Variation in Subcutaneous Adipose Tissue Distribution Associated With Age, Sex, and Maturation

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ABSTRACT Age-, sex-, and maturity-associated variation in subcutaneous adipose tissue (SAT) distribution is reviewed and then considered longitudinally in a sample of Polish youth. Current study of adipose tissue distribution places considerable emphasis on abdominal adiposity, specifically intra-abdominal or visceral adipose tissue (VAT). Most studies of children and adolescents do not include an abdominal skinfold, and when it is available, the skinfold is grouped with others as a sum of skinfolds. Correlations between abdominal VAT and SAT based on computerized tomography in nonobese children are moderate to high, and those between the suprailiac and abdominal skinfolds and abdominal VAT are moderately high. Changes in three individual skinfolds (triceps, subscapular, abdominal) and ratios of the skinfolds were considered by chronological age and relative to the timing of peak height velocity (PHV), and in children of contrasting maturity status in participants of the Wroclaw Growth Study, 193 boys and 197 girls, who were followed longitudinally from 8 to 18 years of age. Individual skinfolds behave differently during childhood and adolescence, and the changes are influenced by the timing of the adolescent growth spurt. Sex differences in estimated velocities are negligible up to about 2 years before PHV; then velocities tend to be higher in girls. The velocity of the triceps skinfold is negative in boys just before and after PHV; estimated velocities for the trunk skinfolds are positive through the growth spurt in both sexes, and are somewhat greater after PHV, especially in girls. The individuality of changes in individual skinfolds during the adolescent spurt contributes to changes in the relative distribution of SAT at this time. The timing of the adolescent growth spurt is an important factor influencing the distribution of SAT both in the total sample and in youth classified as early and late maturing. Am. J. Hum. Biol. 11:189–200, 1999.

Variation in the relative distribution of adipose tissue in the human body is currently a topic of major interest in epidemiological analyses of relationships between adipose tissue distribution and risk for certain diseases, and in studies of the metabolic pathways that link variation in adipose tissue distribution to specific diseases. Superimposed upon these are issues related to changes in adipose tissue distribution associated with growth and maturation, and with the tracking or relative stability of patterns of adipose tissue distribution. Reynolds (1950) and Hammond (1955) were among the first to highlight the developmental contrast of subcutaneous adipose tissue (SAT) distribution on the extremities (peripherally) and the trunk (centrally) during childhood and adolescence using radio-

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Received 26 May 1998; Revision received 28 October 1998; Accepted 7 November 1998

graphic and skinfold measures of adipose tissue, respectively. In 1947, Vague et al. (1988) were among the first to focus attention on the association between the central accumulation of adipose tissue and metabolic complications, specifically diabetes.

Since these early contributions, many researchers have described age- and sex-associated variation and, to a lesser extent, maturity- and ethnic-associated variation in SAT distribution (Malina, 1996). The data are largely descriptive and have addressed health-related implications in a limited manner. The conference held in Quebec in the summer of 1987 was perhaps the first comprehensive consideration of adipose distribution during growth in the context of later health outcomes (Bouchard and Johnston, 1988). Since then, methodological advances in measurement techniques, specifically computerized tomography and magnetic resonance imaging, and clinical and epidemiological studies have focused attention on intra-abdominal adipose tissue (IAAT) or abdominal visceral adipose tissue (VAT) as a significant determinant of the relationship between obesity and morbidity, and as an independent risk factor for several degenerative diseases of adulthood. Data on changes in abdominal adipose tissue, both subcutaneous and visceral, during growth and maturation are rapidly expanding. Comparison of cross-sectional samples in early adolescence and young adulthood suggests that the sex difference in abdominal VAT evident in adulthood is established in later adolescence (Malina, 1996). However, longitudinal data for abdominal visceral and subcutaneous adipose tissue that span the adolescent growth spurt and sexual maturation are not yet available.

Two major approaches have been used to describe variation in SAT during childhood and adolescence, principal components analysis of skinfold thicknesses and ratios of skinfold thicknesses measured on trunk and extremity sites. Results of principal components analyses uniformly yield a primary component that contrasts trunk and extremity skinfold thicknesses; other components (depending on skinfolds included in the analysis) may contrast the upper and lower extremities, or the upper and lower trunk. Ratios essentially provide similar results in contrasting trunk versus extremity SAT. Although ratios have limitations (e.g., they assume a linear relationship between variables, ratios between skinfolds may be fatness dependent), they are relatively simple and are useful in surveys (Malina, 1996).

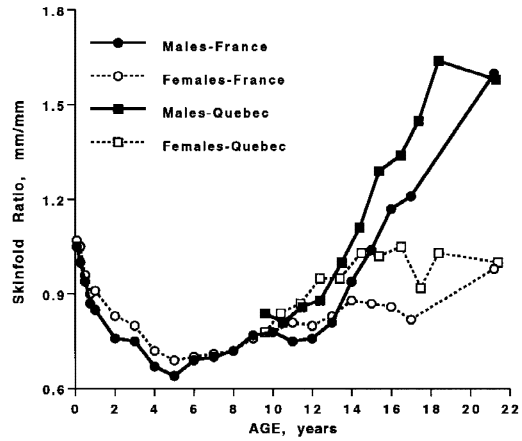

Fig. 1. Trunk/extremity skinfold ratios from infancy into young adulthood. The data for French children are based on (subscapular + suprailiac)/(triceps + biceps) drawn from the data of Rolland-Cachera et al. (1990). The data for Quebec youth are based on (subscapular + suprailiac + abdominal)/(triceps + biceps + medial calf) drawn from the data of Malina and Bouchard (1988).

