

Variation in relative fat distribution associated with maturational timing: The Wrocław Growth study

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Abstract

Complete longitudinal data of 136 boys aged 8–16 years and 124 girls aged 8–15 years were used to evaluate the association between maturational timing and the relative distribution of subcutaneous adipose tissue, specifically a trunk-oriented pattern of distribution. Age at peak height velocity (PHV) was the indicator of maturational timing and three skinfolds (triceps, subscapular, abdomen) were the indicators of subcutaneous fatness. Principal components analysis of the three skinfolds was used to identify indicators of relative subcutaneous adipose tissue distribution. Age at PHV and chronological age significantly influenced scores on the first principal components, which indicated centripetal fat patterning. The data suggest that early maturing subjects accumulate more subcutaneous adipose tissue on the lower trunk compared with later maturing peers of the same age and sex.

Keywords: *Fat distribution, adolescence, maturation, longitudinal study*

Introduction

Fatness *per se* and relative fat distribution are independent risk factors for metabolic and cardiovascular complications in adults (Larsson et al. 1984; Megnien et al. 1999), and most emphasis is currently upon abdominal subcutaneous and visceral adipose tissue. The same trend is suggested in adolescents (Daniels et al. 1999), but data are limited largely to skinfold thicknesses and ratios of skinfolds measured on the trunk and the extremities as indicators of fatness and relative subcutaneous fat distribution. Data on abdominal visceral fat for children and adolescents are relatively limited (Malina 1996, 2005). The adult pattern of relative fat distribution emerges during adolescence and there are considerable inter-individual differences associated with variation in the timing and tempo of the adolescent growth spurt and sexual maturation (Malina et al. 2004).

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Different approaches and skinfold thicknesses have been used to address variation in the relative distribution of subcutaneous adipose tissue associated with maturity status during adolescence (Malina 1996). Results vary to some extent with criteria of maturity status and age of subjects. For example, cross-sectional studies of early and late maturing 12-year-old girls (skeletal age, secondary sex characteristics) and 17-year-old girls (recalled age at menarche) indicate differences in overall fatness but not in relative fat distribution (Deutsch et al. 1985). Among 14-year-old boys, on the other hand, early maturers (skeletal age, secondary sex characteristics) have proportionally more subcutaneous fat on the trunk compared with late maturers (Deutsch et al. 1985). The association between proportionally more subcutaneous fat on the trunk compared to the extremities and advanced maturity status has also been reported in other samples of males but not in females (Frisancho and Flegel 1982; Baumgartner and Roche 1988).

Corresponding analyses in longitudinal samples give variable results. Early maturing boys (age at peak height velocity, PHV) in the Leuven Longitudinal Study of Belgian Boys have proportionally more subcutaneous fat on the trunk compared to late maturing boys from 13 through 18 years and also at 30 years of age (Beunen et al. 1994). On the other hand, early and late maturing boys (skeletal age and age at PHV) in the Amsterdam Growth Study do not differ in relative fat distribution from 13 to 16 years and at 21 and 27 years (van Lenthe et al. 1996). Early and late maturing (skeletal age) Amsterdam girls also do not differ in relative subcutaneous fat distribution during adolescence and in young adulthood, but with age at menarche as the criterion, early maturing girls have proportionally more subcutaneous fat on the trunk (van Lenthe et al. 1996). The results for girls classified on the basis of age at menarche contrast with those for a cross-sectional sample of 17-year-old girls (Deutsch et al. 1985).

Variation among studies probably reflects the different skinfolds used and in the criteria of maturation and cut-offs for defining groups of contrasting maturity status (Malina et al. 2004). In addition, the two longitudinal studies cited above have a limited lower age boundary (13 years) so that changes in relative subcutaneous fat distribution during the transition from childhood into adolescence could not be assessed.

The present study considers the association between maturational timing (age at PHV) and relative subcutaneous adipose distribution in the longitudinal data of the Wrocław Growth Study. It builds upon an earlier study that considered the behaviour of individual skinfolds and ratios of skinfolds during the adolescent spurt (Malina et al. 1999). This study compares the relative subcutaneous fat distribution (defined by principal component scores) of individuals of contrasting maturity status throughout the interval of adolescence (8–16 years) in boys and girls from the Wrocław Growth Study.

