REGULAR ARTICLE

Body fat measurement in adolescent girls with type 1 diabetes: a comparison of skinfold equations against dual-energy X-ray absorptiometry

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ABSTRACT

Aim: Skinfold measurement is an inexpensive and widely used technique for assessing the percentage of body fat (%BF). This study assessed the accuracy of prediction equations for %BF based on skinfold measurements compared to dual-energy X-ray absorptiometry (DXA) in girls with type 1 diabetes and healthy age-matched controls.

Methods: We included 49 healthy girls and 44 girls with diabetes aged 12–19 years old, comparing the predicted %BF based on skinfold measurements and the %BF values obtained by a Lunar DPX-L scanner. The agreement between the methods was assessed using an Bland–Altman plot.

Results: The skinfold measurements were significantly higher in girls with diabetes (p = 0.003) despite a nonsignificant difference in total %BF (p = 0.1). A significant association between bias and %BF was found for all tested equations in the Bland–Altman plots. Regression analysis showed that the association between skinfold measurements and %BF measured by DXA differed significantly (p = 0.039) between the girls with diabetes and the healthy controls.

Conclusion: The accuracy of skinfold thickness equations for assessment of %BF in adolescent girls with diabetes is poor in comparison with DXA measurements as criterion. Our findings highlight the need for the development of new prediction equations for girls with type 1 diabetes.

INTRODUCTION

There have been several reports of increased body mass index (BMI) in adolescents with type 1 diabetes in comparison with healthy controls. This difference has mainly been observed in girls (1–3), but some studies have reported similar differences in boys (4–6). The inference of these findings is that increased BMI reflects excessive fat accumulation, and this has been confirmed when body composition has been measured with dual-energy X-ray absorptiometry (DXA) (7) and skinfold thickness measurements (4,8).

Skinfold measurements are noninvasive and inexpensive and have therefore been frequently used in studies of children and adolescents with type 1 diabetes (3,4,7–9). Multiple equations have been developed to predict the percentage of body fat (%BF) in healthy adolescents and young adults from skinfold measurements (10–15), but none have been developed from skinfold measurements of adolescents with type 1 diabetes. To our knowledge, no study has validated the existing equations in a population of adolescents with type 1 diabetes.

The aim of this study was to validate the most commonly used skinfold equations to estimate %BF using body composition measurements by DXA as the criterion in adolescent girls with type 1 diabetes and to compare the associations with that of age-matched healthy controls.

PATIENTS AND METHODS
Subjects
Data for 44 girls with type 1 diabetes and 49 healthy girls matched for age were pooled from two different studies

Key Notes
- Skinfold measurement is an inexpensive and widely used technique for assessing the percentage body fat.
- This study showed that using skinfold thickness equations to assess the percentage body fat in 44 adolescent girls aged 12–19 with type 1 diabetes was less accurate compared to measurements obtained using dual-energy X-ray absorptiometry as criterion.
- There is a need to develop new prediction equations for girls with type 1 diabetes.

conducted at the Department of Pediatrics, Örebro University Hospital, Sweden (7,16). All the subjects and their parents gave informed consent, and the study was approved by the Ethics Committee of Örebro County Council.

Body composition assessments

All measurements were performed in the fasting state in the morning before breakfast to minimise differences in hydration. Height and weight were measured, and BMI (kg/m^2) was calculated for each subject. Weight was measured in light clothing to the nearest 0.1 kg, and height was measured to the nearest 0.5 cm. Waist circumference was measured at the level of the umbilicus.

Skinfold thickness was measured with a Harpenden calliper (British Indicators Ltd, West Sussex, UK) at the biceps, triceps, subscapular and suprailiac areas (17). Three skinfold measurements were performed at each site, and the mean of the three measurements was calculated. Two highly experienced investigators performed all the measurements.