The purpose of this article is twofold: first, to briefly review trends in the currently available data for age-, sex-, and maturity-associated variation in SAT distribution; and second, to evaluate changes in specific skinfolds and ratios of skinfolds in youth followed longitudinally from childhood through adolescence in the Wroclaw Growth Study.

OVERVIEW OF TRENDS IN SAT DISTRIBUTION

Ratios of the sum of trunk to extremity skinfold thicknesses in French (Rolland-Cachera et al., 1990) and Canadian (Malina and Bouchard, 1988) subjects from childhood through adolescence are shown in Figure 1. Data for the former are based on four skinfolds, the ratio of the sum of the subscapular and suprailiac skinfolds to the sum of the triceps and biceps skinfolds; while the latter are based on six skinfolds, the ratio of the sum of the subscapular, suprailiac, and abdominal skinfolds to the sum of the triceps, biceps, and medial calf skinfolds. The trends are similar in the two samples. There are no sex differences in childhood and, except for infancy and early childhood, it appears that trunk and extremity SAT are accumulated in proportionally similar amounts. During adolescence, however, the

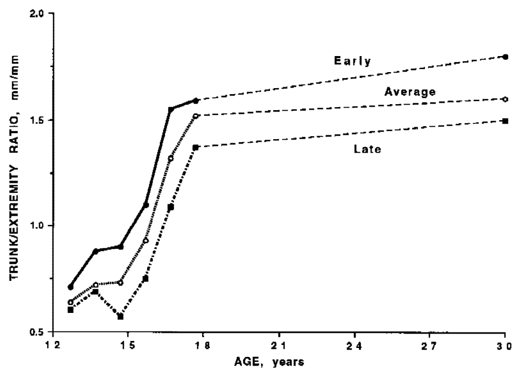

Fig. 2. Trunk/extremity skinfold ratios (subscapular + suprailiac)/(triceps + calf) in early, average, and late maturing boys (based on ages at PHV) followed longitudinally during adolescence and at 30 years of age. Drawn from the data of Beunen et al. (1994).

ratios are rather stable in girls but increase in boys, indicating proportionally greater accumulation of trunk SAT in males. The changes in boys are related to an absolute decrease in extremity skinfolds during the adolescent spurt. The age- and sex-associated trends in ratios based on skinfolds are similar to those for a trunk/leg fat ratio based on dual energy X-ray absorptiometry measures (Cowell et al., 1997).

Adolescent girls (12 and 17 years) advanced and delayed in skeletal or sexual maturity do not differ in relative SAT distribution, while 14- and 17-year-old boys of contrasting maturity status differ in SAT distribution. Boys advanced in maturity status have proportionally more trunk SAT than later maturers (Deutsch et al., 1985). The same trend is apparent in Belgian boys followed longitudinally from 13–18 years. Boys with an earlier age at peak height velocity (PHV) have proportionally more trunk SAT than boys with average and later ages at PHV (Fig. 2). The difference in SAT distribution evident during adolescence persists to 30 years of age (Beunen et al., 1994).

Tracking of indices of relative SAT distribution across childhood and adolescence is low to moderate. Among British (Kaplowitz et al., 1988), Australian (Baumgartner and Roche, 1988), and Belgian (Beunen et al., 1986) youth, interage correlations between values at younger ages and several adolescent ages are variable and range from about 0.2 to 0.6. The correlations tend to be slightly higher in girls (Kaplowitz et al., 1988). The instability of the trunk and extremity SAT contrast during adolescence is related to individual differences in the timing of the adolescent spurt and to variation in changes in individual skinfold thicknesses during adolescence, particularly in males. Extremity skinfolds (triceps and calf) show negative velocities from about 1 or 2 years before to 1 or 2 years after PHV; in contrast, trunk skinfolds (subscapular and suprailiac) have positive velocities through the growth spurt (Beunen et al., 1988; Beunen and Malina, 1988; see also Cronk et al., 1983; Tanner et al., 1981).

In the context of current emphasis on abdominal VAT, many studies of children and adolescents do not include an abdominal skinfold. The correlations between abdominal VAT and SAT based on computerized tomography in non-obese children is high, 0.87, but when body fat mass is controlled the partial correlation is moderate, 0.53 (Goran et al., 1997). Correlations between the suprailiac and abdominal skinfolds and abdominal VAT are moderately high, 0.78 and 0.74, respectively (Goran et al., 1995).

LONGITUDINAL CHANGES IN SKINFOLDS AND RATIOS

Longitudinal study of changes in the abdominal skinfold or abdominal VAT during growth, and specifically the adolescent spurt and puberty, may provide insights into sex differences and maturity-associated variation. To this end, changes in three individual skinfolds and ratios of the skinfolds were considered relative to the timing of PHV and in children of contrasting maturity status in participants of the Wroclaw Growth Study in southwestern Poland (Bielicki and Waliszko, 1975; Waliszko and Jedlinska, 1976; Bielicki et al., 1984; Bielicki and Hauspie, 1994). Boys ($n = 193$) and girls ($n = 197$) were followed longitudinally from 1961 to 1971/1972, 8 to 18 years of age. Three skinfolds, the triceps (T), subscapular (S), and abdominal (A, one-third the distance between the umbilicus and anterior superior iliac spine), were measured annually. Velocities were calculated for each skinfold as (log[b] − log [a])/(Age b − Age a). The skinfolds were also considered in ratio form: S/T, A/T, S/A. The skinfolds and ratios were analyzed by age, sex, and tempo of maturation, and relative to age at PHV. Sex-specific medians were calculated for each variable by chronological age and by years before and after PHV.

