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BODY COMPOSITION ORIGINAL ARTICLE

Body fat throughout childhood in 2647 healthy Danish children: agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry

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BACKGROUND/OBJECTIVES: Total body fat percentage (%BF) evaluated by dual energy X-ray absorptiometry (DXA) scans (DXA %BF) is widely recognized as a precise measure of fatness. We aimed to establish national reference curves for DXA %BF, %BF calculated from skinfolds (SF %BF) and waist circumference (WC) in healthy children, and to compare agreement between the different methods.
SUBJECTS/METHODS: Based on 11 481 physical examinations (anthropometry) and 1200 DXA scans from a longitudinal cohort of Danish children ($n = 2647$), we established reference curves (LMS-method) for SF %BF, WC (birth to 14 years) and DXA %BF (8–14 years). Age- and sex-specific Z-scores for body mass index (BMI), WC and SF %BF were compared. Sensitivity and specificity were calculated for agreement of WC, SF %BF and BMI with DXA %BF to identify obese children ($> +1$ s.d.).
RESULTS: %BF differed with age, sex, pubertal stage and social class. SF %BF correlated strongly with DXA %BF ($r = 0.86$). BMI and WC also correlated positively with DXA %BF (*Z*-scores; $r =$ 0.78 and 0.69). Sensitivity and specificity were 79.5 and 93.8 for SF %BF, 75.9 and 90.3 for BMI and 59.2 and 95.4 for WC.
CONCLUSIONS: SF %BF showed the highest correlation and best agreement with DXA %BF in identifying children with excess fat ($+1$ s.d.).

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Keywords: body composition; body fat percentage; dual X-Ray absorptiometry; skinfold thickness; body mass index; waist circumference

INTRODUCTION

Overweight and obesity among children and adolescents are associated with higher risk of adult obesity, morbidity and premature mortality.[1–3] Overweight and obesity in children are usually assessed by age- and gender-specific body mass index (BMI) or weight for height percentiles. However, as BMI and weight reflect both fat and lean body mass, they are not the most sensitive markers for detecting excess body fat and it has therefore been speculated that BMI may be inaccurate for detecting future risk.[4] A number of methods to measure body composition exist. Magnetic resonance imaging and underwater weighing are of limited use because of cost and availability. Dual energy X-ray absorptiometry (DXA) is associated with very low radiation doses compared with background radiation and correlates well with carcass analysis (gold standard),[5,6] but its use may also be limited by cost and availability. Bioelectrical impedance may (depending on the equation used) overestimate body fat percentage (%BF) in leaner subjects and underestimate %BF in fatter subjects.[7] Waist circumference (WC) is simple to measure and appears to be highly predictive of cardiovascular risk in adults.[8] Measuring skinfold (SF) thickness is widely used in epidemiological studies as it is also a simple and inexpensive evaluation of fatness. SF measurements can be used as absolute values (in mm)[9] or used in equations to estimate %BF. Slaughter's equation[10] has been evaluated as the best predictor of %BF in children[11] and has been used for reference materials for US, British and German children.[12–14]

In the Bogalusa Heart Study, both BMI and SF thickness in school children were strongly associated with various obesity-related risk factors in adulthood, such as high blood pressure and serum concentrations of triglycerides.[15] But in the Amsterdam Growth and Health Study adolescent SF thickness was superior to BMI as a predictor of adult body fat.[16] Also other studies suggest that SF measurements alone or in combination with BMI may be a better measure of fatness than BMI alone,[17,18] and that BMI may underestimate obesity as defined by %BF.[19] This, however, depends on the cutoff points used for excess fat. Cutoff points for excess body fat in adults are often defined as 25% in males and 30% in females[20,21] but controversy exists.[22] For children, there is no consensus on cutoffs. Although obese children are easily detected irrespective of methodology, children with high %BF despite normal BMI may be overlooked. However, they appear to share common health risks with overtly obese populations.[23] Our hypothesis was that SF measurements could give a valid

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estimation of %BF and help identifying so called 'normal weight obese' children.

We have measured WC, SFs and performed DXA scans in a large cohort of healthy Danish children in order to establish reference curves and to compare specificity and sensitivity of different methods of fat assessment.

