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ORIGINAL ARTICLE

Air displacement plethysmography can detect moderate changes in body composition

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Objectives: To determine the sensitivity of air displacement plethysmography (APD) for evaluation of changes in body composition in normal subjects.
Design: Comparison of measurements with and without oil or water loads.
Subjects and methods: Ten healthy volunteers were analyzed, without and with 1 l and 2 l of oil or water. The measured and true changes in fat mass and fat-free mass were compared by paired *t*-tests. A correlation study and a Bland & Altman procedure was performed on the 60 measurements of adiposity changes in 30 subjects carrying 0.5 l ($n = 8 \times 2$), 1 l ($n = 10 \times 2$) and 2 l ($n = 12 \times 2$) oil and water loads.
Results: Fat-free mass increased when the 10 subjects were carrying water. When they carried oil, fat mass increased, however, a ~0.5 kg increase of fat-free mass was also detected. Two liters loads led to distinct changes: $+1.49 \pm 0.59$ kg fat and $+0.50 \pm 0.60$ kg fat-free with oil and $+0.37 \pm 0.57$ kg fat and $+1.70 \pm 0.56$ kg fat-free with water (both $P < 0.001$). Mixed loads (+1 l oil and 1 l water) led to detect $+0.85 \pm 0.48$ kg fat and $+1.09 \pm 0.45$ kg fat-free (both $P < 0.005$ vs without load). For the 30 subjects analyzed thrice, measured changes in fat and fat-free mass were slightly underestimated (−15%, NS) but correlated with the true changes. Measured changes in adiposity were correlated with the true changes, with no bias as indicated by the Bland & Altman procedure.
Conclusion: APD detects ~2 kg changes in fat or fat-free mass in small populations.
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Introduction

Assessment of body composition provides important information on physical status. Numerous physical or isotopic methods can be used to distinguish fat and fat-free mass, but only a few are applicable to clinical practice. They include DEXA (Heymsfield *et al*., 1989) or bioelectrical impedance analysis (BIA) (Boulier *et al*., 1990), and more recently air displacement plethysmography (APD) (Dempster and Aitkens, 1995). According to a recent review (Fields *et al*., 2002), the commercially available device for APD (BOD POD) is a 'safe, quick, reliable and valid' technique for evaluating body composition in a wide range of subject types, agreeing within 1% with the reference hydrostatic weighing technique.

An obvious advantage of a quick, nonaggressive and simple technique is that it allows repeated measurement in patients with changing body weight. However, clinically relevant alterations in body weight often amount to a few kilograms.

To find out whether APD could detect small changes in body composition, normal subjects were weighed and introduced into the BOD POD chamber with and without fat or fat-free loads. First, searching for the threshold for the detection of body composition changes, we used paired *t*-tests to compare the estimation of fat and fat-free mass by APD with and without 1.0 and 2.01 of oil or water in 10 subjects. Second, to further explore the precision of the APD-

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measured changes of fat and fat-free mass, we compared them to the real changes in thirty distinct subjects with 0.5 l ($n=8\times2$), 1.0 l ($n=10\times2$) and 2.0 l ($n=12\times2$) oil and water charges, by a correlation analysis and a Bland & Altman procedure. We also checked that the presence of an empty bottle did not affect the results in 10 more subjects (control study).

Materials and methods

Subjects
In total, 30 normal subjects participated in the study of APD sensitivity. They were mainly women (24 women, six men), with normal weight (body mass index (BMI): 21.9±3.0 kg/m^2) of mean age 30±10 years. In all, 10 underwent the complete oil or water study (basal, +1 l oil, +2 l oil, +1 l water, +2 l water, and +1 l oil +1 l water together), eight subjects underwent the +0.5 and twelve the +2.0 l oil or water study. Ten more subjects (four women, six men; age 24±5 years, BMI: 23.0±2.1 kg/m^2) underwent a control study, to check that the presence of an empty bottle in the chamber, or the time between the measurements, did not affect the results. Informed consent was obtained from each subject, and the study was approved by the ethical committee of our institution.