TABLE 1. Ages at peak height velocity (years) by maturity category in boys and girls from the Wroclaw Growth Study

Maturity category	Boys			Girls		
	n	Mean	SD	n	Mean	SD
Early	71	13.1	0.7	60	10.9	0.9
Average	60	14.1	0.7	71	12.0	0.5
Late	62	15.1	0.9	66	12.7	0.7

The Preece-Baines model 1 (Preece and Baines, 1978) was used to estimate age at PHV for each subject. Growth curves for each skinfold and ratio for individual children were plotted relative to PHV, a biological marker, independent of the chronological age at which PHV occurred. This procedure reduces the time spread across the chronological age axis in studies of adolescent growth and in turn reduces variation among individuals at this time.

Tempo of maturation was based on skeletal age (TW2 method; Tanner et al., 1975; Koniarek et al., 1983) at a chronological age of 12 years in girls and 14 years in boys. The sample was divided by tertiles of the difference between skeletal and chronological ages into contrasting maturity groups: early, average, and late. Ages at PHV of the three contrasting maturity groups are shown in Table 1, but the focus of comparison for skinfolds and ratios is the extremes, i.e., early and late maturers.

Skinfolds by age and relative to PHV

Changes in the three skinfolds by chronological age and relative to PHV are shown in Figure 3. The y-axis in this and subsequent figures is the same in boys and girls. The triceps skinfold shows a slight decline in adolescence in boys, while the abdominal and subscapular skinfolds increase with age with a small difference between the two skinfolds (Fig. 3A). In girls, the three skinfolds show, on average, slight change between 8 and 12 years, followed by an increase, especially in the abdominal skinfold (Fig. 3B). Relative to PHV, the triceps skinfold declines in boys from −2 years to +1 year, while the two trunk skinfolds increase linearly from −4 to +4 years (Fig. 3C). The triceps skinfold is rather stable in girls from −4 years to PHV and then increases, while the two trunk skinfolds show a gradual increase from −4 years to PHV and then a marked increase after PHV (Fig. 3D). Menarche occurs, on average, about 1 year after PHV; hence, it appears that the increase in SAT begins before menarche and continues after this maturational event.

Velocities of the three skinfolds relative to PHV are shown in Figures 4A–C. Sex differences in estimated velocities of each skinfold are negligible up to about 2 years before PHV; then velocities tend to be higher in girls. The velocity of the triceps skinfold (Fig. 4A) is negative in boys from −1.5 years to +1 year, and begins to increase in girls from −1 year to about +2 years. With few exceptions, velocities of the subscapular (Fig. 4B) and abdominal (Fig. 4C) skinfolds are consistently positive through the growth spurt in both sexes, and are somewhat greater after PHV, especially in girls.

Skinfold ratios

There is no sex difference in the ratio of the subscapular to triceps skinfolds (S/T, Fig. 5A) from 8–14 years; then the ratio is higher in males, indicating proportionally more upper trunk SAT. When the ratio is plotted relative to PHV, it is consistently higher in males before and after the age of maximum growth (Fig. 5B).

In contrast to the S/T ratio, the ratio of the abdominal to triceps skinfolds (A/T, Fig. 5C) is higher in girls from 8–15 years, indicating proportionally more lower trunk or abdominal SAT. There is, however, no sex difference in the ratio in later adolescence. When the ratio is plotted related to PHV, it is consistently higher in girls from about −2 years through the growth spurt (Fig. 5D).

The ratio of the subscapular to abdominal skinfolds (S/A, Fig. 5E), which contrasts upper and lower trunk SAT, is rather stable across chronological age and is consistently higher in boys. A higher ratio indicates proportionally less lower trunk than upper trunk SAT in boys; conversely, a lower ratio indicates proportionally more lower trunk (abdominal) than upper trunk (subscapular) SAT in girls. The same trends are evident when the S/A ratio is plotted relative to PHV (Fig. 5F).

The trunk–extremity contrast is more apparent after PHV in both sexes. However, the S/T and A/T ratios in males differ only slightly (higher A/T), while the A/T ratio is considerably higher than the S/T ratio in girls (Fig. 6).