Material and methods

Sample

The Wrocław Growth Study followed boys and girls at approximately annual intervals between 1961 and 1972. All participants were inhabitants of the city of Wrocław in south-western Poland (Bielicki and Waliszko 1975; Waliszko and Jedlińska 1976). The project started with 425 boys and 435 girls. During the first 8 years of the study, 390 subjects dropped out. At the end of the examination period, the number of participants was reduced to 196 boys and 212 girls. The subjects who persisted in the study did not differ in height and weight from those who dropped out at the age of 8 years. Thus, dropout at this stage seems to have been random.

All subjects annually underwent an anthropometric battery in the spring (April–May) of each year. All dimensions were measured by the same professional staff throughout the study. This study utilizes only height, weight and the triceps, subscapular and abdominal skinfold thicknesses. Complete data for all age classes of 136 boys and 124 girls are used in the analysis.

Maturation timing

All subjects had from 8 to 13 measurements. Mean ages (and standard deviations) of the first and last examinations were 7.95 ± 0.32 and 18.30 ± 0.96 years in boys, and 7.93 ± 0.31 and 17.25 ± 0.82 years in girls. The Preece–Baines model 1 (PB1) was fitted to individual records of height for 196 boys and 212 girls (Preece and Baines 1978; Hauspie et al. 1980). The FORTRAN program based on the efficient, non-linear least-squares technique developed by Powell (1969) for the Harwell Subroutine Library (VA05A) was applied for the curve-fitting procedure. Goodness of fit was judged by comparing the standard error of estimate and some estimate of the measurement error (Hauspie et al. 1992).

Age at PHV derived from the fitted Preece–Baines model 1 was used as the indicator of maturational timing. Tertiles of the distribution of ages at PHV were used to identify three maturity groups: early, average and late. There were approximately equal numbers of subjects in each group. Note that age at PHV is continuous characteristics; the division into tertiles was used only to derive gradients which permitted the application of statistical procedures for significance testing.

Analysis

Ratios and principal components analysis (PCA) of skinfolds taken at various sites on the trunk and extremities are the more commonly used methods for estimating relative fat distribution (Malina 1996). Both methods were used in the present study. Before undertaking the PCA, three ratios (one for each skinfold site measured in the Wrocław Growth Study) were initially calculated as follows:

$$\log(\text{one skinfold site}/\text{sum of skinfolds}).$$

The ratio adjusts for variation in overall subcutaneous fatness. Subsequently, PCA was applied to identify components which present the maximum contrast among the log of ratios. Finally, scores for the principal components for individual subjects in the Wrocław Growth Study were used in further analysis.

Scores on each of the identified principal components were compared among the three contrasting maturity groups of boys and girls using a sex-specific multiple analysis of variance (MANOVA) with repeated measurements. In such a design, the total variance is partitioned additively into three parts: maturation- and age-dependent variance and interaction-dependent variance (maturation timing and age range). Univariate analysis of variance was used to test differences between principal component scores in the three maturation groups within age groups.

All analyses were conducted using the statistical package STATISTICA 6.0 PL for personal computer (StatSoft Inc. 2003).

Table I. Means and standard deviations for age at PHV in three maturity groups of boys and girls.

Maturation	Boys			Girls		
	<i>n</i>	Mean	SD	<i>n</i>	Mean	SD
Early	64	12.9	0.5	67	10.8	0.6
Medium	63	13.9	0.3	63	11.9	0.2
Late	66	15.3	0.7	67	12.9	0.5

Table II. Results of principal components analyses of the three skinfold thicknesses.

Quotient of skinfolds	Boys		Girls	
	PC1	PC2	PC1	PC2
Subscapular	-0.489	0.869	-0.263	-0.962
Triceps	0.993	-0.048	-0.890	0.441
Abdominal	-0.802	-0.590	0.982	0.142
Eigenvalue	1.868	1.107	1.828	1.141
% variance	62.3	36.9	60.9	38.0

Results

Goodness of fit statistics for the Preece–Baines model 1 applied to individual data of 184 boys and 166 girls indicated good precision. The pooled residual variance (0.773 cm \pm 0.534 for boys and 0.268 cm \pm 0.186 for girls) and standard error of estimate (0.875 cm \pm 0.287 for boys and 0.518 cm \pm 0.173 for girls) were lower than or comparable to values from other studies (Kaczmarek 1995; Koziel et al. 1995). The runs-test did not show any significant bias for the model used. The standard error of estimate for girls was also comparable with the intra-observer measurement error for stature (0.39 cm) but was two times higher in boys. Both residual variance and standard errors show significant sex difference (Mann–Whitney *U*-test; $Z = 11.4$, $p < 0.01$); this was due to a higher residual variance and right skewness in boys.