Six skinfold equations were selected for validation, and these were derived from an original population with appropriate age and based on biceps, triceps, suprailiac and/or subscapular skinfolds (10–15) (Table 1). The equation devised by Siri was used to convert body density to %BF using the equation %BF = 495/body density minus 450. Body composition was also measured using a Lunar DPX-L scanner (Lunar Corp, Wisconsin, USA). The measurement gave a coefficient of variation (CV) for fat measurements of 10.4%, 1.7% and 0.3%, assessed in three different phantoms with a fat content of 10, 20 and 40 kg, respectively.

Laboratory measurements

Haemoglobin A1c (HbA1c) was measured by high-pressure liquid chromatography using the Mono-S standard (18). The values were converted to the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) standard using the equation IFCC (mmol/mol) = 10.45 multiplied by Mono−S(%) minus 10.62. The reference level for healthy subjects is 27–42 mmol/mol with the IFCC standard (19).

Statistical analysis

Descriptive statistics were calculated using means, standard deviations (SD) and ranges. The unpaired t-test was used to evaluate differences in the clinical characteristics variables between healthy controls and girls with type 1 diabetes. Agreement between %BF from DXA and estimated %BF from skinfold equations was assessed using the Bland–Altman methods (20).

Regression analysis was used to estimate the association between the sum of the triceps, biceps, suprailiac and subscapular skinfolds in millimetres and %BF from DXA. The two lines in Figure 2 are estimated from the nonlinear regression with %BF from DXA as the outcome variable. The sum of the skinfold measurements – linear and quadratic and group, namely type 1 diabetes or control patient – was used as independent variables in the regression.

A stepwise multiple regression analysis was used to calculate a prediction equation of %BF from skinfold values in girls with diabetes. %BF obtained by DXA was used as the dependent variable. Seven variables were included in the first model: BMI, age, log suprailiac skinfold, log biceps skinfold, log triceps skinfold, log subscapular skinfold and HbA1c. When we used a cut-off level of p < 0.01, the final model included all the variables but age, log suprailiac and HbA1c. Stata Statistical Software release 9 (StataCorp, College Station, Texas, USA) was used for all statistical calculations.

RESULTS

Clinical characteristics

Table 2 describes the clinical characteristics and shows that no significant differences were seen between the groups in age, height, weight, BMI or %BF. Triceps, subscapular and suprailiac skinfolds were significantly higher in the girls with diabetes than the controls.

Comparison between estimated %BF by skinfold measurements and by DXA

Table 3 shows the results in terms of bias defined as observed BF% from DXA minus estimated %BF from the skinfold equations. All skinfold equations showed significantly statistically lower %BF among girls with type 1 diabetes in comparison with DXA, except the equations by Slaughter et al. (10) and Parizkova et al. (15). The findings

Table 1 Skinfold equations to estimate percentage body fat used in the study

Author	Number	Sex	Age	BF%	Criterion	Prediction equation
Slaughter et al. (10)	136	F	8–29	Appr. 27.0	MC	BF% = 1.33*A −0.013*A^2 −2.5 or when A > 35 mm BF% = 0.546*A + 9.7
Durnin and Rahaman (11)	38 45	F	13.2–16.4 18.0–29.1	24.0 (4.9) 24.2 (6.5)	UWW	BD = 1.1369 −0.0598*logB BD = 1.1581 −0.072*log B
Deurenberg et al. (12)	34	F	16.8	21.7	UWW	BD = 1.1830 −0.0813*logB
Sloan et al. (13)	50	F	20.2 ± 1.7	22.9 (5.58)	UWW	BD = 1.0764 −0.00081 suprailiac −0.00088 triceps
Thorland et al. (14)	133	F	16.5 ± 1.4	14.5 ± 4.3	UWW	BD = 1.0987 −0.00122C + 0.00000263C^2
Parizkova et al. (15)	62	F	13–16	Appr. 4–38	UWW	BD = 1.114 −0.031log triceps −0.041log subscapular

BF% = percentage body fat. BD = body density. A = triceps + subscapular skinfold (mm), B = triceps + biceps + subscapular + suprailiac skinfolds (mm), C = triceps + subscapular + suprailiac skinfolds (mm). MC = multicompartment model, UWW = underwater weighing.

