Evaluation of a new pediatric air-displacement plethysmograph for body-composition assessment by means of chemical analysis of bovine tissue phantoms[1–3]

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ABSTRACT

Background: Body-composition assessment reflects infant growth and nutritional status but is limited by practical considerations, accuracy, and safety.

Objective: This study evaluated the precision and accuracy of a new air-displacement plethysmography (ADP) system for pediatric body-composition assessment.

Design: We used 24 phantoms constructed from bovine lean muscle and fat. The phantoms varied in mass (1.3894–9.9516 kg) and percentage fat (%Fat; 2.08–34.40%), thereby representing infants between birth and 6 mo of age. Estimates of %Fat obtained with chemical analysis (CA), hydrostatic weighing, and ADP were compared.

Results: There was no significant difference between %Fat measured with ADP ($\%Fat_{ADP}$) and %Fat measured with CA ($\%Fat_{CA}$); the mean values were 18.55% and 18.59%, respectively. SDs for $\%Fat_{ADP}$ and $\%Fat_{CA}$ were not significantly different (0.70% and 0.73%, respectively). %Fat measurements obtained with ADP, CA, and hydrostatic weighing were highly correlated ($r > 0.99$, $P < 0.0001$). The regression equation ($\%Fat_{CA} = 0.996\%Fat_{ADP} + 0.119$; SEE = 0.600; adjusted $R^2 = 0.997$; $P < 0.0001$) did not differ significantly from the line of identity ($\%Fat_{CA} = \%Fat_{ADP}$). There was high agreement between individual measurements of $\%Fat_{ADP}$ and $\%Fat_{CA}$, as shown by the narrow 95% limits of agreements between methods (−1.22% to 1.13%), and there was no systematic bias in individual differences across the phantom mass and %Fat ranges.

Conclusion: ADP provides a highly precise and accurate estimate of %Fat in bovine tissue phantoms in the pediatric ranges of body weight and body fatness. *Am J Clin Nutr* 2003;77:364–70.

KEY WORDS Body composition, infants, air-displacement plethysmography, chemical analysis, precision, accuracy, body fat, infant growth, infant nutrition, pediatrics, pediatric nutrition

INTRODUCTION

Body-composition assessment is recognized as the most accurate method of measuring infant growth and nutritional status. However, because of the specific challenges associated with the infant population, body-composition assessment has yet to replace length and weight measurements as the standard method of evaluating infant growth and nutritional status. In fact, even though various methods have been used to measure infant body composition (1), their use has been restricted because of practical considerations, training requirements, limited availability, cost, accuracy, and safety.

Air-displacement plethysmography (ADP) is a method used to measure body composition in children, adults, and the elderly (2–4) that has yet to be applied in the infant population. ADP uses gas laws to determine body volume, which is used with body mass to compute body density. Body density is then used in a 2-compartment model (5, 6) to determine fat mass, fat-free mass, and percentage fat (%Fat).

The only commercially available ADP system is the BOD POD Body Composition System (Life Measurement Inc, Concord, CA), which has been used to measure body composition in different populations (2–4). Compared with 2-, 3-, and 4-compartment models, the ADP testing procedure offers greater accuracy and simplicity, allowing for the evaluation of children, adults, and the elderly (2, 4). Therefore, ADP has the potential to be applied successfully in the infant population.

The present study was designed to evaluate the precision and accuracy of a new pediatric ADP system, the PEA POD Infant Body Composition System (Life Measurement Inc, Concord, CA), in reference to chemical analysis (CA). We tested this ADP system using bovine tissue phantoms varying in mass and fat content. Hydrostatic weighing (HW) was also performed. This study was part of the development of PEA POD; the objective was to assess its potential use for body-composition assessment in the pediatric population.

MATERIALS AND METHODS

Air-displacement plethysmography system

Although the pediatric and adult ADP systems differ in layout, the pediatric ADP system used in this study has the same theoretical basis for the calculations and operation principles reported previously in detail for the adult ADP system (7). A concise overview of the pediatric ADP system used in this study follows.

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The PEA POD is an ADP system consisting of 2 chambers, a test chamber and a reference chamber, connected by a volume-perturbing diaphragm. The diaphragm creates volume changes in the 2 chambers that are equal in size but opposite in sign. The opening and closing of a calibration valve allows the test chamber to be connected to a known reference volume used to calibrate the system. The test chamber is mounted on the top surface of a movable cart with the reference chamber and calibration volume housed inside the cart along with the electronic components, computer, printer, keyboard, and mouse. Both chambers are made of clear acrylic plastic. An electronic scale and a computer screen are secured to the top surface of the cart.