MATERIALS AND METHODS

Study population

The study is based on 11 481 examinations of 2647 Danish children between 0 and 15 years of age from an ongoing population-based mother–child cohort conducted at Rigshospitalet, Copenhagen, Denmark (Supplementary Figure 1). Mothers were recruited between 1997 and 2001 in early pregnancy. Only Caucasian children were included in the cohort. The cohort has previously been described in detail.[24] The children were examined at 0, 3, 6, 9, 12, 18, 36 months, once in 2006–2007 (mean age: 7.0 years, range: 4.5–9.7 years)[25] and again yearly (one to three times) in 2010–2012 (mean age: 11 years, range: 6.0–15.0 years; not all at all time points).

A subgroup of the children was not population based. They were recruited after birth in 2001–2003 to study children conceived after assisted reproductive techniques ($n = 549$). These children underwent the same clinical examinations at 3, 18, 36 months of age and in 2010–2012. They were not included in the reference material, but data were used for analyses of correlations and agreement between DXA and other measures of fatness, as well as for illustrating differences in %BF with age, sex, social class and within pubertal stages.

The study was conducted according to the Helsinki II Declaration and was approved by the local ethics committee (KF 01–030/97/KF 01276357/ H-1–2009–074) and the Danish Data Protection Agency (1997-1200-074/ 2005-41-5545/2010-41-4757). The families gave their informed written consent to the study.

Clinical examinations

Height was measured using a wall-mounted stadiometer to the nearest mm (Holtain Ltd, Crymych, UK) and weight was measured to the nearest 0.1 kg using electronic scales (SECA delta model 707, Seca, Hamburg, Germany, and Bisco model PERS 200, Bisco, Farum, Denmark). WC was measured with a measuring tape parallel to the floor at the midpoint between the ribs and the top of the iliac crest.

SFs were measured at four anatomical sites (triceps, subscapular, suprailiac and biceps) with a Harpenden calliper (John Bull, British Indicators LTD, Weybridge, UK) with a precision of 0.1 mm after allowing the jaws to close for approximately 2 s.[11] All anthropometrical measurements were measured in triplicate and means were used for tables and analyses. Data were checked for implausible values and two measurements were excluded. The physicians in the study participated in workshops to assure and maintain standardization. Intra-observer variation was evaluated using the means of the three measures from the same child by same examiner. Coefficients of variability were calculated as (s.d./mean) $\times$ 100. Mean coefficients of variability was 1.8, 1.8, 2.2 and 2.4 for triceps, subscapular, suprailiac and biceps SFs, respectively. In a subgroup of participants ($n = 18$), all measurements were done independently by two examiners. Mean inter-observer coefficients of variability was 9.0, 6.8, 13.1 and 7.5 for triceps, subscapular, suprailiac and biceps SFs, respectively.

SF %BF was calculated using Slaughter's equation:[10] for girls: $(1.33(\text{triceps} + \text{subscapular}) - 0.013(\text{triceps} + \text{subscapular})^2 - 2.5)$ when sum of triceps and subscapular SF was <35 mm and $(0.546(\text{triceps} + \text{subscapular}) + 9.7)$ when the sum was >35 mm. For prepubertal boys: $(1.21(\text{triceps} + \text{subscapular}) - 0.008(\text{triceps} + \text{subscapular})^2 - 1.7)$, for pubertal boys: $(1.21(\text{triceps} + \text{subscapular}) - 0.008(\text{triceps} + \text{subscapular})^2 - 3.4)$ and when sum of triceps and subscapular SF was >35 mm: $(0.783(\text{triceps} + \text{subscapular}) + 1.6)$.

Pubertal stages were assessed according to Tanner and Marshall.[26,27] A child was considered in puberty if they were either $\geqslant$PH2 or $\geqslant$B2/G2 and similarly the highest pubertal stage (G1-5/B1-5 or PH1-5) was used for descriptive analyses. BMI was calculated as weight (kg) divided by height squared (m^2). BMI *Z*-scores were calculated according to national standards.[28] Numbers of children with excess fat were identified using $+1$ s.d. and international cutoff points for overweight and obesity defined by the International Obesity Task Force (BMI for age extrapolated backwards from 25 kg/m^2 and 30 kg/m^2 at 18 years of age, respectively).[29]

DXA scans

DXA scan was performed once at age 6.0–15.0 years (Lunar Progidy Advance, GE Healthcare, WI, USA) on the same day as the clinical examination. All children wore standardized light clothing.