Table 2 Clinical characteristics

	Controls (n = 49)			Type 1 diabetes (n = 44)			
	Mean	SD	Range	Mean	SD	Range	p-value*
Age (years)	16.8	1.7	12.3–19.9	16.4	1.9	12.1–19.0	0.210
Weight (kg)	64.3	11.9	44.2–87.6	66.7	11.0	42.0–88.9	0.305
Height (m)	1.66	0.06	1.54–1.82	1.65	0.07	1.49–1.79	0.236
BMI (kg/m^2)	23.1	3.7	17.4–31.1	24.5	3.3	16.5–31.1	0.062
Biceps skinfold (mm)	12.4	6.3	4.9–27.8	14.8	6.8	5.2–31.9	0.084
Triceps skinfold (mm)	20.6	7.1	9.2–34.1	24.3	7.0	8.9–36.8	0.014
Subscapular skinfold (mm)	16.3	7.7	6.6–35.4	21.1	11.1	5.3–54.1	0.016
Suprailiac skinfold (mm)	17.0	7.7	4.8–37.7	23.0	8.6	6.1–40.0	<0.001
Sum skinfolds (mm)	66.3	25.6	26.5–125.0	83.1	28.1	29.2–148.7	0.003
% body fat (DXA)	32.2	8.3	13.0–46.7	34.9	7.6	13.5–48.5	0.104
Waist circumference (cm)	76.6	9.2	62.0–97.5	79.2	9.4	61.0–100.0	0.173
HbA$_{1C}$ (mmol/mol)				70.1	13.2	46.9–102.2	
Daily dosages of insulin (U/kg/d)				1.1	0.3	0.6–2.1	

*p-values from *t*-test.

Table 3 Bias and 95% limits of agreement for percentage body fat predicted by skinfold thickness equations against DXA measurements

	Control girls			Type 1 diabetes		
Equation	Bias (95% CI)	95% limits of agreement	Corr (r)	Bias (95% CI)	95% limits of agreement	Corr (r)
Slaughter	2.9 (1.7–4.1)	−5.5 to 11.2	0.07[NS]	0.8 (−0.6 to 2.2)	−8.6 to 10	−0.4[S]
Durnin and Rahaman	1.4 (0.1–2.7)	−7.6 to 10.4	0.74[S]	1.1 (0.0–2.3)	−6.3 to 8.6	0.74[S]
Deurenberg	5.0 (3.9–6.2)	−2.9 to 12.9	0.51[S]	3.9 (2.9–4.9)	−2.4 to 10.2	0.45[S]
Sloan	8.2 (6.8–9.6)	−1.6 to 18.1	0.63[S]	7.3 (5.9–8.6)	−1.7 to 16.2	0.50[S]
Thorland	6.8 (5.7–8.0)	−1.4 to 15.1	−0.05[NS]	3.7 (2.3–5.1)	−5.3 to 12.7	−0.35[S]
Parizkova	−0.2 (−1.4 to 1.0)	−8.5 to 8.1	0.64[S]	−0.5 (−1.6 to 0.5)	−7.3 to 6.2	0.43[S]

Bias: Percentage body fat by dual-energy X-ray absorptiometry minus values from skinfold thickness equations. 95% limits of agreement: ± 2 SD of the mean difference between methods. r = correlation between bias and percentage body fat. S = significant, NS = nonsignificant.

in the healthy control group were similar, with significant underestimations of %BF by skinfold measurements in all equations, except for the equation by Parizkova et al. (15).

Bias was significantly correlated to the level of average % BF – the sum of the DXA and skinfold measurements divided by two – in all equations among girls with diabetes (Fig. 1). In four of the six equations, the correlation was positive, indicating higher bias and a possible underestimation of BF% by skinfold when the level of the average %BF was high. In the healthy control group, only two of the six equations, Slaughter (10) and Thorland (14), showed nonsignificant correlations.