Each ADP test is preceded by an automated system calibration. Pressure changes associated with volume perturbations are continuously monitored and recorded in both chambers. These pressure changes never exceed 1 cm of H_2O. During calibration, the test chamber is emptied and the calibration valve is kept closed initially and then opened. The pressure changes collected during this procedure and the known calibration volume are used to perform a 2-point calibration, which results in a linear relation between the ratio of the pressures recorded in the 2 chambers and changes in volume in the test chamber.

During a test, the subject or object being tested is placed in the test chamber with the calibration valve open. The ratio of the pressures recorded in the 2 chambers is then used to compute the volume of the subject or object being tested. For this study, the calibration procedure and each measurement period lasted 50 s.

The ADP principles used to calculate volumes from pressure measurements result from the different ways that air behaves under isothermal and adiabatic conditions. Under isothermal conditions, air temperature remains constant as its volume changes. In contrast, under adiabatic conditions, air temperature does not remain constant as its volume changes. Boyle's Law and Poisson's Law govern the compressibility characteristics of gases under isothermal and adiabatic conditions, respectively. These laws are expressed as follows:

$$\text{Boyle's Law: } P_1/P_2 = V_2/V_1 \quad (1)$$

$$\text{Poisson's Law: } P_1/P_2 = (V_2/V_1)^{1.4} \quad (2)$$

where P_1 and V_1 represent pressure and volume at an initial condition, and P_2 and V_2 represent pressure and volume at a final condition. On the basis of these 2 equations, it must be true that, for small pressure changes, air under isothermal conditions is about 40% more compressible than is air under adiabatic conditions (7). Because the ADP system measures volume with the assumption that all the air in the test chamber behaves adiabatically, a correction is automatically performed for air that is maintained under isothermal conditions by the surface area of the object or subject being tested. A lung volume correction factor is also automatically performed, for the same reason, when live subjects are tested.

Bovine tissue phantoms

In this study, we used 24 phantoms constructed from bovine muscle and fat. The phantoms varied in terms of mass and fat content. The mass range (1.3894–9.9516 kg) and %Fat range (2.08–34.40%) of the phantoms represented the ranges of body weight and body fatness of infants between birth and 6 mo of age. To avoid confounding between mass and %Fat, the phantoms tested were divided into the following %Fat subgroups: %Fat ≤ 10% (7 phantoms ranging in mass between 1.3894 and 9.7737 kg), 10% < %Fat ≤ 20% (5 phantoms ranging in mass between 1.4646 and 9.4554 kg), 20% < %Fat ≤ 30% (8 phantoms ranging in mass between 1.4147 and 9.9516 kg), and %Fat > 30% (4 phantoms ranging in mass between 1.4883 and 9.7338 kg).

Phantoms were constructed to achieve the above-specified %Fat and mass values. Each phantom included a fat compartment and a lean muscle compartment. Fat compartments were made from frozen bovine internal fat deposits that were band sawed into parallelepipeds to allow measurement of the phantom's surface area. The same procedure was performed to make the lean muscle compartments; frozen lean cuts were used.

Testing procedure

Measurements were performed on each phantom in the following order: surface area, mass, volume by ADP (V_{ADP}), volume by HW (V_{HW}), and %Fat by CA ($\%Fat_{CA}$). Surface area measurements were performed because they are needed to correct the volumes measured by the ADP system. As specified above, the ADP system measures volumes with the assumption that all the air in the test chamber is under adiabatic conditions, resulting in a 40% overestimation of volumes of air behaving isothermally (in this case, air near the surface of the samples). This overestimation of the volume of air in the test chamber causes an equal underestimation of sample volume. To correct for this effect, surface area was measured and then multiplied by k, a constant determined empirically (by testing aluminum sheets with known volumes and areas) and calculated so that its multiplication by the surface area of the objects tested would equal the difference between the volume measured by the ADP system and the object's actual volume. As defined, the value of k is negative; therefore, the volume measured by the ADP system was corrected by subtracting from it the product of $k \times$ the surface area of the sample. It is important to note that when living subjects are tested, the ADP system automatically uses a surface area prediction equation to correct for this surface area effect.

