Secular Trends in the Skinfold Thicknesses of Young People in Developed Countries

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INTRODUCTION

There is now an enormous literature documenting the increasing global prevalence of pediatric overweight and obesity as defined by various body mass index (BMI) criteria (Lobstein et al., 2004). BMI has many advantages as an index of adiposity: it can be measured with high accuracy and precision, with little training and equipment, and there is a very large historical database. At the same time, it is widely recognised that BMI is an imperfect index of fatness, and that the application of identical cut-offs to different populations is problematical. Criterion methods for assessing body composition-underwater weighing and dual X-ray absorptiometry (DXA) -are unfeasible for large samples. Skinfolds provide a "middle way" between BMI and criterion methods. They can be measured with reasonable accuracy and precision by experienced anthropometrists; there are very substantial historical data; and they can provide information on the distribution of subcutaneous fat within individuals.

While there have been many studies of skinfold thicknesses in various populations of children, there have been very few studies charting secular trends. Some studies have compared the skinfold thicknesses of young people of the same age and sex from the same geographical region at two or more time points (e.g. Ross et al., 1987; Chinn and Rona, 1994; Dollman et al., 1999), but none has generalised this analysis to young people of different ages from different geographical areas and across a wide time span. This is in part due to the dispersion of skinfold data into areas of "grey" literature-technical reports, theses, government-commissioned studies-and in part due to methodological issues. Secular changes in skinfold thicknesses are likely to be very small, and unless very large samples spanning long time periods are used, measurement error can obscure underlying changes.

The aim of this study was to gather existing data on skinfold thicknesses in young people in developed countries in order to describe secular trends across the developed world. The specific questions addressed in this study were:

- What has been the magnitude of secular changes in skinfold thicknesses in young people from developed countries?
- What has been the magnitude of secular changes in estimates of percentage body fat derived from skinfold measurements?
- Have there been secular changes in the ratio of central to peripheral subcutaneous fat?
- Have there been changes in the distribution of skinfold thickness values across the population?

METHODS

Inclusion Criteria for Studies

Initial candidate studies were those reporting mean or median values for triceps or subscapular skinfold thicknesses, measured by calipers, in young people ("young people" and "children" are defined here as anyone under 19 years of age). These two sites were selected because of consistency in site definition, which is a major source of error in skinfold measurement (Ruiz et al., 1973); because they are easy to locate and measure; have been used in a number of very large surveys; and are inputs into the Slaughter equations (Slaughter et al., 1988) which estimate percentage body fat. Only data from developed countries, defined as those classified by the World Bank as being "high-income" or "upper-middle income", were included, because the pattern of change is likely to be quite different in developing countries, or in the more precarious transitional economies of the former USSR.

In terms of sampling frames and methodologies, our approach was quite promiscuous. While samples showing obvious biases (e.g. sportspeople, anorexics, the obese) were excluded, the studies included used a wide range of sampling procedures, from random national surveys to convenience samples. They also used a wide range of caliper types, which may yield slightly different results (Lohman and Pollock, 1981), and anthropometrists with varying levels of training. Measurement sites varied only slightly, but sometimes the left instead of the right hand side of the body was used. While we recognise that this inclusive strategy will increase variability, it will not bias trend estimates unless there is systematic, time-related variability in the methodologies which also impacts on the measured skinfold thicknesses. Searches were initially conducted through databases (MedLine, CINAHL, SportDiscus) using combinations of the following keywords: triceps, subscapular, skinfold, children, youth. However, most studies were uncovered by "snowballing" references in published articles and through consultation with anthropometrists. Studies in all languages were considered.

A total of 116 studies meeting these criteria were located (references available on request), which included data on 364,077 young people. Of these, raw data were available from 11 studies (n = 53,103), and the rest provided summary data only (means, standard deviations and/or medians). Most of the data came from the USA (119,509 young people), the United Kingdom (82,770), Australia (38,465) and Canada (14,992). Data were also available from Belgium, the Czech Republic, France, Germany, Greece, Hong Kong, Ireland, Italy, Japan, the Netherlands, New Zealand, Poland, Portugal, Russia, South Africa, Spain, Slovakia, Sweden, Taiwan and Turkey. The earliest data were from 1952 and the most recent from 2002. The dataset included 1782 reports at the age x sex x country level (for example, 10-year-old Australian boys).