Questionnaire information

All families completed a questionnaire regarding current parental work situation at the same time as the clinical examination in 2010–2012. Socioeconomic status was based on parental education and occupation according to national standards.[30] The social class (1 = high to 5 = low) of the highest-ranking parent living with the child was used.

Statistical analysis

Sex-specific reference curves were estimated using the LMS method[29] summarizing the data in three smooth age-dependent curves: *L*, *M* and *S*. The *M* curve corresponds to the age-dependent median, *S* is the age-dependent coefficient of variation curve and *L* adjusts for age-dependent skewness. The method is based on the Box-Cox power transformation, which transforms the data to follow a Gaussian distribution for each age.

Z-scores for %BF and WC were calculated using the formula:

$$\frac{(\%\text{BF}/M)^L - 1}{LS}$$

The formula can be used for new individuals using the sex-specific *L*, *M*, *S* values for age.

Correlations between BMI, WC, SF %BF and DXA %BF *Z*-scores in children between 8 and 15 years were investigated with Pearson correlations. Differences between DXA %BF and SF %BF as well as DXA and SF %BF *Z*-scores were tested with paired *t*-test. Bland–Altman plots[31] were constructed for DXA %BF versus SF %BF, BMI and WC *Z*-scores.

We used DXA %BF as the gold standard for excess body fat and tested two criteria: $+1$ s.d. and/or $>25\%$ in males and $>30\%$ in females against $+1$ s.d. for BMI and $+1$s.d. for WC and SF %BF as well as International Obesity Task Force criteria for BMI.

DXA and SF %BF were not normally distributed and were log transformed for further analyses.

Sex differences in %BF were tested with *t*-test at time points: 0, 3, 18 and 36 months and with multiple regression analysis adjusting for age in older children. Association between age and DXA %BF was tested with linear regression analysis for each sex separately. Trend of association between pubertal stage and %BF was tested with linear regression analysis adjusting for age. Results are presented as the mean difference between girls and boys, the mean difference for each year in the age analysis and the mean difference for each pubertal stage in % (95% CI), respectively. Trend of associations between socioeconomic status and DXA and SF %BF Z-scores were tested with linear regression and results are presented as the mean difference in s.d. (with 95% CI) for each increase in social class.

Paired *t*-test was used for analysis of trends of %BF from 0 to 3 months and from 3 months to 3 years (presented as mean difference with 95% CI).

RESULTS

Reference curves for BF% (boys and girls) were constructed using 950 DXA scans (age 8–14 years; Figure 1) and 11 481 examinations (age 0–14 years) of SFs (Figure 2) and WC (Figure 3). Characteristics of children included in the DXA reference curves are presented in Supplementary Table 1. LMS values for selected age points are given in Supplementary Tables 2–4.

BMI ($r = 0.78$), WC ($r = 0.69$) and SF %BF ($r = 0.86$) correlated positively with DXA %BF (*Z*-scores; Supplementary Figure 2). Absolute values of %BF from SFs were lower than from DXA (mean absolute difference: 2.8%, relative difference: 13.4%) but DXA and SF %BF *Z*-scores were not significantly different (mean difference: -0.016 (CI: -0.05 to 0.017), $P = 0.34$). Bland–Altman plots for the *Z*-scores showed that variation was not dependent on the *Z*-score level (Supplementary Figure 3).

DXA %BF was 29.7% (CI: 24.2; 35.2) higher in girls than in boys. SF %BF was also higher in girls than in boys at all time points except at birth (no significant difference) and at 3 months where boys had marginally higher SF %BF (2.7%, CI: 1.0; 4.6).