Maturity contrasts—boys

The S/T ratio does not differ between early and late maturing boys before 13

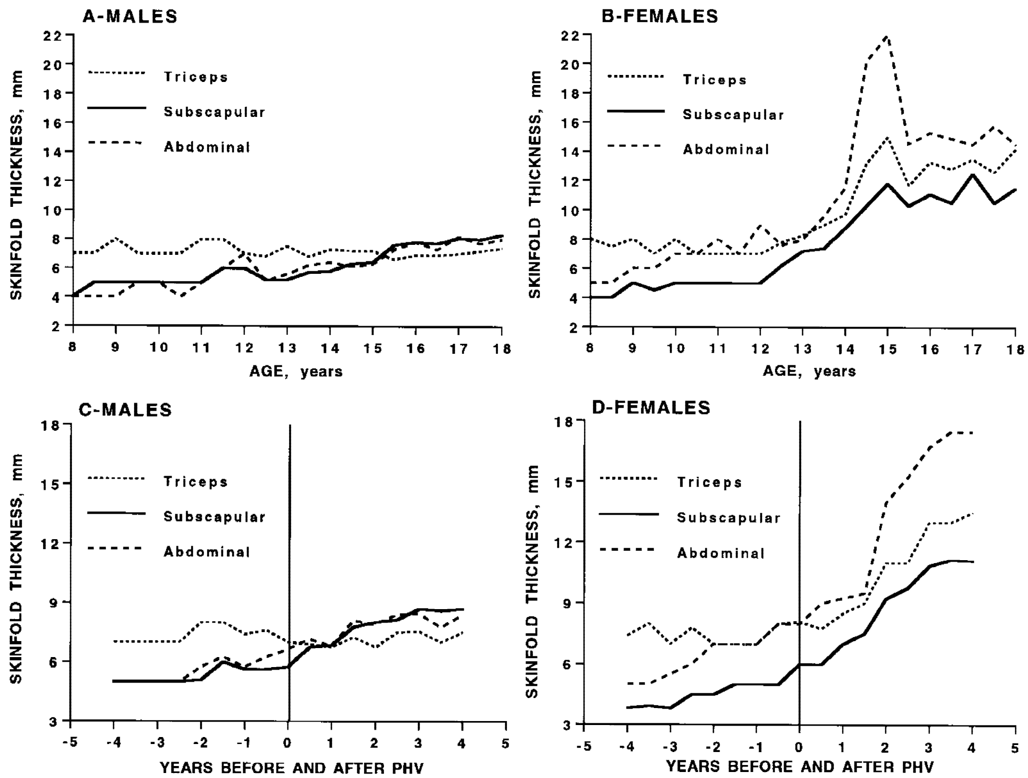

Fig. 3. Median skinfold thicknesses plotted by chronological age and relative to the time of PHV in boys (**A,C**) and girls (**B,D**).

years of age; subsequently, the ratio is higher in early maturers (Fig. 7A). Early maturing boys have proportionally more upper trunk SAT than late maturing boys during adolescence. Relative to PHV, the differences between boys of contrasting maturity status are reduced before PHV and are not apparent after PHV (Fig. 7B). It may be of interest that prior to PHV, the S/T ratio is slightly greater in late maturing boys, suggesting proportionally more upper trunk SAT in late maturers when PHV is the landmark.

The A/T ratio is consistently higher in early maturers from 10 years of age on (Fig. 7C), indicating proportionally more lower trunk SAT in early than in late maturing boys. However, when the A/T ratio is plotted relative to time before and after PHV, the difference between the contrasting maturity groups disappears (Fig. 7D).

The S/A or upper/lower trunk SAT ratio differs between boys of contrasting maturity status only between 11 and 14 years (Fig. 7E). At these ages, it is lower in early maturers, indicating proportionally more lower trunk (abdominal) than upper trunk (subscapular) SAT. The difference is due to a decrease in the ratio in early maturers through 13 years, followed by an increase. In contrast, the ratio is rather stable across age in late maturing boys from 10–18 years. Relative to PHV, the ratio is constant from −4 to +4 years in late maturers, but decreases from −4 years to PHV in early maturers, with a subsequent increase (Fig. 7F). The ratio does not differ in early and late maturing boys after PHV. The trends relative to chronological age and PHV in early maturing boys suggest proportionally greater accumulation of abdominal SAT than subscapular SAT prior to maximum growth. SAT accumulation at these ages is sometimes referred to as the “pre-adolescent fat wave” (Tanner, 1962), and the present data suggest that it is more apparent abdominally in early than in late maturing boys.

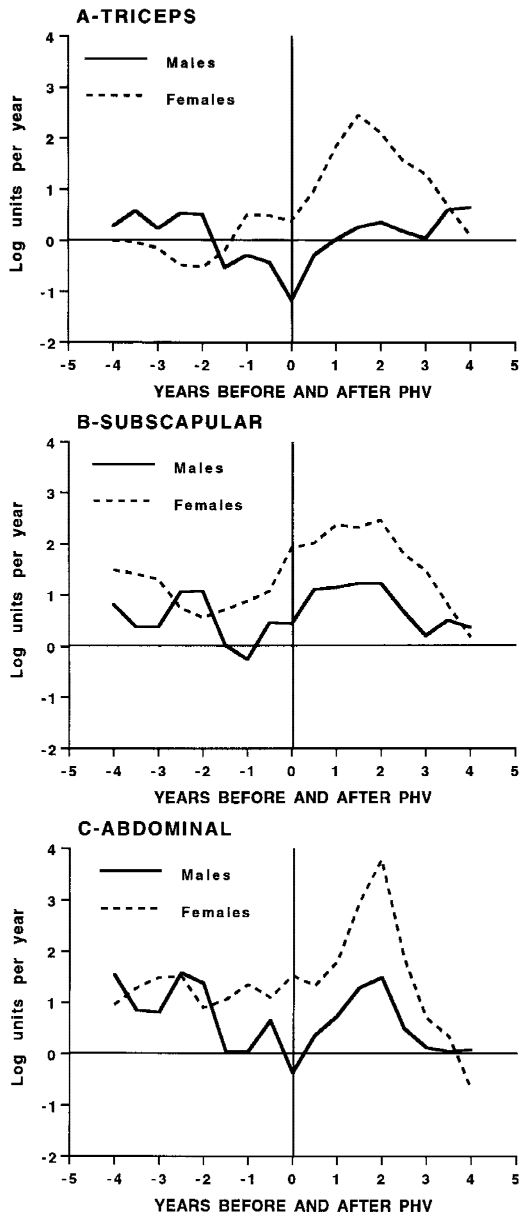

Fig. 4. Median velocities for the triceps (**A**), subscapular (**B**) and abdominal (**C**) skinfolds plotted relative to the time of PHV in boys and girls.