Data Treatment

The chief response variables of interest in this study were:

- triceps and subscapular skinfold thicknesses;
- estimated percentage body fat (%BF);
- the triceps:subscapular ratio (T:S), an index of fat distribution;
- the coefficient of variation (CV) for skinfold thicknesses, an index of distributional scatter; and
- the difference between the mean and median skinfold thicknesses (expressed as a percentage of the average of the mean and median thicknesses), an index of distributional skewness.

Some studies reported mean values and others median values. To simplify analysis, we estimated median values for all studies. To do this, median values were regressed against mean values using data from studies where both median and mean values were reported at the age x sex x country level (n = 555 for the triceps and n = 408 for the subscapular). For both skinfolds there were very strong linear relationships between mean and median values [triceps: $r = 0.97$, $p < 0.0001$, standard error of estimate (SEE) = 0.70 mm; subscapular: $r = 0.92$, $p < 0.0001$, SEE = 0.99 mm]. All skinfold thicknesses were then analysed as either reported or estimated median values.

Estimated group median percentage body fat at the age x sex x country level was calculated according to the process shown in Figure 1. If the study reported %BF values estimated by the Slaughter equations, these were used. Where raw data were available, %BF at the age x sex x country level was estimated by calculating %BF for all individuals and calculating the median value. Where median values for skinfolds were available at the age x sex x country level in the absence of raw data, they were entered into the Slaughter equations to estimate the group median. When values calculated in this way were compared to values calculated on the basis of individual data for those datasets where raw data were available, there was a close agreement [mean (SD) difference = 0.05 (0.40) %BF]. Where only mean skinfold values were reported, they were used to estimate median values, which where then entered into the Slaughter equations. When values calculated in this way were compared to values calculated from individual data, the mean (SD) difference was 0.45 (0.99) %BF. These indirect methods therefore yielded values very similar to those calculated directly from individual skinfold data. Estimated percentage body fat could only be calculated for children aged 8 years and over, which is the validated age range for the Slaughter equations.

Where the year of measurement was not clear in the text, it was assumed that measurements were made two years before the year of publication, which was the median gap between measurement and publication in those studies where both were known. Where measurements occurred over a range of years (e.g. 1965-1967), the mid-point was used (in this case 1966.5, i.e. half-way between 1965.0 and 1967.99). Age was expressed as age at last birthday. Where average