Surface area measurements were computed by using the triangulation method, which is one of the methods used for the determination of the surface area of the human body. Boyd (8) described this technique in detail. We subdivided each phantom into regular geometric figures, mainly triangles. Areas were calculated from the linear dimensions of the geometric figures. Six mass measurements were taken to the nearest 0.1 g with a calibrated electronic scale (BLB-12; Tanita Corp, Tokyo). After each mass measurement, an ADP volume measurement was performed. After concluding all 6 mass and ADP measurements, the water temperature in the HW tank and the internal temperature of the phantom were measured with a digital thermometer (Model 15-078D; Fisher Scientific, Pittsburgh). Internal phantom temperature was measured by inserting the thermocouple in the phantom's core. The mass in water of each phantom was then measured once to the nearest 0.1 g with a calibrated electronic scale (P65002-S DeltaRange; Mettler Toledo Inc, Columbus, OH). V_{HW} was determined by using the following formula:

$$V_{HW} = (M_P - M_W)(D_{WT})^{-1} \quad (3)$$

where M_P is average mass of the phantom, M_W is mass of the phantom in water, and D_{WT} is density of the water in the HW tank at the temperature recorded. The mass and volume obtained by using ADP and HW were used to calculate %Fat in each phantom with a classic 2-component body-composition model (9). Therefore, %Fat in each phantom was determined by using the following formula:

$$\%\text{Fat} = [D_F(D_M - D_P)][D_P(D_M - D_F)]^{-1} \times 100 \quad (4)$$

where D_F is the density of fat adjusted to the phantom's temperature (10), D_M is the density of muscle adjusted to the phantom's temperature (11), and D_P is phantom density, with $D_P = M_P/V_{ADP}$ when calculating %Fat by ADP ($\%Fat_{ADP}$) and $D_P = M_P/V_{HW}$ when calculating %Fat by HW ($\%Fat_{HW}$).

Seventy-two samples weighing ≈5 g each were chemically analyzed (3 samples were obtained from each phantom). To obtain representative samples, each phantom was first cut into 4-cm pieces and was then completely homogenized by passing it through a meat grinder 5 times. Each sample was weighed (wet weight), frozen, freeze-dried, and weighed again (dry weight). The fat content in each sample was determined by diethyl ether extraction in a Sohxlet apparatus for 7 d. Each sample was allowed to air dry after the ether extraction procedure and was then weighed (fat-free weight). All mass measurements in the CA procedure were recorded to the nearest 0.01 g by using a calibrated electronic scale (P65002-S DeltaRange; Mettler Toledo Inc). The %Fat in each sub-sample was calculated as follows:

$$\%\text{Fat} = (\text{dry weight} - \text{fat-free weight})(\text{wet weight})^{-1} \quad (5)$$

In summary, %Fat values were determined from 6 measurements for ADP, 1 measurement for HW, and 3 measurements for CA.

Ethics

Frozen tissues were obtained from the University of California, Davis, Meat Lab. All animals processed in this facility were used with the approval of the Campus Animal Use and Care Committee.

Statistical analysis

The data were analyzed with SPSS, version 10.0 and SYSTAT, version 9.0 (SPSS Inc, Chicago). Values are expressed as means ± SD. Normal probability plots and the Shapiro-Wilk test were used to determine whether the %Fat values for the 24 phantoms followed a normal distribution. Levene's test was used to assess the homogeneity of variances.

The precision of estimating phantom mass, $\%Fat_{ADP}$, and $\%Fat_{CA}$ was determined by calculating the SD and CV for repeated measurements. The nonparametric Wilcoxon signed rank test was used to determine whether there was a significant difference between the SDs of $\%Fat_{ADP}$ and $\%Fat_{CA}$. Furthermore, the comparison of CV values for mass, $\%Fat_{ADP}$, and $\%Fat_{CA}$ among the 4 phantom %Fat subgroups (%Fat ≤ 10%, 10% < %Fat ≤ 20%, 20% < %Fat ≤ 30%, and %Fat >30%) was performed by using the nonparametric Kruskal-Wallis test.

Pearson product-moment correlation coefficients were calculated to assess correlations between the 3 different %Fat measurement techniques (CA, ADP, and HW). Repeated-measures one-way analysis of variance was performed to detect significant differences in %Fat by method, and Tukey's honestly significant difference multiple comparison procedure was further used to compare differences in %Fat among the 3 methods (CA, ADP, and HW).