Body composition assessment
Weight was measured as part of the BOD POD procedure. The BOD POD was calibrated for an empty chamber and a known volume (49.771 l cylinder) before each measurement. The subjects were weighed, and then entered the BOD POD chamber, wearing only underclothes and a swimcap. Duplicate measurements of body volume were performed according to the BOD POD manufacturer's recommendations (Life Measurement Instruments, CA, USA); a third measurement was performed when they differed by more than 150 ml. Predicted lung volume was used for the calculation of body volume, using adult-specific equations (Crapo *et al*., 1982). Fat and fat-free mass were calculated using the equation of Siri (1961).

All the subjects were studied in the fasting state. Each measurement took 5–10 min, and the period between the measurements was less than 5 min: the whole tests duration was 1 h for the 10 subjects who were studied six times, and 30 min for the 20 subjects who were studied thrice. The oil and water charges were in open plastic bottles (empty weight = 71 g), at room temperature, their volume were 0.5, 1 and 2 l and their weight was 0.510, 1.020 and 2.040 kg for water (density 1.02) and 0.470, 0.940 and 1.880 kg for oil (density 0.94).

For the control study, the 10 subjects underwent three measurements: one without the bottle (T0), one 10 min later with the empty open bottle, and one 30 min later without the bottle.

Statistical analysis
Fat and fat-free mass with and without the oil or water loads were compared by paired *t*-tests. Measured changes in fat and nonfat mass were compared and correlated (linear regression analysis) to the true changes (+0.510, +1.020 and +2.040 kg fat-free for water loads, and +0.470, +0.940 and +1.880 kg fat for oil loads, respectively). A linear regression analysis between the measured and true changes in adiposity (BF%) was also performed, with a Bland & Altman procedure (Bland and Altman, 1986) using the true changes as reference. SPSS 10.1 software was used for the calculations. Results are presented as mean±s.d. with $P<0.05$ considered significant.

Results

Threshold for detection of body composition changes (n = *10)*
In all, 10 subjects (four men and six women) underwent six body composition analysis (basal, +1 l oil, +2 l oil, +1 l water, +2 l water, and +1 l oil +1 l water together). Their mean age was 24±5 years, BMI 21.4±2.5, fat-free mass 50.9±10.8 kg, fat mass 12.6±4.2 kg and adiposity was 20.2±7.2%.

The fat and fat-free mass changes measured with the oil and water loads are depicted in Figure 1. The fat mass increased significantly with all the oil charges (1 l: +0.44±0.54 kg, 2 l: +1.49±0.59, $P<0.001$ vs 1 l), whereas it did not change with the water charges. The fat-free mass increased significantly with the water charges (1 l: +0.96±0.70 kg, 2 l: +1.70±0.56, $P<0.001$ vs 1 l), however an increase was also detected both with the 1 l (+0.56±0.51 kg, $P<0.01$) and 2 l (+0.50±0.60 kg, $P<0.05$) oil charges. One liter oil vs water charges did not lead to significantly different changes of fat ($P=0.07$) and fat-free mass ($P=0.06$). Two liters charges increased more fat than fat-free mass with oil ($P<0.05$), more fat-free than fat mass with water ($P<0.005$), and a significant increase of both fat (+0.85±0.48 kg, $P<0.001$) and fat-free mass (+1.09±0.45, $P<0.001$) was detected with the simultaneous 1 l oil +1 l water charge.

Precision of the APD-measured changes of fat and fat-free mass (n = *30)*
The mean real fat mass change during the 30 experiments with oil loads was +1.08±0. 54 kg. The mean fat mass change measured during these experiments was +0.90±0.74, a −17% underestimation (NS). Measured fat mass changes were correlated with the weight of the oil load ($n=30$, $r=0.55$, $P<0.005$). Measured fat-free mass changes were not correlated with the weight of the oil load.