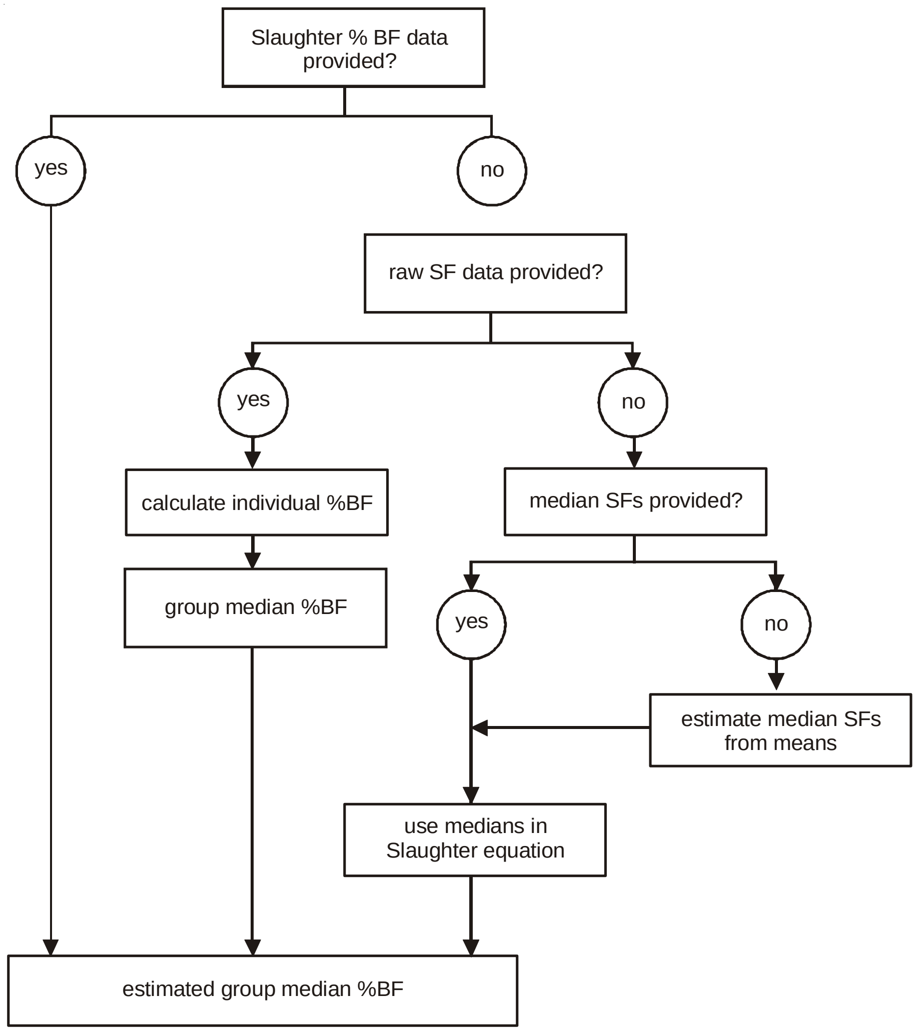

Fig. 1. Procedure used to estimate percentage body fat.
%BF = percentage body fat; SF = skinfold.

ages were not stated, it was assumed that children reported as, for example, 12 years old, were on average 12.5 years old. Where data were reported for a range of ages, the midpoint age was used (e.g. 10-12 years was recorded as 11.5 years).

Data Analysis

Secular trends were calculated using data at the age x sex x country level using least-squares regression of the variable of interest (skinfold thickness, %BF, etc.) on year of measurement. Regressions were not weighted. Progressively higher polynomial models were used until there was no further statistically significant improvement in the fit at the 5% level. In all cases, linear fits provided the best model.

A second type of analysis was performed with %BF. In 92 cases, data were available on the same age x sex x country group in at least two years of measurement. For each of these cases, linear regression was used to calculate the slope and intercept of the line of best fit for all datapoints from the first year of measurement

(Y_0) to the final year of measurement (Y_f). From the equation of the regression line, the estimated %BF values corresponding to Y_0 (BF_0) and Y_f (BF_f) were calculated. Let the annual percentage rate of change which would need to occur for BF_0 to become BF_f over the course of ($Y_0 — Y_f$) years be d%. Assuming that the rate of change (expressed as a percentage) has been uniform,

$BF_0[(100 + d)/100]^{Y0 — Yf} = BF_f$

and therefore

$d = 100 (X_f/X_0)^{1/(Y0 — Yf)} — 100$

A value of d% was therefore ascribed to each year from Y_0+1 to Y_f

This process was repeated for all comparisons in the population of interest (for example, all girls, or all children aged 8-10 years). The average of the d values (d_x) for each year was then calculated. This represented the average rate of change of %BF for that year. To now describe the time-related patterns of %BF (as opposed to rates of change in %BF), we used an iterative procedure. Starting with an initial value of 100 for the average body fat value at year Y_0, we calculated what that value would be after one year given that it would be subject to an average annual rate of change of dx_1. That is:

initialise: $BF_0 = 100$

then $BF_1 = BF_0 + BF_0\, d_{xi}/100$

where dx_1 is the average rate of change during the first year. This process was then applied iteratively:

$BF_{i+1} = BF_i + BF_i\, d_{xi}/100$

to construct a series of annual relative %BF values (BF_1 ... BF_n). Using this method, the evolution of % BF could be determined for young people from various subgroups (age, sex, country).

RESULTS

Skinfold Thicknesses

Triceps skinfold thickness increased over the fifty-year period at an average rate of 0.63 (95% confidence limits 0.54-0.72) mm per decade (r = 0.30, n = 1748 age x sex x country slices, p < 0.0001). This represented a rate of increase of 6.1% of median values per decade. Subscapular skinfold thickness increased at 0.55 (0.47-0.63) mm per decade (r = 0.34, n = 1338 age x sex x country slices, p < 0.0001). This represented a rate of increase of 8.0% of median values per decade. Rates of increase were similar for boys and girls. There was no change for children aged 0-5 years (0-0.2 mm per decade), and modest absolute increases for children aged 6-8 years (0.4 mm per decade). From age 8 to 15, the rates of change were slightly greater (0.4-0.7 mm per decade). From age 16 upwards, absolute increases were again slightly smaller (0.3-0.6 mm per decade).

