

Body fat in neonates and young infants: validation of skinfold thickness versus dual-energy X-ray absorptiometry¹⁻³

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ABSTRACT

Background: There is an interest in noninvasive measurement of body fat in newborns and infants. Measurement of skinfold thickness (SFT) is a simple clinical method.

Objective: We correlated fat mass (FM) values of neonates and infants predicted from SFT measurements and compared them with FM values measured by dual-energy X-ray absorptiometry (DXA), a validated in vivo method for determining body fat.

Design: The weight, length, body composition (DXA measurement of FM and percentage of body fat), and SFT of 104 healthy term and preterm infants were measured at 0, 2, and 4 mo of age.

Results: Mean (\pm SD) FM determined by DXA increased from 440 ± 220 g at birth to 1310 ± 450 g at 2 mo of age and to 2170 ± 605 g at 4 mo of age. The percentage of body fat increased from 13.3% at birth to 24.5% and 31.2% at 2 and 4 mo of age, respectively. An equation was developed to calculate FM (in g) in newborns by using the sum of SFT measurements (in mm) and body length (l ; in cm): $FM = 68.2 \cdot \sum SFT^{0.0162 \cdot l} - 172.8$ ($R^2 = 0.948$, $P < 0.001$).

Conclusions: With the use of statistical bootstrap analysis, the results provide an in vivo validation of SFT measurements against DXA for newborns and young infants. Body fat measurements by SFT correlate with FM values determined by DXA ($R^2 = 0.936$). Estimation of nutritional status is possible with errors (SD) of ± 75 , ± 170 , ± 300 , and ± 380 g for infants with an FM ≤ 500 , 501–1000, 1001–2000, or > 2000 g, respectively. *Am J Clin Nutr* 2002;76:1096–100.

KEY WORDS Growth, neonates, infants, body composition, body fat, nutrition, skinfold thickness, dual-energy X-ray absorptiometry

INTRODUCTION

Accurate and fast in vivo measurement of infant body composition at bedside is useful in evaluating the amount and quality of weight gain. This may help to monitor adequate physical growth in early infancy and to study the effect of different nutritional regimens on the development of body composition.

Measurement of skinfold thickness (SFT) is a fast and noninvasive in vivo method. For older children, adolescents, and adults, it has been shown that SFT measurements correlate with body fat assessed by direct measurements such as dual-energy X-ray absorptiometry (DXA) (1, 2). Prediction equations have been published to estimate body composition, although the accuracy of

individual estimates is limited (2–6). To our knowledge, the present study is the first to validate the use of SFT measurements to predict fat mass (FM) in newborns and young infants. For this critical postnatal period, the development of an easy and reliable bedside method is of clinical interest because such a method could be used to assess nutritional status during the intrauterine and postnatal period and thus to characterize physical growth more precisely.

To evaluate the usefulness of SFT measurements in a group of newborn and young infants, SFT data have to be compared with data from a reference method. It was shown in piglets that FM determined by DXA (FM_{DXA}) yields acceptable estimates of body fat because FM_{DXA} correlates closely with the chemically determined total FM of carcasses (7–10). The absolute content of body fat may be obtained from DXA measurements by using device-specific conversion equations.

The aims of the present study were to correlate the measurement of body fat by DXA with the measurement of SFT and to establish and validate a prediction formula that is specific for the early postnatal period. A second aim was to prove the validity of published formulas, which are currently used to predict FM from SFT measurements in pediatric subjects, for a group of newborns and young infants.

SUBJECTS AND METHODS

Subjects

From November 1998 to October 1999, 104 healthy neonates (60 males and 44 females) who were born in the maternity ward of the university hospital in Greifswald, Germany, and were breast-fed or formula fed were included in the study as part of a nutritional intervention study. A study coordinator visited the

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² Supported in part by Novartis Nutrition, Berne, Switzerland (to CH). The dual-energy X-ray absorptiometry device was obtained through support provided by the Swiss National Research Foundation (grant 3200-43586) and Novartis Nutrition.

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Received January 5, 2001.