Maturity contrasts—girls

The S/T ratio is slightly but consistently greater in early maturing girls from 8–14 years, after which the differences are negligible (Fig. 8A). Early maturing girls thus have proportionally more upper trunk SAT than late maturers. The situation is reversed when the S/T ratio is plotted relative to PHV (Fig. 8B). The ratio is slightly higher in late maturing girls from about −3 years to +2 years, suggesting proportionally more upper trunk SAT in late maturers when PHV is the landmark.

The A/T ratio is also higher in early maturing girls from 8–14 years (Fig. 8C), but the difference between girls of contrasting maturity status is greater than those for the S/T ratio. Relative to PHV, the ratio does not consistently differ between early and late maturing girls −4 years to −1 year before PHV (Fig. 8D). At and after PHV, the A/T ratio (with one exception) is higher in early maturing girls, indicating proportionally greater accumulation of lower trunk SAT at and after PHV.

The S/A ratio is slightly but consistently lower in early maturing girls from 8–14 years, indicating proportionally more lower trunk (abdominal) than upper trunk (subscapular) SAT (Fig. 8E). The slightly lower ratio in late maturers in late adolescence may suggest later accumulation of abdominal SAT. Relative to PHV, the S/A ratio declines from −3 years to PHV in early maturers, but increases from −2 years to PHV in late maturers (Fig. 8F). The contrasting trends suggest differential accumulation of upper and lower trunk SAT in early and late maturing girls during the interval of maximum growth. Nevertheless, the S/A ratio is (with one exception) consistently lower in early maturing girls, indicating that they accumulate proportionally more abdominal than subscapular SAT during the interval of maximum growth in stature than late maturing girls.

DISCUSSION

The trends based on longitudinal data spanning childhood through adolescence are limited to three individual skinfolds and ratios of pairs of skinfolds. However, the longitudinal series includes the abdominal skinfold and, as noted earlier, abdominal SAT is moderately to highly correlated with abdominal VAT based on computerized tomography (Goran et al., 1997). The three skinfolds and their ratios were considered by chronological age and relative age at PHV in boys and girls, and then by age and relative to PHV in boys and girls of contrasting maturity status. Note, however, that ratios of skinfolds reflect SAT and do not re-