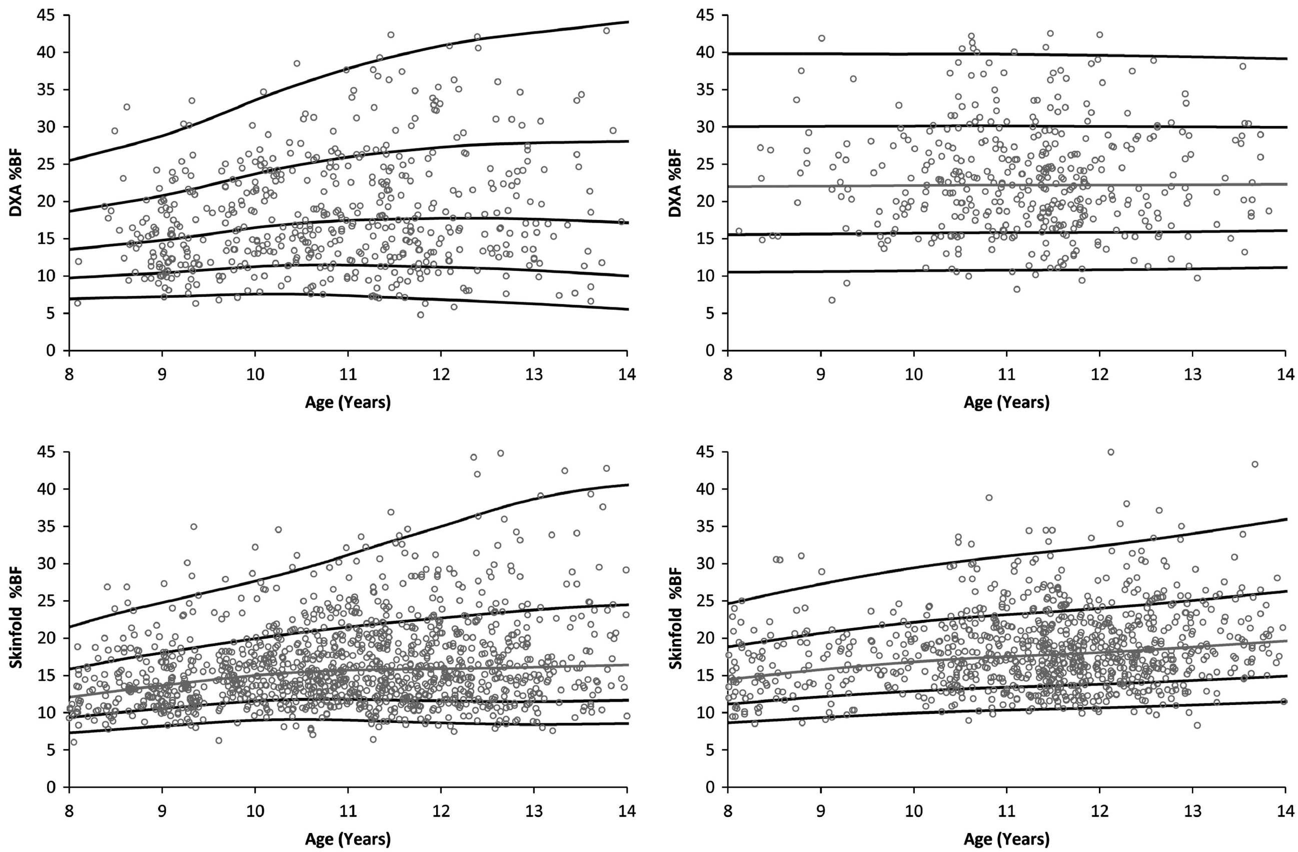

Figure 1. Body fat percentage (%BF) in healthy Danish boys (left) and girls (right) from 8 to 14 years derived from dual X-ray absorptiometry (DXA; upper panel) and skinfolds for comparison (lower panel; also included in Figure 3; lines represent −2 s.d., −1 s.d. mean, +1 s.d., +2 s.d.).

SF %BF increased to 58.6% (CI: 56.5; 60.8) between birth and 3 months and decreased to 7.8% (CI: 6.5; 9.2) between 3 months and 3 years. From 8 years of age DXA %BF increased 3.3% (1.4; 5.2) per year in girls and 5.2% (3.0; 7.4) in boys. SF %BF increased 3.0% (1.6; 4.2) per year in girls and 5.2% (3.8; 6.9) in boys.

During puberty, %BF showed an increasing trend with pubertal stages in girls (mean % increase with each pubertal stage: 7.3% (CI: 3.0; 11.7) for DXA %BF and 5.4% (CI: 2.3; 9.6) for SF %BF. In boys, %BF also had an increasing trend with pubertal stages: 7.3% (CI: 2.8; 11.4) for DXA %BF and 3.5% (CI: 0.2; 6.7) for SF %BF, but with a biphasic pattern with a peak in early puberty (stage 2), and a decline between stage 2 and 3 (−12.5%, CI: −3.9; 31.8 for DXA %BF and −10.7%, CI −3.0; 26.4 for SF %BF; Figure 4).

