 1140-9.
30. Cotes, J. E., Chinn, D. J. & Reed, J. W. (2001) Body mass, fat percentage, and fat free mass as reference variables for lung function: effects on terms for age and sex, Thorax, 56, 839-44.
31. Collins, L. C., Hoberty, P. D., Walker, J. F., Fletcher, E. C. & Peiris, A. N. (1995) The effect of body fat distribution on pulmonary function tests, Chest, 107, 1298-302.

32. Harik-Khan, R. I., Wise, R. A. & Fleg, J. L. (2001) The effect of gender on the relationship between body fat distribution and lung function, J Clin Epidemiol, 54, 399-406.
33. Lazarus, R., Gore, C. J., Booth, M. & Owen, N. (1998) Effects of body composition and fat distribution on ventilatory function in adults, Am J Clin Nutr, 68, 35-41.
34. Maiolo, C., Mohamed, E. I. & Carbonelli, M. G. (2003) Body composition and respiratory function, Acta Diabetol, 40 Suppl 1, S32-8.
35. King, G. G., Brown, N. J., Diba, C. et al. (2005) The effects of body weight on airway calibre, Eur Respir J, 25, 896-901.