Linear regression analyses were performed with $\%Fat_{CA}$ as the dependent variable to determine whether the regression line differed significantly from the line of identity (slope = 1, intercept = 0). Finally, agreement between ADP and CA in measuring %Fat of individual phantoms was assessed by using the method of Bland and Altman (12). With this method, bias was calculated as the mean difference between methods ($\%Fat_{ADP} - \%Fat_{CA}$), and 95% limits of agreement were calculated as the bias ± 2 SD of the difference between methods. In addition, regression analysis was performed to assess whether the differences in %Fat measured with ADP and CA were a function of phantom mass.

RESULTS

By design, the phantoms varied widely in mass (1.3894–9.9516 kg) and %Fat (2.08–34.40%). The average SD for mass was 0.0039 kg. The SDs for $\%Fat_{ADP}$ and $\%Fat_{CA}$ were not significantly different from each other (0.70% and 0.73% for ADP and CA, respectively) (**Table 1**). To assess whether measurement variability was similar across the range of %Fat values, CV values were compared among the 4 %Fat subgroups. The CV values for the mass and $\%Fat_{CA}$ measurements did not differ significantly among the 4 %Fat subgroups. However, the CV values for $\%Fat_{ADP}$ were significantly different among the 4 %Fat subgroups ($P = 0.001$), with a higher mean CV (18.14%) in the lowest %Fat subgroup than in the other 3 subgroups (4.13%, 2.58%, and 3.21%) (**Table 2**).

There were high correlations ($r > 0.99$, $P < 0.0001$) for each of the 3 possible combinations of %Fat measurement techniques (ADP, CA, and HW) (**Table 3**). Mean $\%Fat_{ADP}$ did not differ significantly from mean $\%Fat_{CA}$ (18.55% and 18.59%, respectively; $P = 0.917$), but there was a significant difference between $\%Fat_{HW}$ and $\%Fat_{CA}$ (18.29% and 18.59%, respectively; $P = 0.028$).

Linear regression and Bland-Altman analyses of $\%Fat_{ADP}$ and $\%Fat_{CA}$ (**Figure 1**) indicated a high degree of agreement. The regression equation ($\%Fat_{CA} = 0.996\%Fat_{ADP} + 0.119$) gave very low SEE and very high adjusted R^2. The slope and intercept of the regression line were not significantly different from 1 and 0, respectively (left panel). Furthermore, the 95% limits of agreement from Bland-Altman analyses were −1.22% to 1.13% Fat, with no trend in $\%Fat_{ADP} - \%Fat_{CA}$ as %Fat varied (right panel). In addition, the mean difference between ADP and CA (ie, $\%Fat_{ADP} - \%Fat_{CA}$) was −0.04% fat, with individual differences ranging from −1.54 to 0.81% fat.

Regression analysis was also performed to assess whether the differences between $\%Fat_{ADP}$ and $\%Fat_{CA}$ were a function of phantom mass. As shown in **Figure 2**, the differences in %Fat between methods were not significantly related to phantom mass ($r < 0.0001$, $P = 0.33$), indicating that none of the individual differences were a function of phantom mass.

DISCUSSION

This was the first study to evaluate the performance of a new ADP system designed for the infant population using CA of bovine tissue phantoms as the reference method. Our data suggested that ADP provided precise and accurate measurement of %Fat when compared with CA of phantoms in the pediatric ranges of body weight and body fatness.

The unique feature of the study design was that we used phantoms with wide ranges of mass and %Fat values. The ranges of mass (1.3894–9.9516 kg) and %Fat (2.08–34.40%) of the phantoms tested covered the ranges of body weight and body fatness of preterm and term infants from birth to 6 mo of age, for which the ADP system was designed. This represented an improvement over previous studies designed to evaluate other methods of infant body-composition assessment as compared with CA; in these studies, the ranges of body weight, body composition, or both of

TABLE 1
Mass and percentage fat of individual phantoms, determined by using chemical analysis ($\%Fat_{CA}$), air-displacement plethysmography ($\%Fat_{ADP}$), and hydrostatic weighing ($\%Fat_{HW}$), in 4 %Fat subgroups