Both DXA and SF %BF (*Z*-scores) were associated with socio-economic status. %BF increased to 0.15 s.d. (CI: 0.10; 0.23) and 0.14 (CI: 0.8; 0.21%), respectively, for each increase in social class 1–5.

DXA %BF in children with a normal BMI for gender and age according to national BMI standards ($-1<$ BMI *Z*-score <1)[28] ranged from 6 to 37%.

Numbers of children identified as having excess fat using a cutoff point of DXA %BF +1 s.d. were displayed against children with +1 s.d. for BMI, WC and SF %BF in Table 1. Sensitivity and specificity were 79.5 and 93.8 for SF %BF, 75.9 and 90.9 for BMI and 59.2 and 95.4 for WC.

Numbers of children identified with excess fat by DXA using adult cutoffs (25% for males 30% for females) were also displayed against children with overweight + obesity according to International Obesity Task Force criteria and +1s.d. for SF %BF (Table 2). These BMI criteria gave a high specificity (99.3), but only identified 97 of 191 children with DXA %BF above adult cutoffs, corresponding to a sensitivity of 50.8.

DISCUSSION

This large study of unselected healthy children and adolescents explored sensitivity of BMI, WC and SFs to determine excess body fat in apparently normal weight adolescents. Our data show that the simple, low-cost measurement of triceps and subscapular SFs provides an estimate of total %BF, which correlates better with DXA measurements than BMI and WC.

DXA %BF and %BF calculated from SFs were highly correlated. Our comparison only included children at school age, but previous studies, of which one included 3- 8-year-old children, reported similar findings.[7,11] The absolute values of %BF were slightly higher for DXA than those derived from SFs, which is in accordance with previous studies.[7,32] However, *Z*-scores were highly concordant between these two methods, thus children were also generally categorized similarly (normal/excess fatness) by the two methods.

Although whole-body DXA scan is often used as gold standard for measurement of body composition, it also has some methodological limitations. Different types of DXA scanners yield slightly different results on %BF.[33] Furthermore, DXA tends to overestimate %BF in the most obese and underestimate %BF in the leanest subjects compared with the four-compartment model/underwater weighting method.[34] The inter observer variation in skinfold measurements was acceptable in comparison to the large inter individual variation in our population. Thus, this assessment of %BF seems to be applicable not only on a population level, but also individually.

No international consensus exists on cutoff levels for %BF in children. In adults, most authors suggest >25% for males and more than 30–35% for females.[21,35] Based on biological end points