Accepted for publication December 18, 2001.

mothers on the third or fourth day after they had given birth, and detailed information was given to the parents. All infants were white and had a gestational age of ≥ 34 wk; 8 subjects were twins. To ensure that only healthy infants were assessed, the following exclusion criteria were adopted: major congenital, chromosomal, or metabolic anomalies; multiple births other than twins; umbilical arterial blood pH < 7.00 ; and 10-min Apgar score < 7 . Body composition (DXA and SFT) was assessed within the first 10 d after birth (t_0 ; $n = 68$) and at 2 (t_1 ; $n = 65$) and 4 (t_2 ; $n = 52$) mo of age. The different number of observations at the 3 time points is explained by subjects dropping out of the study (t_1 : $n = 28$; $t_1 + t_2$: $n = 40$) and by the fact that SFT measurements could not be made in the first subjects studied because the skinfold caliper was not available (t_0 : $n = 36$; t_1 : $n = 9$; t_2 : $n = 7$). In addition, 7 data points had to be excluded because of DXA motion artifacts (t_0 : $n = 0$; t_1 : $n = 2$; t_2 : $n = 5$). A complete longitudinal data set (including length, weight, DXA, and SFT measures) was available for 38 subjects. A total of 185 measurements were performed.

The study was approved by the University Ethical Committee and the State Authority for Radiation Exposure and Control. Written, informed consent was given by all parents.

Procedure for measurements

DXA and anthropometric measurements were obtained in a quiet, warm room at the Children's Hospital usually after the infants had been fed. If the infants were still sleeping after their clothes were taken off, they were swaddled in cotton blankets without additional clothing or diaper, and DXA measurement was performed immediately. After this procedure, anthropometric variables, including SFT, were assessed. If the infants did not continue to sleep after their clothes were removed, anthropometric measurements were performed first; then the infants were swaddled in blankets, and DXA scans were performed after the infants fell asleep.

Anthropometry

The weight of the naked infants was measured to the nearest 10 g by using a standard beam balance (Seca, Hamburg, Germany). Accuracy was confirmed by using calibrated weights of known mass. Height and head circumference were measured in triplicate to the nearest 0.5 and 0.1 cm, respectively, by using a standard tape measure.

For the assessment of body length, measurements made with the tape measure were compared ($n = 95$) with those obtained by using a measuring board (Schäfer, Karlsruhe, Germany). The mean (\pm SD) difference between the 2 measurements (0.02 ± 0.55 cm) was not significant.

Triceps, biceps, suprailiac, and subscapular SFTs were measured in triplicate on the left side of the body under standard conditions by using a standard skinfold caliper (Holtain Ltd, Croswell, Crymych, United Kingdom) that was operated with a constant pressure of 10 g/mm². While the infant was supine and the arm was slightly abducted and extended, biceps SFT was measured 1 cm proximal to the skin crease of the elbow. Then the infant was turned to the right side. Triceps SFT was then measured parallel to the long axis of the arm midway between the acromion and the olecranon, with the arm slightly flexed.

Suprailiac SFT was carefully measured along the midaxillary line just above the iliac crest. The subscapular SFT was measured below the inferior angle of the left scapula at a diagonal in the natural cleavage of the skin.

The caliper was left in place until a constant reading was obtained. Triplicate measurements were performed, and the mean was used. Most of the measurements were made by one observer (HRS), but a well-trained medical, technical assistant made measurements while the principal observer was on vacation.

Dual-energy X-ray absorptiometry

The basic theory and methodology of DXA are described elsewhere (10). The infants were measured on a whole body scanner (QDR 1500; Hologic, Waltham, MA) that was operated in a single-beam mode. The X-ray tube was pulsed between high and low voltage (140 or 70 kV) at a rate of 50 Hz to produce dual-energy X-ray beams. A detector mounted above the infant measured the transmitted intensity on a pixel-by-pixel basis. External calibration was performed with a step phantom with known equivalent amounts of fat and lean tissue.

Daily quality control scans were performed with the use of a manufacturer-supplied anthropometric spine phantom with a known amount of calcium hydroxyapatite embedded in a cubical epoxy block. For ethical reasons, duplicate measurements were not performed.

All scans were performed on an infant platform with the infant in a supine position and used the infant whole-body scan procedure. The infant platform filtered the low-energy beam to improve system linearity in the small subjects and to reduce the radiation dose. The scan time was ≈ 8 min. All scans were analyzed by using modified infant whole-body software (version 5.67; Hologic) with separate drift corrections for both X-ray levels as previously described (9). This modification was implemented by the manufacturer as a result of a pilot study in which we investigated the performance of our DXA system in measuring small bodies (C Fusch, unpublished observations, 1997). CVs for repeated DXA measurement of FM were reported to be $\approx 5\%$ (7–10). Data are given as raw FM_{DXA} values without applying device-specific conversion equations.