The mean real fat-free mass change during the 30 experiments with water loads was +1.20±0.61 kg. The mean fat-free mass change measured during these experiments was +1.02±0.82, a −15% underestimation (NS).

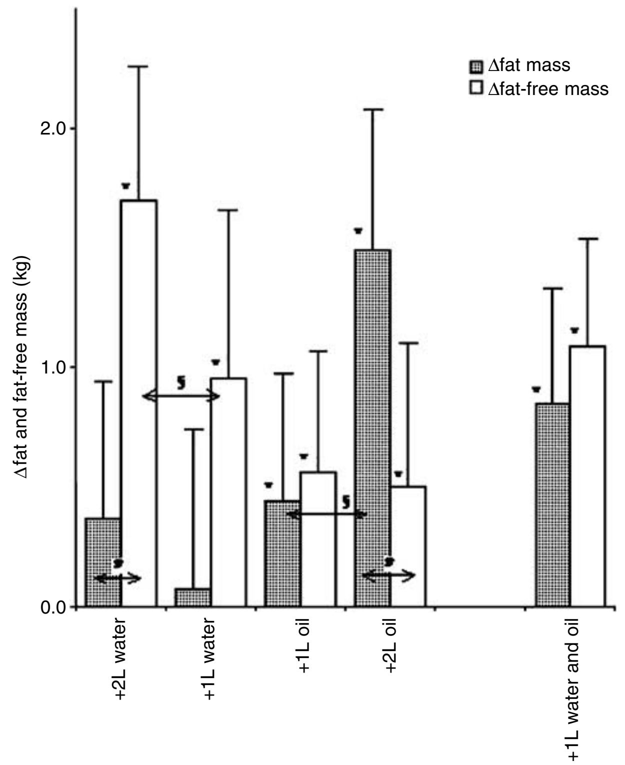

Figure 1 Fat and fat-free mass changes (kg) for the 10 subjects who were studied six times, carrying 1 l and 2 l oil and water loads. *Indicates $P<0.05$ vs measurement without the load, § indicates $P<0.05$ between 1 and 2 l loads, # indicates different changes of fat and fat-free mass during the 2 l loads.

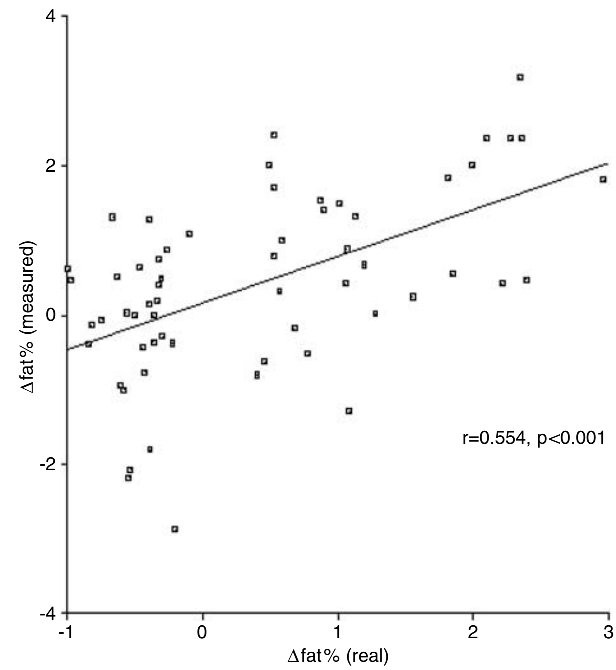

Figure 2 Measured changes of adiposity (Δfat%) as a function of the real changes for the 60 experiments in 30 subjects ($n=8$ carrying 0.5 l oil or water loads, $n=10$ carrying 1 l oil or water loads, $n=12$ carrying 2 l oil or water loads).