Figure 2 shows the evolution of triceps skinfold thicknesses in boys and girls when data were divided into the three time slices: 1952-1968, 1969-1986 and 1987-2002. These curves show the familiar age-related pattern of a rapid increase in the first few years, followed by a fall, bottoming at about 5-7 years. The “adiposity rebound” is followed by the “pre-pubertal fat wave”, a rapid accumulation of body fat prior to puberty. Skinfold thicknesses continued to increase post-pubertally in girls, and to plateau or decline in boys. Figure 2 shows an overall increase in skinfold thicknesses across the time periods for both boys and girls, most marked in the 5-15 year age span. Increases appear to have been greater in the latter half of the time period.

Estimated Percent Body Fat

Using regression analysis, estimated percentage body fat increased at a rate of 1.0 (0.8-1.2) %BF per decade (r = 0.31, n = 1081 age x sex x country slices, p < 0.0001), representing a relative rate of increase of 6% of median values per decade. Rates of change were relatively consistent across age groupings, except for girls aged 16 or more, where there was no change. When corrected for age, the relative rate of increase was 5.5 (4.8-6.3)% per decade, being considerably higher in boys (7.1% per decade) than in girls (3.8%). There were also differences in rates of change among countries. In the UK, the increase was only 3.3% per decade, compared to 6.9% in the USA and 8.5% in Australia. Figure 3 shows %BF for boys and girls when data were divided into the three time slices.

When changes were calculated for those cases where data were available for the same age x sex x country groups across time, the overall trend was similar. Body fat increased by 34% between 1952 and 2002. The increase was considerably greater in boys (43%) than in girls (25%). Increases were also greater in younger than in older children. Between 1952 and 2002, %BF increased by 38% in 8-10 year olds, 32% in 11-13 year olds, 28% in 14-15 year olds, and 27% in those aged 16 years

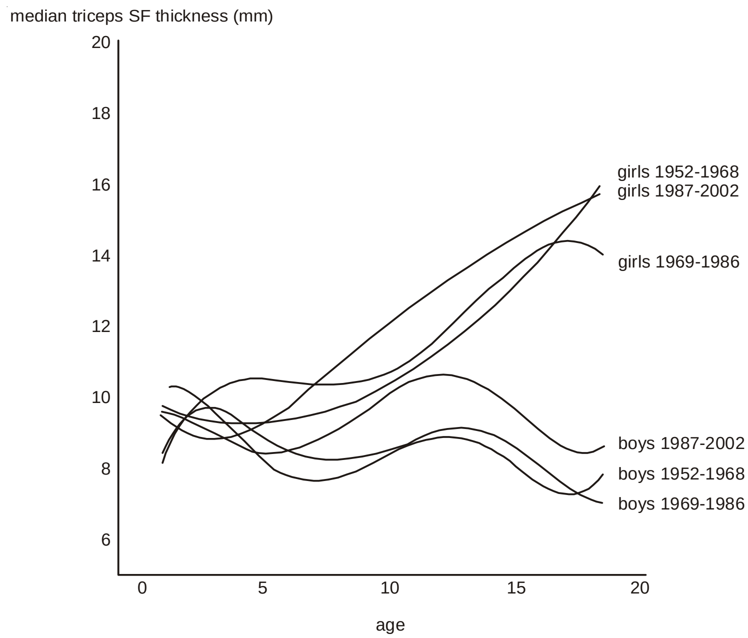

Fig. 2. Median triceps skinfold thicknesses for boys (lower, lighter lines) and girls (upper, darker lines) aged 0 to 18. The lines shown are the best-fit fifth-order polynomials for the years 1952-1968, 1969-1986 and 1987-2002.