Prediction of body density and fat mass from published equations

The predictive value of 5 published equations to calculate percentage of body fat (%BF) from SFT in infants was evaluated by comparison with values of %BF measured by DXA (4, 11–14). These equations were established for use in adolescents and children but have not been validated in newborns. Details of the equations used are given in **Table 1**.

Predicted density (d) was converted to %BF by using the modified Siri equation (15) as proposed by Weststrate and Deurenberg (16)

$$\%BF = [562 - 4.2(\text{age} - 2)]/d - [525 - 4.7(\text{age} - 2)] \quad (1)$$

where age is given in years, and d is given in kilograms per liter. %BF values predicted from SFT on the basis of the 5 published equations were compared with measured %BF_{DXA} values.

Statistical analysis

All 185 data points were used for statistical analysis. Data are given as means \pm SDs. Comparisons between FM_{DXA} and FM estimated from SFT measurements (FM_{SFT}) were made by using regression analysis (SPSS for WINDOWS 10.0; SPSS Inc, Chicago). An equation to predict FM was derived from anthropometric data. Systematic and random errors between FM_{DXA} and

TABLE 1Published equations for predicting body density (d in kg/L) or percentage of body fat (%BF) in pediatric subjects¹

Reference	Equation	No. of skinfold sites	Characteristics
Slaughter et al (4) 1988 ($n = 66$)	M: %BF = $1.21 \times \Sigma\text{SFT} - 0.008 \times \Sigma\text{SFT}^2 - 1.7$ F: %BF = $1.33 \times \Sigma\text{SFT} - 0.013 \times \Sigma\text{SFT}^2 - 2.5$	2	Children with $\Sigma\text{SFT} < 35$ mm
Durnin and Rahaman (11) 1967 ($n = 86$)	M: $d = 1.1533 - 0.0643 \times \log \Sigma\text{SFT}$ F: $d = 1.1369 - 0.0598 \times \log \Sigma\text{SFT}$	4	Adolescents 12–16 y of age
Johnston et al (12) 1988 ($n = 308$)	M: $d = 1.1660 - 0.0070 \times \log \Sigma\text{SFT}$ F: $d = 1.144 - 0.060 \times \log \Sigma\text{SFT}$	4	Children and adolescents 8–14 y of age
Brook (13) 1971 ($n = 23$)	M: $d = 1.1690 - 0.0788 \times \log \Sigma\text{SFT}$ F: $d = 1.2063 - 0.0999 \times \log \Sigma\text{SFT}$	4	Children 1–11 y of age
Deurenberg et al (14) 1990 ($n = 212$)	M: $d = 1.1133 - 0.0561 \times \log \Sigma\text{SFT} + 1.7 (\text{age} \times 10^{-3})$ F: $d = 1.1187 - 0.063 \times \log \Sigma\text{SFT} + 1.9 (\text{age} \times 10^{-3})$	4	Children, mean age: 11 y

¹ ΣSFT , sum of skinfold-thickness measurements.

FM_{SFT} were analyzed by using the procedure proposed by Bland and Altman (17). Statistical significance was set at $P \leq 0.05$.

To validate the derived formula, 1 000 sets of bootstrap samples (18) of a sample size of 185 were randomly drawn from the original data set. This procedure represents a reliable model for validating prediction formulas. For each set of bootstrap samples, an R^2 value between the measured and predicted values of FM was calculated. The mean R^2 and the 95% CI are given. The mean error of the FM values calculated with the derived formula was determined as follows:

$$\text{Mean error} = \sqrt{\Sigma(\text{FM}_{\text{DXA}} - \text{FM}_{\text{SFT}})^2/n} \quad (2)$$

RESULTS

The mean gestational age at birth was 38.3 wk. Ten children were born before 37 wk of gestational age. Eighteen children were small for gestational age (<10th percentile) and 5 children were large for gestational age (>90th percentile) on the basis of actual age- and sex-related percentile charts (19). The anthropometric characteristics of all the subjects are shown in **Table 2**. A total of 185 data points was obtained at 0, 2, and 4 mo of age. As assessed by measurements of weight, length, and head circumference, the somatic growth of all the subjects was within the normal range during the study period. Mean FM_{DXA} increased from 440 ± 220 g at birth to 1310 ± 450 g at 2 mo of age and to 2170 ± 605 g at 4 mo of age. %BF_{DXA} increased from 13.3% at birth to 24.5% and 31.2% at 2 and 4 mo of age, respectively.