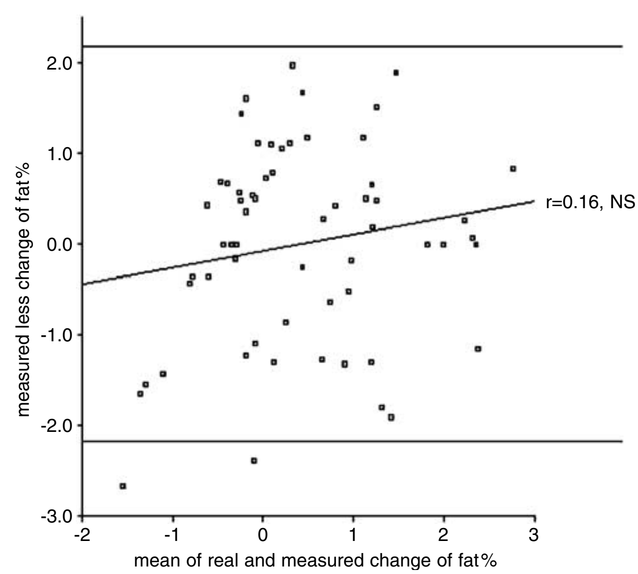

Figure 3 Bland & Altmann plots of differences between the APD-measured adiposity changes (Δ%fat) less the true changes as a function of average Δ%fat changes for the 60 experiments in 30 subjects ($n=8$ carrying 0.5 l oil or water loads, $n=10$ carrying 1 l oil or water loads, $n=12$ carrying 2 l oil or water loads).

Measured fat-free mass changes were correlated with the weight of the water load ($n=30$, $r=0.57$, $P<0.005$). Measured fat mass changes were not correlated with the weight of the water load.

The correlation between measured (mean: $+0.41\pm1.21\%$) and true ($+0.41\pm1.05\%$) changes in adiposity during the 60 experiments in the 30 subjects was significant ($n=60$, $r=0.55$, $P<0.001$) as shown in Figure 2. The Bland & Altman plot for the measured changes in adiposity (taking the true change as reference) is shown in Figure 3: no bias was detected. The results with the oil ($n=30$) and water ($n=30$) loads were also considered separately: measured changes of adiposity (mean: $+1.00\pm1.10\%$) were correlated to the real changes (mean: $+1.30\pm0.70\%$) with the oil loads ($r=0.41$, $P<0.05$), with no bias according to the Bland & Altman procedure. The measured ($-0.16\pm1.02\%$) and real ($-0.48\pm0.22\%$) adiposity changes were small with the water load, and did not correlate.

Control study (n = 10)

As shown in Table 1, body weight, fat and fat-free mass were not affected by the presence of the empty bottle, nor the time between the measurements (all NS by paired *t*-tests). The results of the fat and fat-free mass with the empty bottle, and after a 30 min delay, were well correlated to the basal

Table 1 Body weight, fat and fat-free mass (kg) in 12 subjects, at baseline, with an empty bottle, and without the bottle 30 min later

	T0	*+ Empty bottle*	*Correl. with T0*	*Absolute difference with T0*	*T + 30 min*	*Correl. with T0*	*Absolute difference with T0*
Body weight	68.6±11.1	68.6±11.1			68.6±11.1		
Fat mass	14.4±6.6	14.5±6.8	r = 0.98	0.9±0.6	14.4±6.8	r = 0.99	0.7±0.6
Fat-free mass	54.1±12.5	54.0±12.4	r = 0.99	0.9±0.6	54.1±12.2	r = 0.99	0.7±0.5

results, and the mean absolute differences between the measurements was <1 kg. As expected, the empty bottle (71 g) was not detected during the measurement, its participation to the true body composition changes was therefore neglected in the calculations.