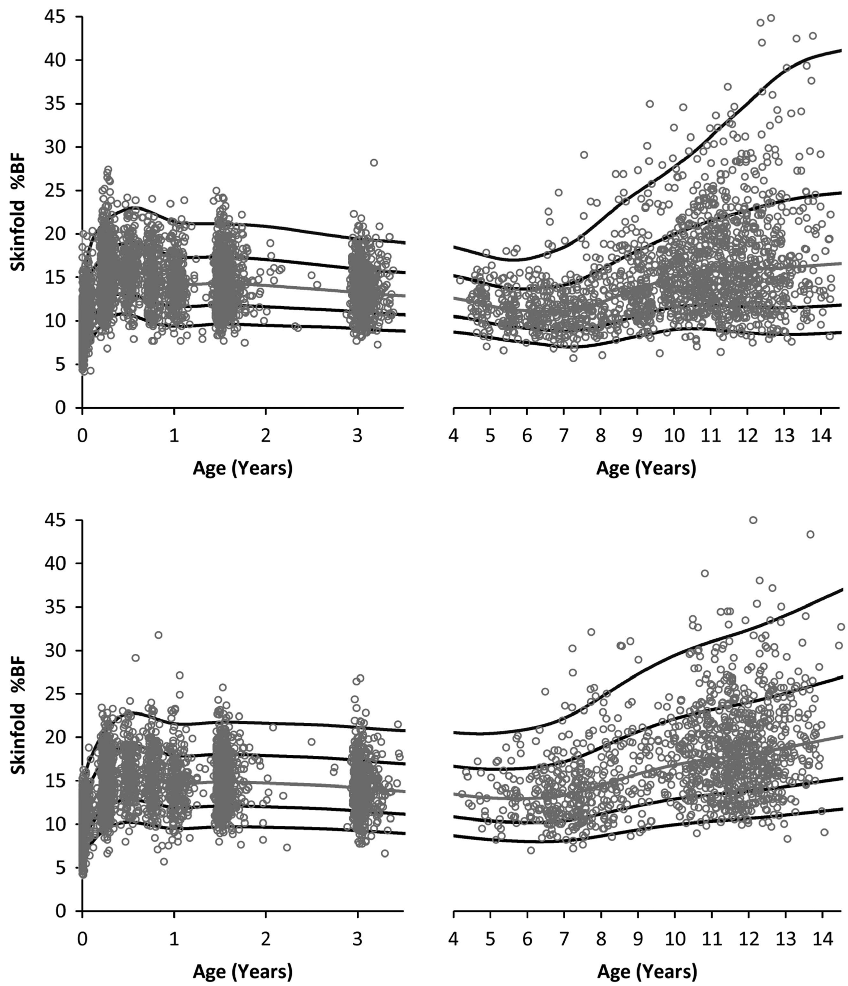

Figure 2. Body fat percentage (%BF) in healthy Danish children derived from skinfolds (lines represent −2 s.d., −1 s.d. mean, +1 s.d., +2 s.d.) in boys (upper panel) and girls (lower panel) from birth to 14 years.

such as blood pressure and blood lipid profiles, some authors have suggested similar cutoffs: 25% and 30% for adolescent boys and girls, respectively,[36] or 20% in boys and 30% in girls.[37] In our population, we applied upper limits of normal of both +1 s.d. as well as 25% in males and 30% in females.

When using +1 s.d. for DXA %BF as cutoff for excess fat and comparing with +1 s.d. for SF %BF, BMI and WC, we found the best agreement (best combination of sensitivity and specificity) between DXA and SF %BF. The highest specificity was found for WC, but in combination with a quite low sensitivity (many false negatives).

When evaluating the number of overweight/obese children by international BMI criteria,[29] against DXA %BF above 25% in males and 30% in females, BMI showed high specificity, but low sensitivity; ignoring so-called 'normal weight obese' subjects. This is in line with a meta-analysis of the diagnostic performance of BMI in adults, concluding that the specificity of BMI to detect fatness was high, whereas the sensitivity was low, as BMI failed to identify half of the subjects with excess %BF.[20] 'Normal weight obese' adults have a higher prevalence than lean adults of both cardiovascular and metabolic risk factors and diseases.[38] Whether this is true in a pediatric population is yet unknown. However, a recent study of adolescents showed that SFs predicted serum lipid concentrations just as well as DXA %BF.[23] Thus, similar risk patterns may apply to children at school age with %BF above the upper limit.

Our study provides gender-specific reference curves for WC (age 0–14 years) and %BF determined by both DXA (age 8–14 years) and SFs (age 0–14 years). Except for in infancy where we found that boys temporarily had higher %BF, girls generally had higher %BF than boys throughout childhood and puberty in accordance with previous reports.[39,40] %BF increased throughout puberty in girls, whereas boys in accordance with previous reports[12,14,39–42] appeared to have a peak in early puberty. As expected, this was less discernible in our reference curves for sex and age than in data grouped by sex and pubertal stages. We were also able to show an early peak of SF %BF in early infancy. This peak is consistent with findings from DXA scans in a previous small-scale study[43] and coincides with the well-known transient postnatal surge of luteinizing hormone and follicle-stimulating hormone leading to increase in male and female sex steroids.[44] Thus, it is plausible to assume that reproductive hormones have an important role in the body fat accumulation throughout life and contribute to the observed gender difference.

We studied healthy Danish children from the Copenhagen area, whose mothers were recruited in pregnancy, thus unselected regarding later outcomes. Lower social class was associated with an increase in body fat whether determined by DXA or SFs, as would be expected.[45] Our reference curves indicate that our population of morbidly obese children is small, especially among the girls. As urban %BF tends to be lower than national values,[14] our data may not be representative of the entire Danish population.