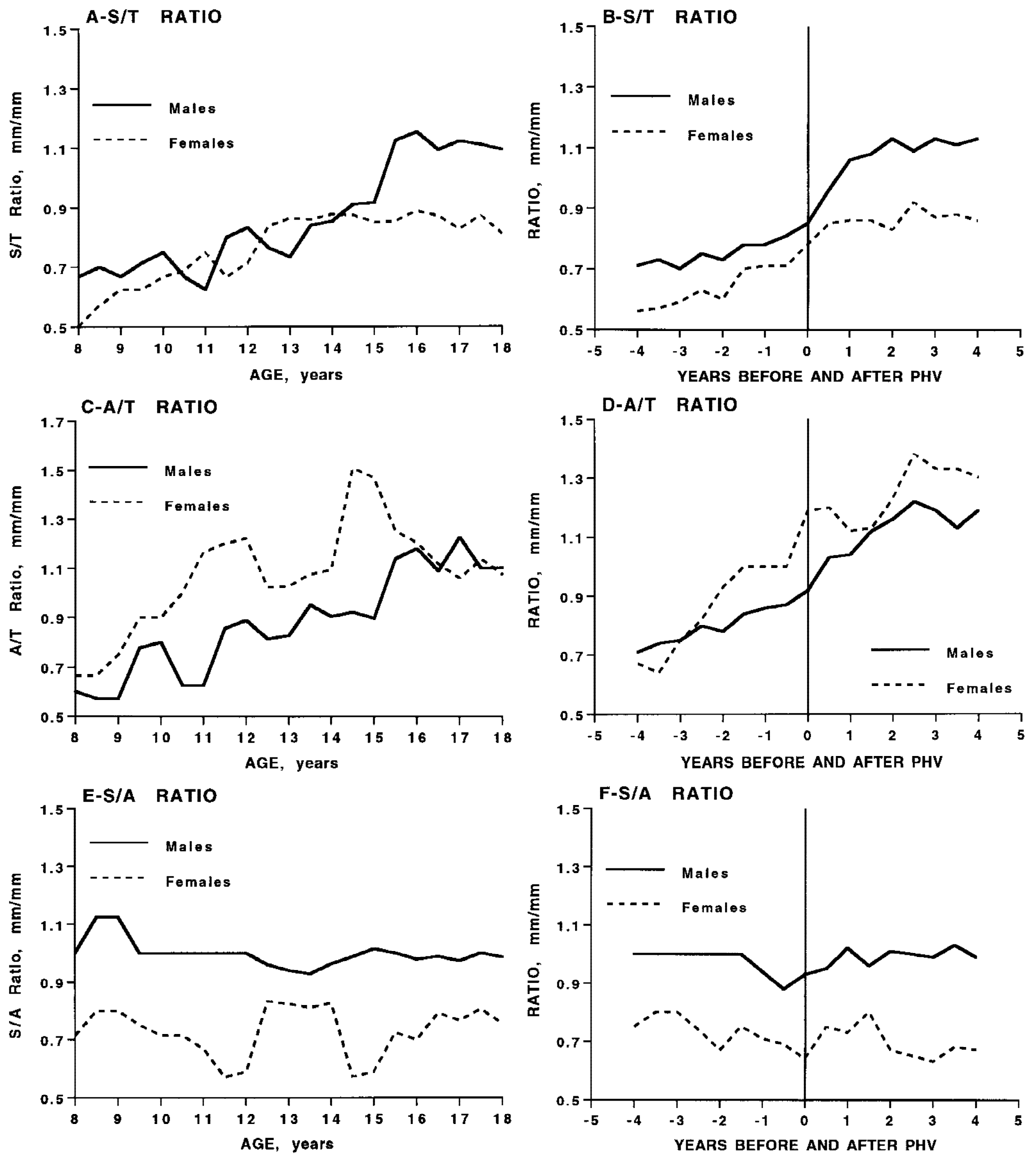

Fig. 5. Median skinfold ratios plotted by chronological age and relative to the time of PHV in boys and girls: subscapular/triceps (S/T) ratio (**A,B**), abdominal/triceps (A/T) ratio (**C,D**), and subscapular/abdominal (S/A) ratio (**E,F**).

flect VAT; the thickness of individual skinfolds or the sum of skinfolds may be a better indicator of VAT.

Age- and sex-associated variation in the S/T ratio are similar to corresponding trends for the same two skinfolds in French children (Rolland-Cachera et al., 1990) and for ratios for the sums of two or three trunk and extremity skinfolds (Rolland-Cachera et al., 1990; Malina and Bouchard, 1988). It is of interest that the A/T ratio shows a different pattern, indicating proportionally more abdominal SAT in females from 8–15 years of age (Fig. 5C). This pattern of sex differences contrasts that for the ratio of the suprailiac to triceps skinfolds in French children (Rolland-Cachera et al., 1990).

Individual skinfolds behave differently

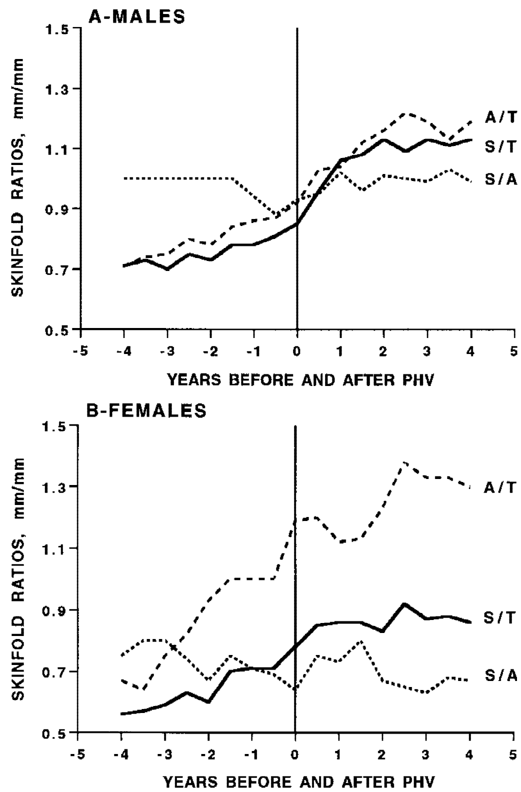

Fig. 6. Median skinfold ratios plotted relative to the time of PHV in boys (**A**) and girls (**B**).

during childhood and adolescence, and the changes are influenced by the timing of the adolescent growth spurt. The individuality of the skinfolds is especially apparent in estimated velocities relative to age at PHV (Fig. 4). Sex differences in estimated velocities are negligible up to about 2 years before PHV; then velocities tend to be higher in girls. The velocity of the triceps skinfold is negative in boys just before and after PHV; at this time, the triceps velocity in girls begins to increase (Fig. 4A). In contrast, estimated velocities for the trunk skinfolds tend to be positive through the growth spurt in both sexes, and are somewhat greater after PHV, especially in girls (Figs. 4B,C). These trends are consistent with other data for adolescent boys and girls (Beunen et al., 1988; Cronk et al., 1983; Tanner et al., 1981). The individuality of changes in individual skinfolds during the adolescent spurt contributes to changes in the relative distribution of SAT at this time.

The timing of the adolescent growth spurt is an important factor influencing the distribution of SAT both in the total sample and in youth classified as early and late maturing. The trunk–extremity contrast, for example, is more apparent after PHV than before (Fig. 5). In both sexes, the S/T ratio is higher in early maturing boys and girls when plotted by chronological age (Figs. 7A, 8A); in contrast, the ratio is higher in late maturing boys and girls when plotted relative to age at PHV (Figs. 7B, 8B). Relative to chronological age, the A/T ratio is greater in early maturing boys and girls (Figs. 7C, 8C). However, when plotted relative to PHV the difference between boys of contrasting maturing status is negligible (Fig. 7D), while that for early and late maturing girls is more apparent at and after PHV (Fig. 8D).

Currently available longitudinal data for abdominal SAT and VAT based on computerized tomography or magnetic resonance imaging do not span the adolescent growth spurt. Hence, the role of interindividual variation in the timing and tempo of the adolescent spurt on abdominal SAT and VAT is not known. Results of the present analysis indicate proportionally more abdominal SAT in girls than in boys relative to both the triceps (A/T ratio) and subscapular (S/A) skinfolds, and proportionally more abdominal SAT in early maturing youth of both sexes.