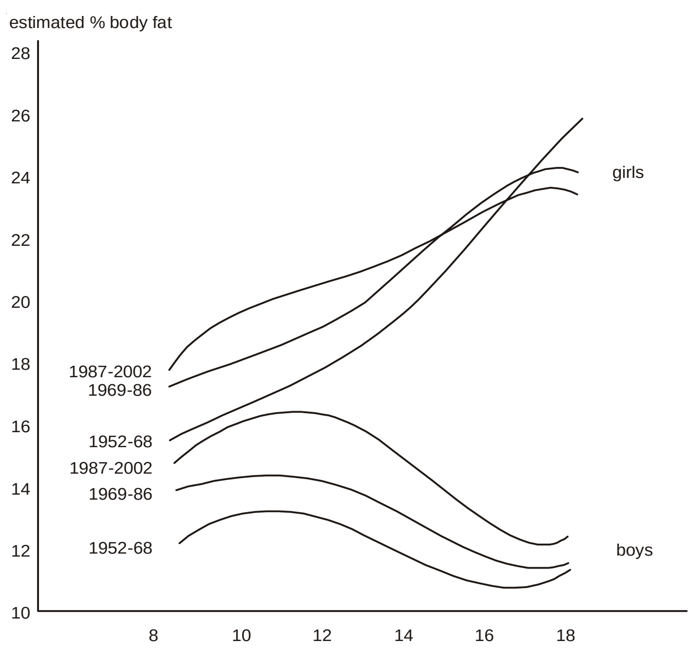

Fig. 3. Estimated percentage body fat using the Slaughter equations for boys (lower, lighter lines) and girls (upper, darker lines) aged 8 to 18. The lines shown are the best-fit fourth-order polynomials for the years 1952-1968, 1969-1986 and 1987-2002.

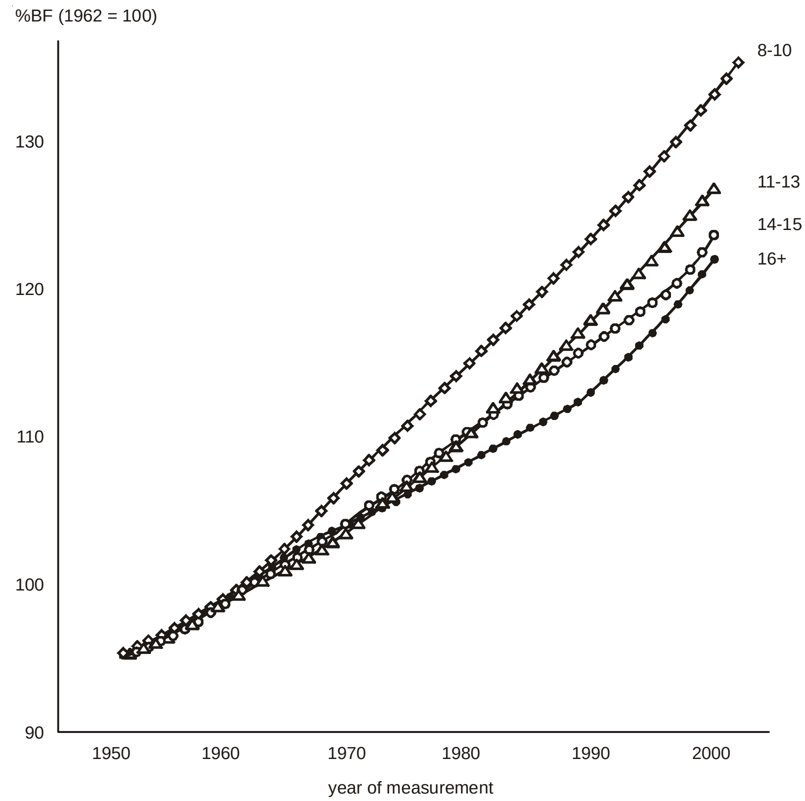

Fig. 4. Changes in estimated percentage body fat (%BF) in young people aged 8-10, 11-13, 14-15 and 16 or more, standardised to a value of 100 in 1962.

or more (Figure 4). When analysed by country, rates of increase were similar in Australia, the US and Germany, but were markedly lower in the UK.