%Fat subgroup	Mass	$\%Fat_{CA}$	$\%Fat_{ADP}$	$\%Fat_{HW}$
	kg	%	%	%
%Fat ≤ 10%				
	1.3894 ± 0.0010[1]	3.57 ± 0.01	3.15 ± 0.66	3.01
	1.7786 ± 0.0016	2.08 ± 0.06	2.50 ± 0.74	2.64
	3.4896 ± 0.0023	2.49 ± 0.08	2.63 ± 0.56	2.17
	5.5873 ± 0.0041	2.18 ± 0.12	2.11 ± 0.20	2.71
	7.4490 ± 0.0057	3.58 ± 0.13	3.36 ± 0.66	3.85
	7.6697 ± 0.0074	6.75 ± 0.19	7.01 ± 0.76	6.53
	9.7737 ± 0.0055	4.42 ± 0.14	3.35 ± 0.49	3.50
Mean SD (n = 7)	0.0039	0.10	0.58	—
10% < %Fat ≤ 20%				
	1.4646 ± 0.0012	12.67 ± 0.60	12.93 ± 0.51	12.29
	1.8938 ± 0.0021	16.44 ± 0.45	16.70 ± 0.44	16.00
	3.4822 ± 0.0021	17.81 ± 0.69	17.20 ± 0.59	17.30
	7.5948 ± 0.0057	19.17 ± 0.81	19.79 ± 0.66	19.71
	9.4554 ± 0.0073	13.26 ± 0.27	13.63 ± 1.00	12.34
Mean SD (n = 5)	0.0037	0.56	0.64	—
20% < %Fat ≤ 30%				
	1.4147 ± 0.0010	25.82 ± 1.29	25.01 ± 0.49	24.82
	1.9282 ± 0.0019	29.41 ± 1.40	28.91 ± 0.48	28.61
	3.5455 ± 0.0031	21.42 ± 1.30	22.00 ± 0.72	21.69
	3.8155 ± 0.0030	29.06 ± 1.08	29.38 ± 0.86	29.28
	5.7140 ± 0.0046	20.79 ± 0.51	20.07 ± 0.56	19.77
	5.7738 ± 0.0041	29.08 ± 1.31	29.11 ± 0.57	28.49
	7.6302 ± 0.0077	27.00 ± 0.76	27.64 ± 0.95	27.12
	9.9516 ± 0.0061	26.47 ± 1.55	26.37 ± 0.69	25.86
Mean SD (n = 8)	0.0039	1.15	0.67	—
%Fat > 30%				
	1.4883 ± 0.0025	34.40 ± 0.67	35.21 ± 0.89	34.56
	1.8663 ± 0.0031	32.66 ± 1.54	32.80 ± 1.70	32.39
	5.3648 ± 0.0041	34.05 ± 1.27	34.19 ± 0.92	34.56
	9.7338 ± 0.0055	31.57 ± 1.25	30.03 ± 0.73	29.79
Mean SD (n = 4)	0.0038	1.18	1.06	—
All subgroups combined				
Mean SD (n = 24)	0.0039	0.73	0.70	—

[1] $\bar{x}$ ± SD, calculated from repeated measurements for mass, $\%Fat_{CA}$, and $\%Fat_{ADP}$; $\%Fat_{HW}$ values are single measurements.

the animals tested did not cover the ranges most often found in infants (13, 14). In the present study, the use of fabricated bovine tissue phantoms enabled evaluation of all possible combinations of mass and %Fat categories within the selected ranges, without confounding of these factors.

The precision (expressed as SD) of both the ADP and CA methods was found to be excellent for assessing the %Fat of phantoms varying in mass and fat content. SD values for the 2 methods were not significantly different from each other, indicating that the precision of ADP compared favorably to that of CA. It was found that with the ADP method, CV values were higher for the lowest %Fat subgroup, but this should not be considered a problem in practical applications as long as enough measurements are taken to obtain a mean value representative of the true value. This was the case in the present study, as shown by the high accuracy of ADP compared with CA even in the lowest %Fat subgroup; the results suggest that 6 ADP measurements should be performed to obtain accurate results.

The results of this study indicate excellent agreement between $\%Fat_{ADP}$ and $\%Fat_{CA}$. In this regard, the 2 methods gave virtually identical mean values for %Fat and very close individual results. Regression analysis of $\%Fat_{ADP}$ against $\%Fat_{CA}$ gave very low SEE and very high R^2, with the intercept and slope not significantly different from 0 and 1, respectively. Furthermore, it is important that a method be valid on an individual basis in addition to reporting statistics for the group. There was excellent agreement between $\%Fat_{ADP}$ and $\%Fat_{CA}$ for individual phantoms; for 22 of 24 phantoms (92%), the difference between methods was less than ± 1%, and these differences were not related to fat content or mass.