Among our children, BMI was slightly higher than previously reported.[28] We do not have directly comparable historical Danish

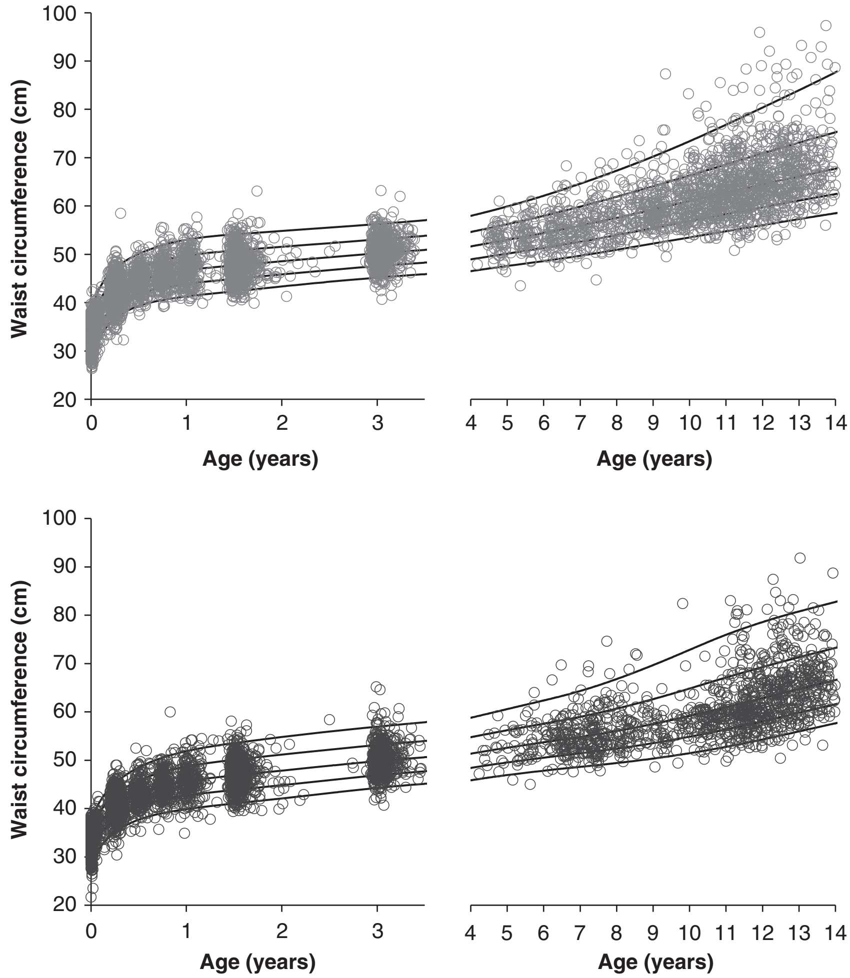

Figure 3. Waist circumference (cm) in healthy Danish children (lines represent −2 s.d., −1 s.d. mean, +1 s.d., +2 s.d.) in boys (upper panel) and girls (lower panel) from birth to 14 years.