Ninety-six percent of the intraindividual variation in triplicate SFT measurements was within a 5% range of variation, indicating

valid SFT measurements. Recommendations require that $\geq 66\%$ of measurements be within a range of $\pm 5\%$ (20).

Regression analysis of the sum of 4 SFT measurements (ΣSFT) against FM_{DXA} showed an exponential relation, provided that body length was included in the equation ($R^2 = 0.948$, $P < 0.001$). The following formula was obtained to convert SFT (in mm) and body length (l ; in cm) into FM_{DXA} (in g):

$$\text{FM}_{\text{DXA}} = 68.2 \cdot \Sigma\text{SFT}^{0.0162 \cdot l} - 172.8 \quad (3)$$

Validation of this formula with the use of the bootstrap sampling method gave a mean R^2 value of 0.9357 ± 0.0008 (95% CI: 0.9342, 0.9373), indicating an acceptable validation of the derived formula.

A plot of the predictive error (Bland-Altman plot) of FM values calculated with Equation 2 is shown in **Figure 1**. The data scattered at higher FM values; however, the relative error was nearly constant. FM_{DXA} values ≤ 500 g were predicted by SFT measurement with an accuracy of 75 g (\pm SD); the mean errors (\pm SD) for 501–1000, 1001–2000, and >2000 g were 170, 300, and 370 g, respectively (**Figure 2**).

A comparison between %BF_{DXA} and %BF predicted by each of 5 prediction equations published for pediatric subjects is shown

TABLE 2Characteristics of the study subjects¹

	t_1 ($n = 68$)	t_2 ($n = 65$)	t_3 ($n = 52$)
Age (d)	6 ± 4	66 ± 6	124 ± 4
Weight (g)	3160 ± 680	5260 ± 840	6880 ± 820
Length (cm)	49.9 ± 5.3	58.4 ± 2.8	64.1 ± 2.8
ΣSFT (mm)	16.2 ± 2.8	25.2 ± 5.1	28.8 ± 4.7
FM_{DXA} (g)	440 ± 220	1310 ± 450	2170 ± 605
%BF _{DXA}	13.3 ± 4.3	24.5 ± 5.8	31.2 ± 6.6

¹ $\bar{x} \pm$ SD. t_1 , t_2 , and t_3 , measurement time points at 0, 2, and 4 mo of age, respectively; ΣSFT , sum of skinfold thickness measurements; FM_{DXA} , fat mass measured by dual-energy X-ray absorptiometry; %BF_{DXA}, percentage of body fat measured by DXA.

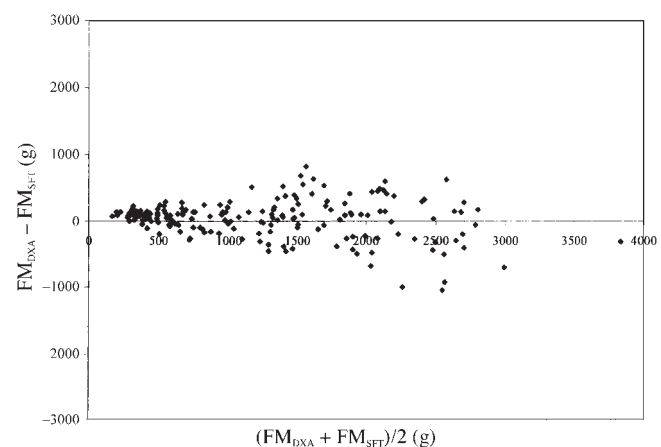


FIGURE 1. Bland-Altman (17) plot for comparing fat mass measured by dual-energy X-ray absorptiometry (FM_{DXA}) with fat mass predicted from skinfold-thickness measurements (FM_{SFT}) with the use of Equation 3 ($n = 185$).