Literature dealing with abdominal SAT and VAT in children commonly uses stage of pubertal maturation as a maturity indicator (de Ridder et al., 1992; Brambilla et al., 1994; Caprio et al., 1995). Grouping subjects by stage of pubertal maturation may overlook variation in SAT and VAT associated with chronological age per se, independent of stage of sexual maturation. Further, individuals within specific stages of sexual maturation may be in different phases of the adolescent growth spurt. Although most girls are in breast and pubic hair stages II and III at the time of PHV, all five stages of breast development and the first four stages of pubic hair development are represented at PHV in girls from the Zurich Longitudinal Study (Largo and Prader, 1983b). Corresponding data indicate that most boys are in stages III and IV of pubic hair and genital development at the time of PHV, but all five stages of pubic hair development and stages II through V of genital development are represented at PHV in Zurich boys (Largo and

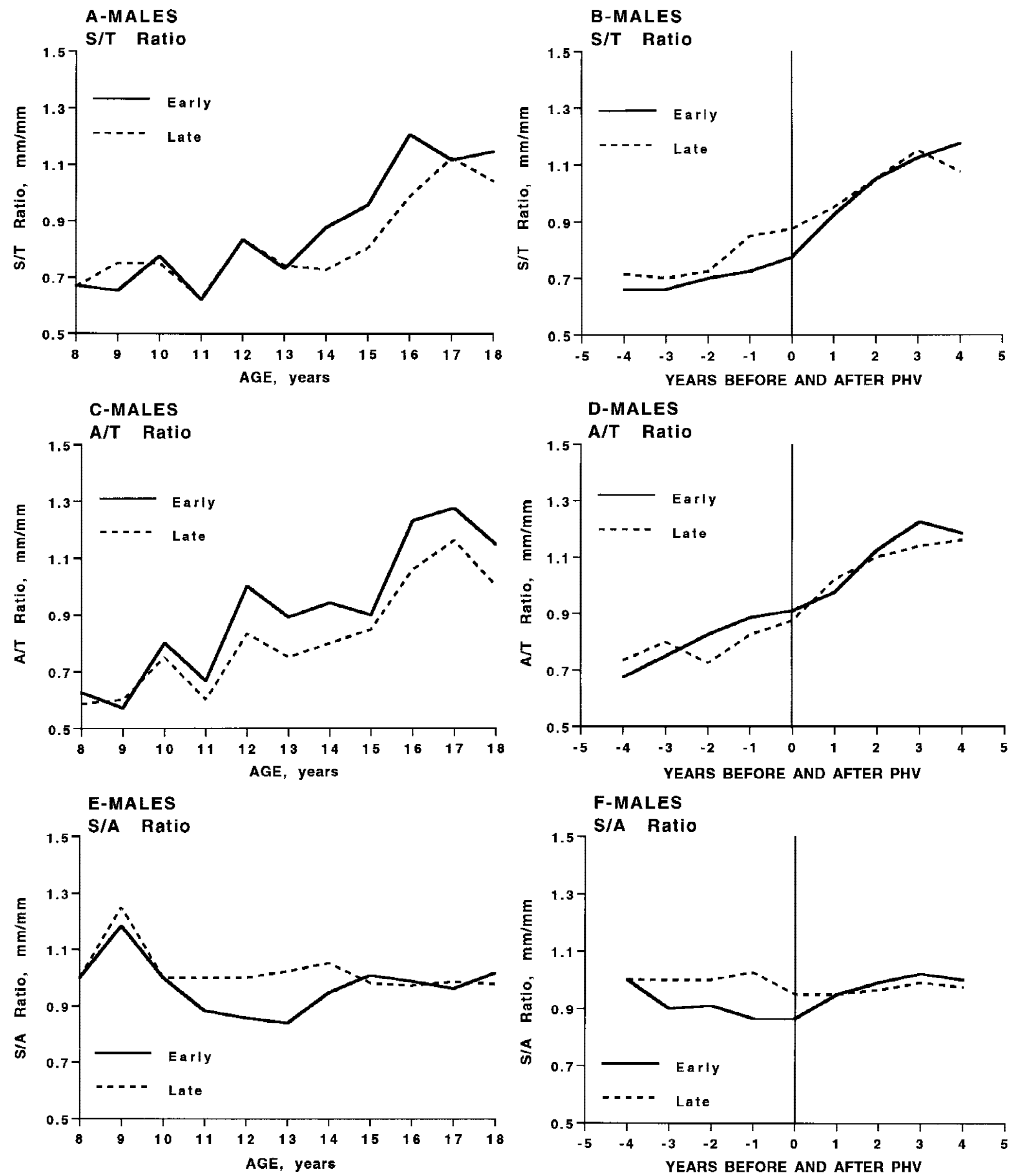

Fig. 7. Median skinfold ratios plotted by chronological age and relative to the time of PHV in early and late maturing boys: subscapular/triceps (S/T) ratio (**A,B**), abdominal/triceps (A/T) ratio (**C,D**), and subscapular/abdominal (S/A) ratio (**E,F**).

Prader, 1983a). Results of the present analysis of skinfolds and ratios emphasize the potential confounding effect of the timing of maximum growth velocity on fatness per se and indices of relative SAT.

At younger ages, subjects are generally described as prepubertal with no overt manifestation of secondary sex characteristics (Goran et al., 1997). There are often, however, maturity differences among prepubertal children, and the only indicator of maturation available before the overt manifestation of secondary sex characteristics is skeletal age (Malina and Bouchard, 1991).