Triceps: Subscapular Ratios

T:S ratio decreased significantly from 1.6 in 1952 to 1.4 in 2002, at the rate of 3.1 (2.2-3.8) % per decade ($r = 0.21$, $n = 1325$ age x sex x country slices, $p < 0.0001$). The rate of decrease was similar for boys and girls, but the decline was attenuated with age (0-5 years: 5.1% per decade; 5-8 years: 3.3%; 8-10 years: 2.5%; 10-12 years: 1.7%; 12-14 years: 2.2%; 14-16 years: 0.1%; 16-18 years: increase of 0.1%).

Coefficients of Variation and Mean-Median Differences

The CV for the triceps skinfold has been increasing at the rate of 2.6 (2.0-3.2) % per decade ($r = 0.26$, $n = 922$ age x sex x country slices, $p < 0.0001$), from 31% in 1950 to 44% in 2002. There has been a more rapid change in the CV for the subscapular skinfold, which has increased at a rate of 5.7 (4.6-6.7) % per decade ($r = 0.38$, $n = 754$ age x sex x country slices, $p < 0.0001$). These changes indicate greater distributional scatter. At the same time, mean-median differences have been increasing. For the triceps skinfold, the difference has increased at the rate of 1.1 (0.6-1.5) mm per decade ($r = 0.21$, $n = 555$ age x sex x country slices, $p < 0.0001$), equivalent to an increase of 12% of median values per decade. For the subscapular skinfold, the mean-median difference has increased at the rate of 2.0 (1.1-2.9) mm per decade ($r = 0.21$, $n = 408$ age x sex x country slices, $p < 0.0001$), or 16% of median values per decade. These shifts are markers of increasing positive skew, as high values in the distribution drag the mean away from the median.

DISCUSSION

Skinfold Thicknesses

There have been significant increases in skinfold thicknesses over the last 50 years. Among boys, triceps skinfold thickness has increased from 7.4 to 10.0 mm, and subscapular skinfold thickness from 5.1 to 7.5 mm. Among girls, they have increased from 10.1 to 13.6 mm (triceps), and from 6.7 to 9.6 mm (subscapular).

The 90th percentile value for skinfolds relative to a given population is occasionally used as a cut-off for over-fatness. If we consider the 90th percentile values from 1952 to indicate excessive adiposity, 49% of young people (using the subscapular skinfold) and 39% of young people (using the triceps skinfold) would be considered overfat in 2002.

A notable feature of changes in skinfold thicknesses has been the absence of change in very young children (Fig. 2). Paul and co-workers (1998) remarked on decreases in skinfold thickness in British children aged 0-2 years between 1968 and about 1990. The authors ascribe the difference to changes in infant feeding practices.

Estimated Percent Body Fat

Estimated percentage body fat has increased by about 6-7% of median values per decade. Young people today will be about 20% fatter than their parents were at the same age. In 1950, the average boy had 10.9% body fat and the average girl 18.2%. By 2002, this had increased to 15.7% for boys and 21.7% for girls. The pattern of evolution appears to be slightly curvilinear, with more rapid increases occurring in recent years (Fig. 4). Increased body fat has been linked to a number of undesirable outcomes. It is associated with poorer performance on tests of aerobic fitness (Olds and Dollman, 2004), increased risk of cardiovascular and metabolic disease (Freedman et al., 1999), sleep troubles and psychosocial disturbances.

In terms of overall fatness, boys are becoming more similar to girls. The boy:girl fatness ratio has risen from 0.69 to 0.74 in 50 years. The relatively greater increase among boys may be due to the fact they were leaner to start with, or may reflect differential exposure to social factors, such as access to sedentary activities and restrictions on physical activity. At the same time, younger children are increasing in fatness at a greater rate than older children (Fig. 4). This too may reflect differential exposure (for example, greater restrictions on the freedom of movement of young children). A noteworthy feature emerging from this analysis of trends is that there has been little or no increase in fatness for girls aged 15-18 years (Fig. 3). This observation may reflect the increasing prevalence of dieting in this demographic.