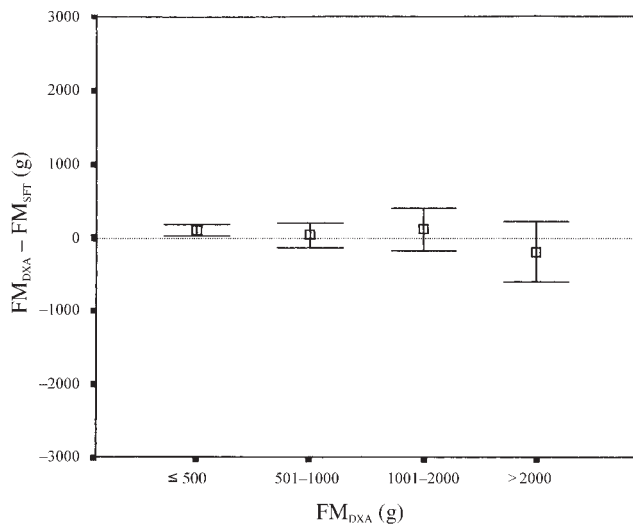


FIGURE 2. Mean (\pm SD) difference between fat mass measured by dual-energy X-ray absorptiometry (FM_{DXA}) and fat mass predicted from skinfold-thickness measurements (FM_{SFT}) with the use of Equation 3 in subgroups with FM_{DXA} values of <500 g ($n = 46$), 501–1000 g ($n = 39$), 1001–2000 g ($n = 66$), and >2000 g ($n = 34$).

in **Table 3**. Generally, a weak correlation was found not to be tight enough to allow individual predictions of FM from SFT when these equations were applied. Moreover, in most cases there was a considerable systematic error that increased with increasing %BF (**Figure 3**).

DISCUSSION

In the present study we showed that SFT correlates closely with FM_{DXA} in newborns and infants aged ≤ 4 mo. The reported errors seem to be acceptable for in vivo and noninvasive measurements of body fat in a group of infants in this early age period. Our data compare favorably with those presented by Koo and Walters (21) at the 1997 meeting of the Society of Pediatric Research.

The precision of the relation between SFT and FM in the present study greatly improved when body length was included in the model. This finding may be explained by data from a previous study showing that postnatal fat accumulation occurs predominantly at the extremities (22). Ninety-five percent of the FM variation in the infants was explained by the model presented here,

TABLE 3

Comparison between percentage of bodyfat (%BF) measured by dual-energy X-ray absorptiometry and %BF calculated from published prediction equations

Published equation	R^2	Difference ¹
		%
Slaughter et al (4) 1988 ($n = 66$)	0.71	-10.7 ± 4.79
Durnin and Rahaman (11) 1967 ($n = 86$)	0.66	-19.8 ± 4.76
Johnston et al (12) 1988 ($n = 308$)	0.71	-22.7 ± 4.22
Brook (13) 1971 ($n = 23$)	0.62	-21.6 ± 1.31
Deurenberg et al (14) 1990 ($n = 212$)	0.77	-6.27 ± 4.32

¹ $\bar{x} \pm SD$.