Discussion

Our results show that APD detects moderate changes in body composition, and precize its limitations. When the subjects carried water, a significant increase of fat-free mass was detected for 1 l loads, with no significant change in fat mass. The water loads did not contain mineral and proteins, the hydration of fat-free mass was therefore not the same for the subjects carrying these loads: the two-compartment model calculation from APD measurements, however, detected the fat-free mass change as shown in Figure 1, and the changes were also well detected when 1 l oil and 1 l water were carried together as a significant +0.85 kg fat and +1.09 kg fat-free increase. A moderate change of hydration seems therefore not to prevent the APD to detect changes of fat or fat-free mass, but the composition of the fat-free mass change, less or more hydrated, is not detected. On the other hand, when the subjects carried oil, a significant increase in fat mass was detected for 0.9 kg loads, but a ~0.5 kg change in fat-free mass was also measured. This bias did not increase further with a higher oil load, but it demonstrates that a 0.5 kg APD-detected change of fat-free (or fat, although the +0.37 kg fat with 2 l water did not reach significance) mass can be wrong. When ~1 kg changes of fat or fat-free mass were detected by the BOD-POD, they always reflected the presence of more oil in the first case, and water in the second, however, less fat than fat-free was detected with the 1 l oil load. The 0.7 kg mean absolute differences in the 10 subjects who were studied twice at a 30 min interval also suggests that a ±1 kg difference should be cautiously interpretated in individuals, although the mean fat and fat-free mass were similar and well correlated ($r \geqslant 0.98$). By contrast, 2 l oil and water loads led to measure significantly different changes of body composition: more fat than fat-free mass with oil, and more fat-free than fat mass with water. A 2 kg change of fat or fat-free mass is therefore well detected by APD, on a relatively small sample size ($n = 10$). The measured changes in fat and fat-free mass were proportional to the loads, although they were underestimated by ~15%, and the estimation of alterations in adiposity was not biased as indicated by the Bland & Altman procedure.

The ability to detect ~2 kg changes of fat or fat-free mass in small samples indicates the sensitivity of APD. Body weight reductions during lifestyle interventions are limited to a few kg: −3.5 kg in the Finnish Prevention Study (Tuomilehto *et al.*, 2001) or −5.6 kg in the Diabetes Prevention Program (Knowler *et al.*, 2002). The pharmacological treatment of obesity leads to moderate weight loss: −2.7 kg with Orlistat or −4.3 kg with Sibutramine (Phelan and Wadden, 2002). On the other hand, the treatment of type 2 diabetes with sulfonylureas (Nathan *et al.*, 1988), glitazones (Smith *et al.*, 2005) and insulin (Larger *et al.*, 2001) is associated with moderate but consistent weight gain (a few kilograms). Moderate weight reductions are clinically relevant as demonstrated by the benefits of lifestyle interventions. Measurement of body composition will help evaluate the beneficial (or deleterious) effects of pharmacologically induced body weight changes. Our study shows that APD can achieve this assessment.

The validity, reproducibility and precision of the BOD POD makes it a good candidate for the assessment of body composition in clinical practice, although more than 30 subjects were thought to be necessary (Fields *et al.*, 2002). Our results indicate that significant differences can be detected in smaller samples. The simplicity and the non-invasive nature of the technique is also an obvious advantage, which was critical for the kind of validation that we carried out. We checked that the presence of the empty bottle, and the time between the measurements, did not affect the results. Similar validation studies with DEXA or BIA apparatus are more difficult to conduct, and gave less convincing results. DEXA has been shown to detect the addition of 8.8 kg of porcine lard on the trunk of six women (Svendsen *et al.*, 1993), or the −1.8 kg reduction in fat-free mass after a hemodialysis session in 10 subjects (Formica *et al.*, 1993). The absence of X-ray exposure is an advantage of APD over DEXA when repeated measurements are performed, or for the study of women during pregnancy. The ability of BIA to detect the fluid loss after a hemodialysis session (Svendsen *et al.*, 1993) or the fluid changes during peritoneal dialysis (Formica *et al.*, 1993) is less clear: fluid removal is underestimated by BIA when hypotension develops during the session (Zaluska *et al.*, 1998), and a segmental analysis may be required to detect truncal fluid changes (Zhu *et al.*, 1998, 2003).