Relationship between the sum of the skinfold measurements and the %BF
Regression analysis showed that the association between skinfold measurements and %BF measured by DXA differed significantly between the girls with diabetes and the healthy controls (Fig. 2). For a given sum of skinfold, the control group had 1.6%-units higher %BF measured by DXA (95% confidence interval 0.1–3.2, p = 0.039). As shown in Figure 2, the relationship between the sum of the skinfold measurements and %BF demonstrated a linear

association for %BF of less than 35, whereas a levelling-off effect was observed in individuals with higher %BF.
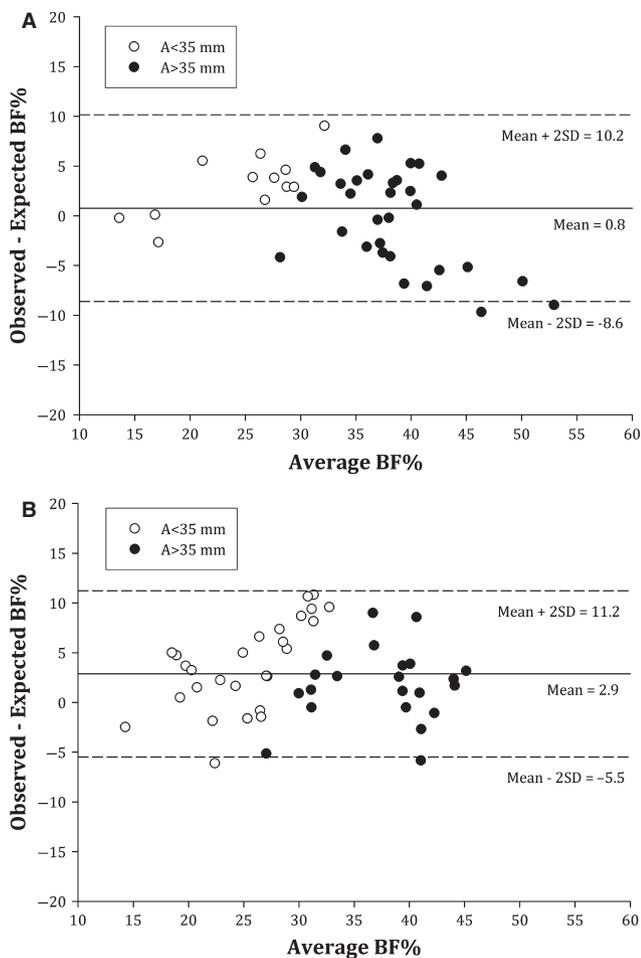
Prediction equation of %BF in girls with type 1 diabetes
The following prediction equation for %BF was developed: %BF = −20.284 + 10.715 × log biceps + 8.871 × log triceps + 6.856 × log subscapular + 0.9128 × BMI. This model explained 91% of the variance in %BF from DXA measurements with an adjusted r^2 of 0.91.

DISCUSSION
The results from the present study suggest that all the prediction equations based on skinfold measurements that we evaluated, except those devised by Parizkova et al. (15) and Slaughter et al. (10), underestimated BF% in comparison with DXA in adolescent girls with type 1 diabetes. Furthermore, we observed a systematic bias for all tested equations, indicating that the prediction of percentage body fat from skinfold measurements deteriorates with increasing fatness.
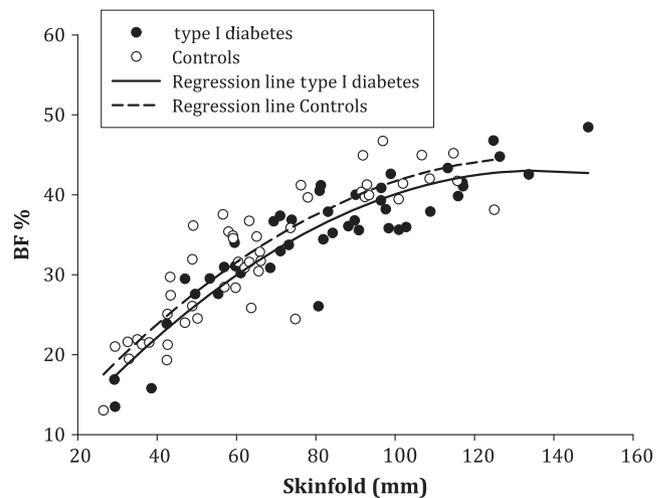
One of the main findings in this study was that skinfold equations often underestimated %BF. Our results suggest