Even though HW is not applicable for infant body-composition assessment, it was included in this study because it has been used frequently as a reference technique when evaluating ADP, and this study afforded for the first time the opportunity to compare HW and ADP to CA, which is considered the best reference method. As specified above, the 3 methods gave almost identical mean values for %Fat. Although there was a significant difference between %Fat measured with HW and with CA, this difference (18.29% and 18.59% for HW and CA, respectively) is most likely negligible from a clinical standpoint.

Concerning infant body-composition assessment, there is currently no method for measuring body fatness that has been found safe, precise, and accurate. The most frequently used methods

TABLE 2
Measurement variability of repeated measurements on individual phantoms of mass and percentage fat by air-displacement plethysmography ($\%Fat_{ADP}$) and chemical analysis ($\%Fat_{CA}$), by %Fat subgroup

%Fat subgroup	CV for mass (kg)	CV for $\%Fat_{ADP}$	CV for $\%Fat_{CA}$
%Fat ≤ 10%	0.07	21.07	0.32
	0.09	29.70	2.87
	0.07	21.38	3.07
	0.07	9.67	5.73
	0.08	19.62	3.49
	0.10	10.82	2.79
	0.06	14.72	3.12
Mean CV (n = 7)	0.08	18.14	3.06
10% < Fat ≤ 20%			
	0.08	3.92	4.77
	0.11	2.62	2.72
	0.06	3.46	3.86
	0.07	3.34	4.23
	0.08	7.32	2.01
Mean CV (n = 5)	0.08	4.13	3.52
20% < %Fat ≤ 30%			
	0.07	1.95	5.01
	0.10	1.65	4.76
	0.09	3.28	6.08
	0.08	2.94	3.70
	0.08	2.77	2.43
	0.07	1.96	4.50
	0.10	3.45	2.81
	0.06	2.61	5.84
Mean CV (n = 8)	0.08	2.58	4.39
%Fat > 30%			
	0.17	2.54	1.95
	0.17	5.18	4.73
	0.08	2.68	3.72
	0.06	2.45	3.97
Mean CV (n = 4)	0.12	3.21	3.50

include dual-energy X-ray absorptiometry (DXA), total body electrical conductivity, and skinfold-thickness measurements.

Many studies have evaluated DXA for assessing body composition by comparing it to CA of animals in the pediatric body weight range. Recently, Speakman et al (15) used DXA to measure the body composition of 16 animals (weighing between 1.8 and 22.1 kg) and subsequently performed CA of the carcasses. The study results indicated that on average, DXA provided acceptable estimates of fat mass (r = 0.98, mean percentage error = 2.04%). However, individual errors were much greater, ranging from underestimates of 20.7% to overestimates of 31.5%. In other validation studies using animal models, fat contents (in grams or

TABLE 3
Correlations among the 3 techniques for measuring percentage fat: chemical analysis (CA), air-displacement plethysmography (ADP), and hydrostatic weighing (HW)[1]

	CA	ADP
HW	0.9994	0.9985
CA		0.9987

[1] The correlations were Pearson's product-moment correlation coefficients (r); all were significant at $P < 0.0001$.

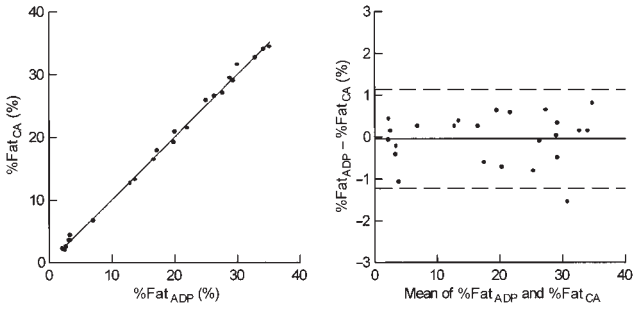

FIGURE 1. Comparison of percentage fat (%Fat) values determined by using chemical analysis (CA) and air-displacement plethysmography (ADP) in 24 bovine tissue phantoms. Linear regression (left panel) of $\%Fat_{CA}$ on $\%Fat_{ADP}$ ($\%Fat_{CA}$ = 0.996$\%Fat_{ADP}$ + 0.119, SEE = 0.600, adjusted R^2 = 0.997, $P < 0.0001$) and its Bland-Altman plot (right panel), in which the solid line shows the mean difference between methods (bias) and the dotted lines represent ±2 SDs from the mean difference (95% limits of agreements).