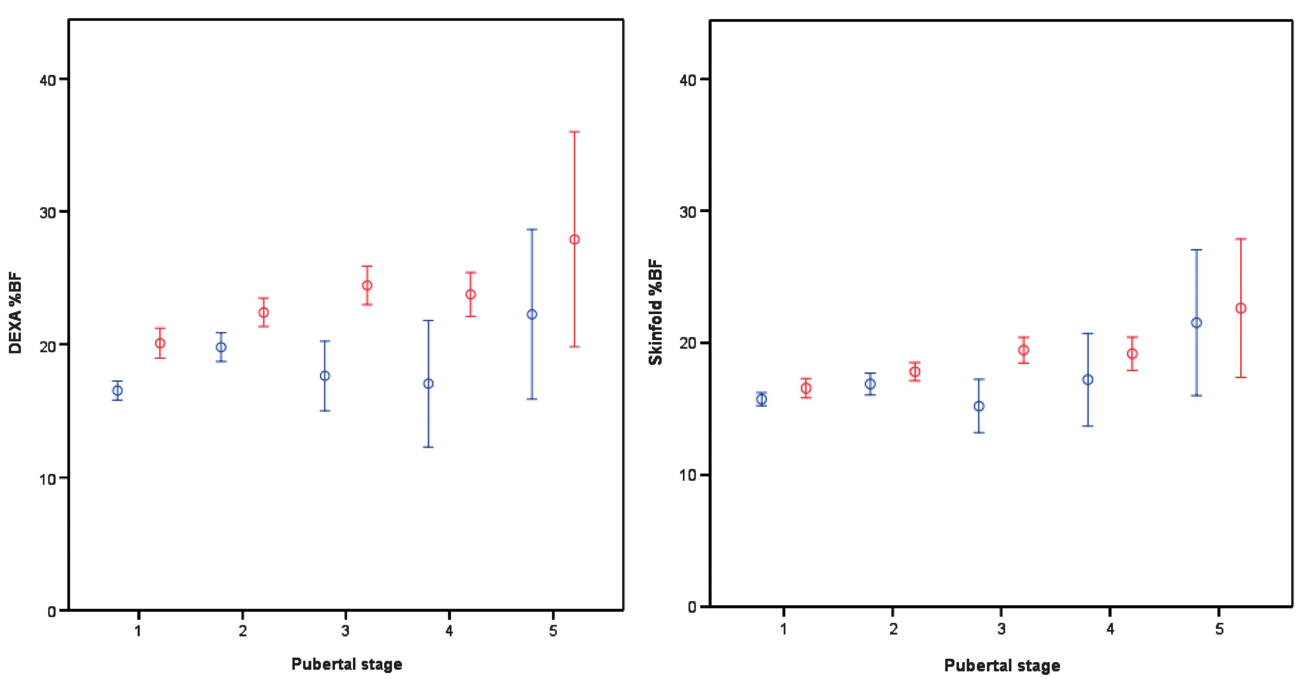

Figure 4. Mean body fat percentage (%BF) (Error bars represent ±2 s.e.) from dual X-ray absorptiometry (DXA) and skinfolds in 1200 healthy Danish 6- to 14-year-old boys (blue) and girls (red); boys according to pubertal stages 1–5. (Highest stage of breast, pubic hair and genital development.)

Table 1. Agreement between DXA %BF $> +1$ s.d. and SF %BF, BMI and WC $> +1$ s.d. in 8- to 14-year-old Danish children

	DXA %BF > +1 s.d.		
	No	*Yes*	*Total*
SF %BF > +1 s.d.			
No	875	40	915
Yes	58	155	213
Total	933	195	1128
Sensitivity = 79.5%, specificity = 93.8%			
BMI > +1 s.d.			
No	848	47	895
Yes	85	148	233
Total	933	195	1128
Sensitivity = 75.9%, specificity = 90.9%			
WC > +1 s.d.			
No	889	80	969
Yes	43	116	159
Total	932	196	1128
Sensitivity = 59.2%, specificity = 95.4%			

Abbreviations: %BF, body fat percentage; BMI, body mass index; DXA, dual energy X-ray absorptiometry; SF, skinfold; WC, waist circumference.

Table 2. Agreement between SF %BF >1 s.d. and overweight/obese children according to BMI criteria[a] compared with increased fatness evaluated by DXA %BF above adult cutoffs

	DXA %BF >25% (boys) or >30% (girls)		
	No	*Yes*	*Total*
SF %BF > +1 s.d.			
No	874	41	915
Yes	63	150	213
Total	937	191	1128
Sensitivity = 78.5%, specificity = 93.3%			
Overweight/obese by BMI criteria			
No	930	94	1024
Yes	7	97	104
Total	937	191	1128
Sensitivity = 50.8%, specificity = 99.3%			

Abbreviations: %BF, body fat percentage; BMI, body mass index; DXA, dual X-ray absorptiometry; SF, skinfold. [a]According to international BMI criteria.[29]

data on %BF, but in a 15-year-old Danish study,[46] the oldest boys appeared to have lower %BF than today, whereas the girls appear more comparable. Similarly, a Danish study found a marked increase in fatness and reduction of fitness (VO_{2max}) in 9-year-old children examined in 1985–1986 and 1997–1998, respectively.[47] In a recent meta-analysis of 154 studies with reports of SF measurements conducted between 1951 and 2004, a secular increase in fatness of young people was found.[48] In the United States, the National Health and Nutrition Examination Survey (NHANES) %BF data are thus regarded as descriptive of the 'state of the nation' rather than as a normative reference material.[49] In this study population with a predominantly high social class, almost 17% had %BF higher than adult cutoffs, which may represent a future health risk.

In conclusion, determination of %BF by SF measurements correlated well with DXA %BF and provided a valid tool to diagnose excess fatness in normal weight children with BMI within normal range.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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