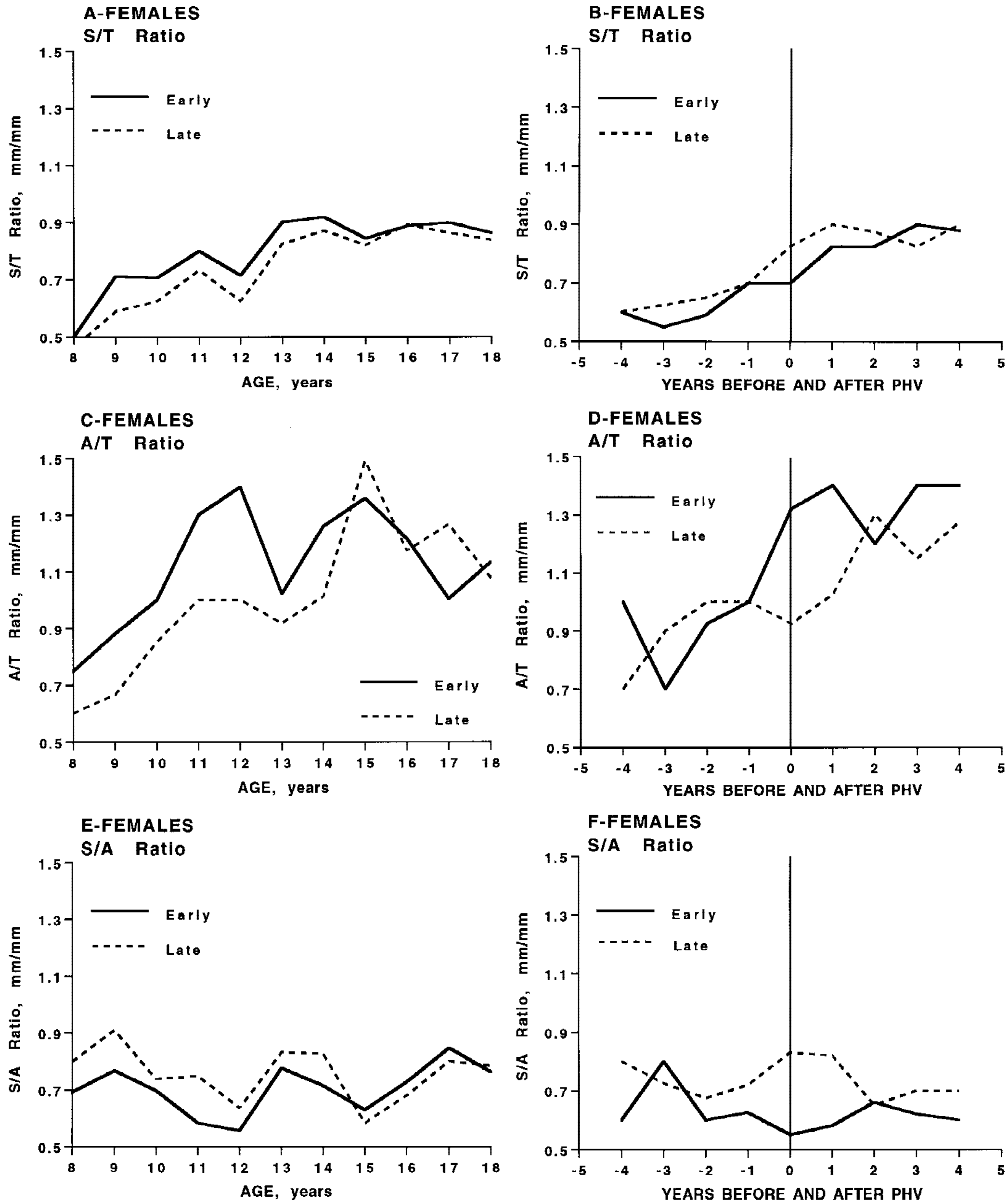

Fig. 8. Median skinfold ratios plotted by chronological age and relative to the time of PHV in early and late maturing girls: subscapular/triceps (S/T) ratio (**A,B**), abdominal/triceps (A/T) ratio (**C,D**), and subscapular/abdominal (S/A) ratio (**E,F**).

The specific contribution of biological maturation to fatness and relative fat distribution needs further study. How much of the variation in fatness and the distribution of abdominal SAT and VAT can be attributed to biological maturation independent of chronological age and body size? Sexual and skeletal maturity accounted for about 20% of the variance in a trunk–extremity SAT principal component in 14-year-old boys, but for none of the variance in the trunk–extremity component in 12-year-old girls (Deutsch et al., 1985). In a similar analysis, skeletal age accounted for 4%, 18%, and 8% of the variance in the trunk–extremity component in 12-, 14-, and 17-year-old boys, respectively, but for 2–3% of the corresponding trunk–extremity component variance in 9–10-year-old girls and none of the variance in 12- and 17-year-old girls (Beunen et al., 1992). The data suggest that skeletal maturation is more associated with SAT distribution in boys than in girls. However, the relatively small amount of variation in the trunk–extremity component of SAT accounted for by indicators of biological maturation indicates a need to consider other variables (e.g., body mass index, overall adiposity) and other indicators of SAT in the analyses. Corresponding analysis of the contribution of biological maturation to abdominal SAT and VAT are also indicated.

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