% of weight) measured with both DXA and CA were generally highly correlated (r > 0.96), and the percentage errors between DXA estimates and CA measurements averaged < 15% (13, 14, 16–21). Such studies found that the mean discrepancies in the estimated fat content across a group of animals were relatively small, but the variations between individuals were found to be 2–10 times greater than the mean errors. Further, the individual variations were occasionally related to body size, fat content, or the scanning program and software solutions for scan analysis (13, 17, 22, 23). In most of these studies, calibration of DXA to the laboratory standard of carcass analysis (ie, using conversion equations or correction factors for DXA) was applied to improve the

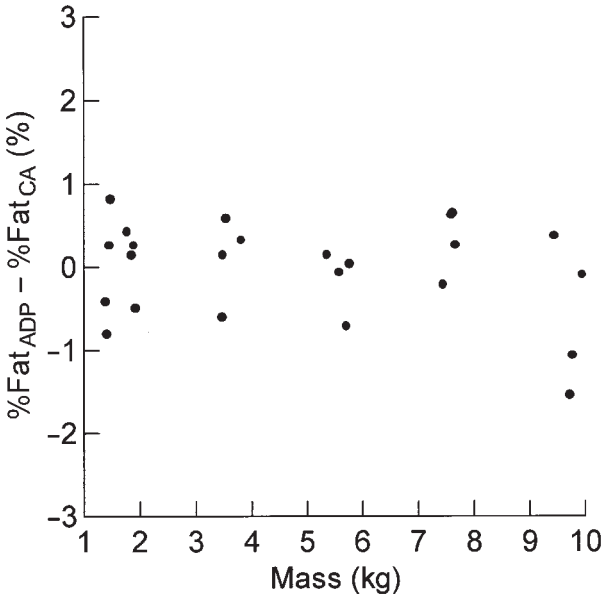

FIGURE 2. Differences between percentage fat (%Fat) values determined by using air-displacement plethysmography (ADP) and %Fat values determined by using chemical analysis (CA) for individual phantoms regressed against phantom mass; the differences in %Fat between methods were not significantly related to phantom mass ($r < 0.0001$, P = 0.33).

accuracy of DXA measurements (13, 16, 18, 24–26). However, even the calibrated results from DXA measurement were only valid for a specific machine with a specific software version and for a specific subject population for which CA could be performed. Therefore, it would be inappropriate to use these conversion equations or correction factors with infants. In contrast, the ADP system evaluated in this study did not require conversion equations or correction factors, and therefore it would be appropriate for use in infants and would result in accurate measurements when compared with other available methods, even though the percentage errors for ADP were found to be similar to those described above for DXA.

Total body electrical conductivity has been validated against CA for measuring fat-free mass in minipigs (27), but limited reports of critical validation and cross-calibration with other techniques for infant body-composition measurements indicate that the accuracy of individual fat estimates obtained with total body electrical conductivity is relatively poor (1).

Body-composition data derived from skinfold-thickness measurements correlated well with data obtained by using other techniques, but had poor agreement for individual measurements of body composition (28, 29). Further, skinfold-thickness measurements involve multiple sources of potential error (ie, the equipment, the techniques, and the observer), which restrict its use to field studies and group comparisons.

In summary, ADP was found to be a highly precise and accurate method for measuring %Fat compared with CA of phantoms in the pediatric ranges of body weight and body fatness. These results are encouraging in light of the potential for ADP to be useful in the infant population. Body-composition assessment in infancy has always been characterized by difficulty in obtaining accurate measurements on an individual basis. In addition, infant body-composition assessment requires a noninvasive testing procedure that involves minimal subject compliance. The ADP system used in this study has these characteristics. Moreover, in addition to the precision and accuracy shown in this study, the ADP system is rapid and noninvasive and has the potential to be very well tolerated by infants, as shown by the successful use of ADP in special populations (2, 4). Therefore, further studies should be conducted to assess the performance of ADP in infants.

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