Figure 2 The relation between sum of skinfolds in millimetre and percentage body fat measured by DXA.

Figure 1 Comparison of predicted percentage body fat between skinfold equation by Slaughter et al. and measurements by DXA in girls with type 1 diabetes (A) and controls (B). Mean differences ± 2 SD for the difference are given in the Figure. White dots indicate when the sum of triceps and subscapular skinfold was less then 35 mm and black dots when the sum was more than 35 mm. Observed = %BF by dual-energy X-ray absorptiometry. Expected= %BF from skinfold thickness equation.

that the sum of the skinfold measurements was significantly higher in girls with diabetes than healthy control girls, despite nonsignificant differences in BMI and %BF. This indicates a different relationship between skinfold measurements and total body fatness between the two groups. We have previously observed this phenomenon in middle-aged diabetic patients with a long disease duration (21), and Tillman et al. (22) observed that girls and boys with diabetes had significantly thicker triceps and biceps skinfold than healthy adolescents, despite having a similar BMI.

One possible explanation for this could be increased stiffness in subcutaneous fat caused by glycated collagen (23). Skin collagen glycation has been associated with HbA1c and proposed as a predictor of microvascular complications (24). However, in our study of young girls with type 1 diabetes, very few other signs of diabetic complications were observed and we found no significant influence of Hba1c in our prediction equation. Therefore, it

is possible that the increased subcutaneous stiffness was an early consequence of type 1 diabetes, preceding other types of long-term effects. It is, however, also possible that there was a real difference in subcutaneous fat deposition between the groups, where girls with diabetes accumulated relatively more fat subcutaneously than healthy girls.

To our knowledge, there have been no previous validation studies in adolescents with type 1 diabetes, but cross-validation studies in healthy adolescents have suggested that the equation by Slaughter et al. is valid for predicting % BF in girls (25,26). Our observations in the healthy control group agreed with these findings. The mean bias was low (2.9%), and no systematic error was observed. This is comparable with previous cross-validations in adolescent girls using underwater weighing (UWW) (bias 2%; limits of agreement ±13%) (27), DXA (bias 1.64%; limits of agreement ±7.4%) (26) or a four-compartment model (bias 0.1%; limits of agreement ±10.2%) (25) as the criterion methods.

Skinfold measurements are often used in large-scale studies to assess body composition. This study shows that the results obtained when calculating %BF from skinfold measurements in adolescent girls with type 1 diabetes need to be viewed with caution. There could, for example, be a risk of misinterpreting the relationship between body fatness and cardiovascular risk factors when using the equations assessed in this study.

New prediction equations need to be developed to improve the accuracy of estimating body fatness from skinfolds in adolescent girls with type 1 diabetes. The prediction equation developed in this study was a good match to %BF from DXA and is the first equation derived from a paediatric population with type 1 diabetes. The weakness of this model was the low number subjects we included and the lack of external validation of the equation developed as part of this study. For that reason, the equation needs to be validated in another larger population of girls with diabetes.

CONCLUSION

Using skinfold thickness equations to assess body composition in adolescent girls with type 1 diabetes showed low levels of accuracy in comparison with DXA measurements as criterion method. Our observations emphasise the need for specific skinfold equations for girls with type 1 diabetes derived from a population with an appropriate range of fatness.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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