Triceps: Subscapular Ratios

The T:S ratio has often been used as an index of the distribution of subcutaneous fat between peripheral and central depots, which has been proposed as a marker of cardiovascular risk (Brambilla et al., 1994). There is mounting evidence of a shift in the distribution of body fat in young people towards central accumulation. Two recent studies (McCarthy et al., 2004; Dollman and Olds, 2006) have documented disproportionate secular increases in the waist girth of children in the UK and Australia. Although not the primary focus of this investigation, the studies analysed here also provided data on the biceps, medial calf, suprailiac (iliac crest) and mid-abdominal skinfolds. Rates of change in the median values of these skinfolds can also be calculated. The rates of change for the peripheral skinfolds (1% per decade for the biceps and 7.5% for the calf) are considerably smaller than those for the central skinfolds (9.5% for the suprailiac and 17.4% for the mid-abdominal). The shift in the distribution of body fat, coupled with increases in overall levels of body fat, is troubling for the future cardiovascular and metabolic health of young people.

Coefficients of Variation and Mean-Median Differences

The distributions of skinfold thickness values in the population are changing. Increasing CVs indicate increasing variance, and increasing mean-median differences index increasingly positive skews. This means that there is likely to be a greater number of young people with very high levels of subcutaneous fat. Gortmaker et al. (1987) also observed increases in skew in skinfold measurements when comparing data from the NHES, NHANES I and NHANES II surveys, as did Dollman et al. (1999) between surveys in 1985 and 1997 in Australia.

Using means rather than medians to calculate secular rates of change will yield higher values, because the slope incorporates both the underlying secular change and the increasing positive skew of the distribution. Using reported median values only, the secular rates of change for the triceps and subscapular skinfolds were 0.60 and 0.56 mm per decade, compared to 0.83 and 0.74 mm per decade when only reported mean values were used. When %BF was calculated using reported medians, the secular increase was 0.95 %BF per decade; using reported means, the rate of increase was 1.37 %BF per decade.

Limitations

While this study has analysed the largest set of skinfold data yet assembled, our conclusions should be tempered with an understanding of the limitations of the analytical methods. The different methodologies used to measure skinfold thicknesses (slightly different site locations, different types of calipers, use of right vs left side of the body, single vs multiple measurements, different degrees of anthropometric training, etc.) will increase variability, as will the variety of sampling frames adopted. However, there is no evidence that this will lead to systematic bias, in the absence of apparent time-related trends in methodology. The data treatment method (estimating medians from means, deriving estimates of group average %BF from average skinfold thicknesses) will also introduce some unavoidable variability. The effect of this will be to attenuate the strength of the relationships between year of measurement and the various response variables.

The equations used to estimate percentage body fat have been developed on a relatively restricted sample, which did not include Asians. The Slaughter equations use slightly different algorithms for Caucasians and Afro-Americans. We have applied the Afro-American algorithm to data on black Africans in general, whereas Afro-Americans are mainly of West African extraction. We used the Caucasian algorithms for any non-black populations, including Asians. In multi-ethnic groups, we applied the algorithm which best described the numerically dominant ethnic group. These assumptions will entail some error, but we felt it preferable to use a single set of equations, given the widely divergent results when applying different equations to the same individuals (Norton, 1996).

CONCLUSION

The overall picture which emerges from this analysis is of a global population of young people — particularly boys and primary (elementary) school-aged children — who are becoming increasingly fat on average. Moreover, the number of very fat individuals is probably increasing, and/or their level of fatness is increasing. The distribution of fat on the bodies of young people is showing a relative shift towards central depots. This is the worst possible combination of changes in terms of the potential for later metabolic and cardiovascular disease.

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KEYWORDS Anthropometry. Body Fat. Children

ABSTRACT To meta-analyse studies of skinfold thicknesses in young people aged 0-18 years in developed countries. A total of 116 studies were analysed, covering 364,077 young people from 24 countries. Percentage body fat (%BF) was estimated using the Slaughter equations. There have been increases in triceps and subscapular skinfold thicknesses, at the rate of 6-8% per decade over the period 1952-2002. %BF has been increasing at the rate of 1%BF per decade (equivalent to an increase of 6-7% of median values per decade). The rate of increase was greater in boys than in girls, and in younger than in post-pubertal children. The distribution of fat on the body, as indexed by the triceps:subscapular (T:S) ratio, has become more central. There has been an increasing positive skew in the distribution of subcutaneous fat thickness in the population. These trends describe very unfavourable changes in the body composition of young people, foreshadowing a potential increase in the incidence of cardiovascular and metabolic disease.

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