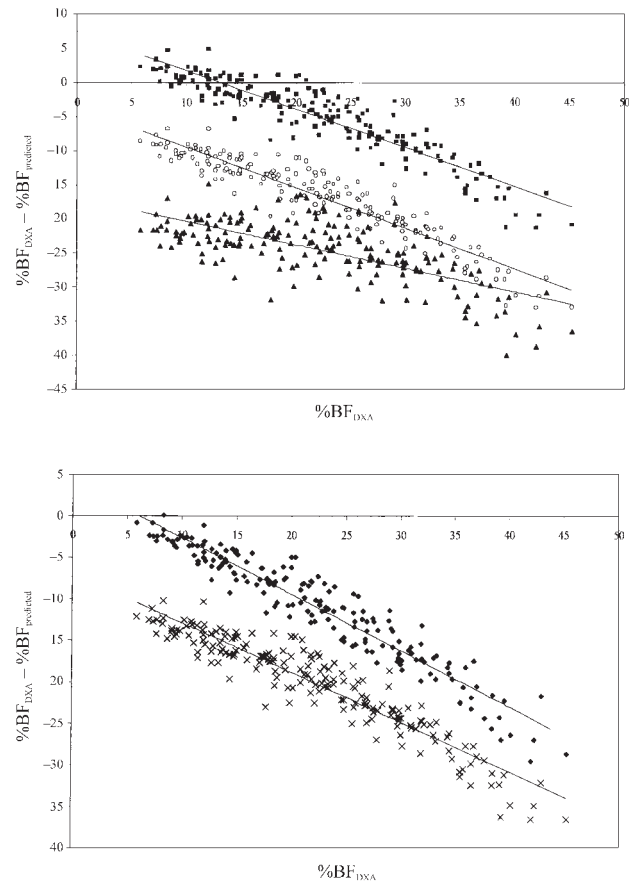


FIGURE 3. Difference between the percentage of body fat (%BF) measured by dual-energy X-ray absorptiometry ($\%BF_{DXA}$) and %BF predicted from each of 5 published equations ($\%BF_{predicted}$) plotted against $\%BF_{DXA}$ ($n = 185$). ■, ○, and ▲, %BF values predicted from the equations of Slaughter et al (4; $y = -0.5654x + 7.4328$; $R^2 = 0.8503$), Durnin and Rahaman (11; $y = -0.5932x - 3.5204$; $R^2 = 0.8809$), and Johnston et al (12; $y = -0.3447x - 16.856$; $R^2 = 0.489$), respectively. ◆ and ×, %BF values predicted from the equations of Brook (13; $y = -0.6777x + 4.1387$; $R^2 = 0.9165$) and Deurenberg et al (14; $y = -0.5967x - 6.9059$; $R^2 = 0.884$), respectively.

which is therefore a realistic model for daily use. Although the formula may look complicated at first glance—mostly because of the power relation—it seems to be a reasonable equation: FM is mainly related to the sum of SFT and is modulated by body length. Moreover, with the widespread use of electronic calculators and personal computers nowadays, FM may be easily estimated from SFT by using this equation.

Interestingly, as observed by Goran et al (2) in a published study of children aged 4–9 y, measurement of SFT is more closely related to the absolute amount of body fat than to %BF. This finding may be due to the rapidly changing anatomical geometry of growing infants, which causes higher variations in the absolute FM than in %BF.

Note that the equations published to predict body fat in older pediatric subjects may not be extrapolated to the newborn and early infant period. The use of these equations introduces a considerable bias when “true” FM is estimated from SFT.

We used DXA to assess in vivo body fat because DXA provides a direct measurement of body composition with accuracy and

precision that are high compared with those of other noninvasive methods that are based on direct and indirect measurements (eg, bioelectrical impedance analysis, deuterium dilution, total-body electrical conductivity, and underwater weighing). A linear relation between values of lean and fat mass measured by DXA and those obtained by chemical carcass analysis has been shown in several animal studies (7–10, 23). Because DXA tends to overestimate FM systematically, equations have been developed that can fully convert values obtained by DXA into those obtained by chemical carcass analysis (7–10).

In the present study uncorrected FM_{DXA} was used because our previously published calibration curve was established only for FM < 700 g (9) and extrapolation beyond the observed range should be avoided. In the present study, however, we observed FM values as high as 3000 g. The use of uncorrected FM_{DXA} does not change the basic finding of this study that SFT correlates highly with body fat.

The use of uncorrected FM_{DXA} may in part be responsible for why we observed body FM values at 4 mo of age that represented as much as 30% of body weight, which seems to be a relatively high value. Nevertheless, as stated before, uncorrected DXA data may give overestimates of “true” body fat (up to one-third), but this should not affect the correlation itself. Another factor is that all the newborns and infants measured in this study had excellent postnatal growth. On the basis of age- and sex-specific growth charts of children born in northern Germany (24), the average centile values of our infants were 63.4 ± 25.7 , 59.6 ± 23.7 , and 60.1 ± 25.7 at 0, 2, and 4 mo of age, respectively. A comparison with longitudinal reference data (25) showed that weight gain (32 g/d compared with 30 g/d from 0 to 2 mo and 29 g/d compared with 23 g/d from 2 to 4 mo) and height gain (1.25 mm/d compared with 1.06 mm/d from 0 to 2 mo and 1.12 mm/d compared with 0.93 mm/d) were considerably higher in our population.

The present study was restricted to healthy white children, and therefore the results cannot be extrapolated to children with severe diseases or to nonwhite children. It would be of further interest to study those groups.

In conclusion, measurement of SFT as part of the ordinary clinical routine may be used as a noninvasive method to give a first, rough, in vivo estimate of body fat and body composition in young infants. Then, to get a more accurate estimate of the body composition of an individual infant, the measurement of SFT may be followed by more sophisticated methods such as DXA. Prediction equations validated in older children for calculating FM from SFT measurements cannot be extrapolated to newborns and young infants.

We thank all the children and parents who took part in this study. We especially thank Monika Hoyer for technical assistance with the anthropometric measurements, Monika Fusch and Ingrid Kadow for recruiting infants for the study, and Matthias Heukäuffer and Susanne Unverzagt for statistical help.

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