In summary, we showed that APD detects addition or 2 kg of fat or fat-free mass, on a sample of 10 healthy subjects. Although they were underestimated by 15%, the measured changes were proportional to the true fat and fat-free mass changes. This sensitivity makes APD a valuable tool for the assessment of the composition of moderate weight changes, as observed with lifestyle or pharmacological interventions.

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References

Bland JM, Altman DG (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **2**, 307–310.

Boulier A, Fricker J, Thomasset AL, Apfelbaum M (1990). Fat-free mass estimation by the two-electrode impedance method. *Am J Clin Nutr* **52**, 581–585.

Crapo RO, Morris AH, Clayton PD, Nixon CR (1982). Lung volumes in healthy non-smoking adults. *Bull Eur Physiopathol Resp* **18**, 419–425.

Dempster P, Aitkens S (1995). A new air displacement method for the determination of human body composition. *Med Sci Sports Exerc* **27**, 1692–1697.

Fields DA, Goran MI, McCrory MA (2002). Body-composition assessment via air-displacement plethysmography in adults and children: a review. *Am J Clin Nutr* **75**, 453–467.

Formica C, Atkinson MG, Nyulasi I, McKay J, Heale W, Seeman E (1993). Body composition following hemodialysis: studies using dual-energy X-ray absorptiometry and bioelectrical impedance analysis. *Osteoporos Int* **3**, 192–197.

Heymsfield SB, Wang J, Heshka S, Kehayias JJ, Pierson RN (1989). Dual-photon absorptiometry: comparison of bone mineral and soft tissue mass measurements *in vivo* with established methods. *Am J Clin Nutr* **49**, 1283–1289.

Knowler WC, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, *et al.*, Diabetes Prevention Program Research Group (2002). Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* **346**, 393–403.

Larger E, Rufat P, Dubois-Laforgue D, Ledoux S (2001). Insulin and weight gain: myth or reality? *Diabetes Metab* **27**, S23–S27.

Nathan DM, Roussell A, Godine JE (1988). Glyburide or insulin for metabolic control in non-insulin-dependent diabetes mellitus. A randomized, double-blind study. *Ann Intern Med* **108**, 334–340.

Phelan S, Wadden TA (2002). Combining behavioral and pharmacological treatments for obesity. *Obes Res* **10**, 560–574.

Siri WE (1961). Body composition from fluid spaces and density: analysis of methods. In: Brozek J, Henschel A (eds). *Techniques for Measuring Body Composition*. National Academy of Sciences: Washington, DC, pp 223–244.

Smith SR, De Jonge L, Volaufova J, Li Y, Xie H, Bray GA (2005). Effect of pioglitazone on body composition and energy expenditure: a randomized controlled trial. *Metabolism* **54**, 24–32.

Svendsen OL, Haarbo J, Hassager C, Christiansen C (1993). Accuracy of measurements of body composition by dual-energy x-ray absorptiometry *in vivo*. *Am J Clin Nutr* **57**, 605–608.

Tuomilehto J, Lindstrom J, Eriksson JG, Valle TT, Hamalainen H, Ilanne-Parikka P, *et al.*, Finnish Diabetes Prevention Study Group (2001). Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med* **344**, 1343–1350.

Zaluska WT, Schneditz D, Kaufman AM, Morris AT, Levin NW (1998). Relative underestimation of fluid removal during hemodialysis hypotension measured by whole body bioimpedance. *ASAIO J* **44**, 823–827.

Zhu F, Schneditz D, Wang E, Martin K, Morris AT, Levin NW (1998). Validation of changes in extracellular volume measured during hemodialysis using a segmental bioimpedance technique. *ASAIO J* **44**, M541–M545.

Zhu F, Hoenich NA, Kaysen G, Ronco C, Schneditz D, Murphy L *et al.* (2003). Measurement of intraperitoneal volume by segmental bioimpedance analysis during peritoneal dialysis. *Am J Kidney Dis* **42**, 167–172.