Mean ages at PHV for the total sample of girls and boys in the Wrocław Growth Study are 11.89 ± 1.0 and 14.06 ± 1.11 years, respectively. Corresponding values for the three maturity groups of boys and girls are indicated in Table I.

Results of the sex-specific PCA of the three skinfolds are summarized in Table II. Two meaningful components have eigenvalues > 1.0 in each sex. Among boys, the positive loading for the triceps skinfold (0.99) and the negative loading for the abdominal skinfold (-0.80) suggest a lower trunk–upper extremity first component (PC1) of relative subcutaneous fat distribution in boys. The second component (PC2) has a positive loading for the subscapular (0.87) and a negative loading for the abdominal (-0.59) skinfolds, and suggests an upper trunk–lower trunk contrast in relative subcutaneous fat distribution in boys. The two components account for 99.2% of the variance in the sum of three skinfolds in boys.

Among girls, PC1 has a positive loading on the abdominal skinfold (0.98) and a negative loading on the triceps skinfold (-0.89) and also suggests a lower trunk–upper extremity contrast in relative subcutaneous fat distribution. PC2, on the other hand, has a negative loading for the subscapular skinfold (-0.96) and a positive loading for the triceps

Table III. Results of the MANOVA of repeated measurements for the first (a) and second (b) principal components in boys and girls.

	Boys		Girls	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
(a) PC1				
Maturational timing	8.00	0.0005	7.09	0.0012
Age	135.00	0.0000	86.42	0.0000
Interaction	1.41	0.1265	1.01	0.4359
(b) PC2				
Maturational timing	1.26	0.2878	0.68	0.5083
Age	18.13	0.0000	67.20	0.0000
Interaction	3.02	0.0001	0.76	0.7152

Table IV. Results of sex-specific univariate ANOVA of PC1 and PC2 scores in individuals of contrasting maturity status (early, average, late age at PHV) in each age group (only *F*-ratios and *p* levels are shown).

Age classes	Boys		Girls	
	PC1	PC2	PC1	PC2
8	2.13	0.76	3.61*	0.08
9	1.01	0.63	4.20**	0.28
10	4.26*	5.39**	8.48***	0.74
11	3.29*	2.35	7.02**	0.69
12	3.06*	5.00**	9.86***	0.08
13	7.35***	1.11	7.68***	0.41
14	12.95***	0.99	4.17*	0.59
15	12.27***	4.03*	2.07	0.50
16	12.00***	1.38		

p* < 0.05; *p* < 0.01; ****p* < 0.001.

skinfold (0.44) and indicates a trunk–extremity contrast in fat distribution. The two components explain 98.9% of the total variance in the sum of three skinfolds in girls. Overall, the total explained variance in the three skinfolds is high in both sexes; however, PC2 appears to have a different meaning for boys and girls.

Results of the MANOVA with repeated measurements are given in Table III. The main effects of maturational timing and chronological age are significant for PC1 in both sexes, while the interaction between timing and age is not significant. This suggests that the timing of PHV influences relative subcutaneous fat distribution independent of age. The results also suggest that early maturing subjects accumulate proportionally more subcutaneous fat on the lower trunk than peers who mature later. On the other hand, PC2 is not significantly influenced by maturational timing. PC2 is significantly associated with chronological age and there is an age–maturational timing interaction in boys.

Results of univariate analyses, which compare the two principal components among early, average and late maturing individuals by age groups are summarized in Table IV, while mean principal component scores for the contrasting maturity groups are illustrated in Figures 1 and 2. Differences in PC1 associated with maturational timing are not significant in boys at 8 and 9 years, but are significant in all other age groups. Mean PC1 scores in boys appear to be stable until 11 years and then decline in the three maturity groups

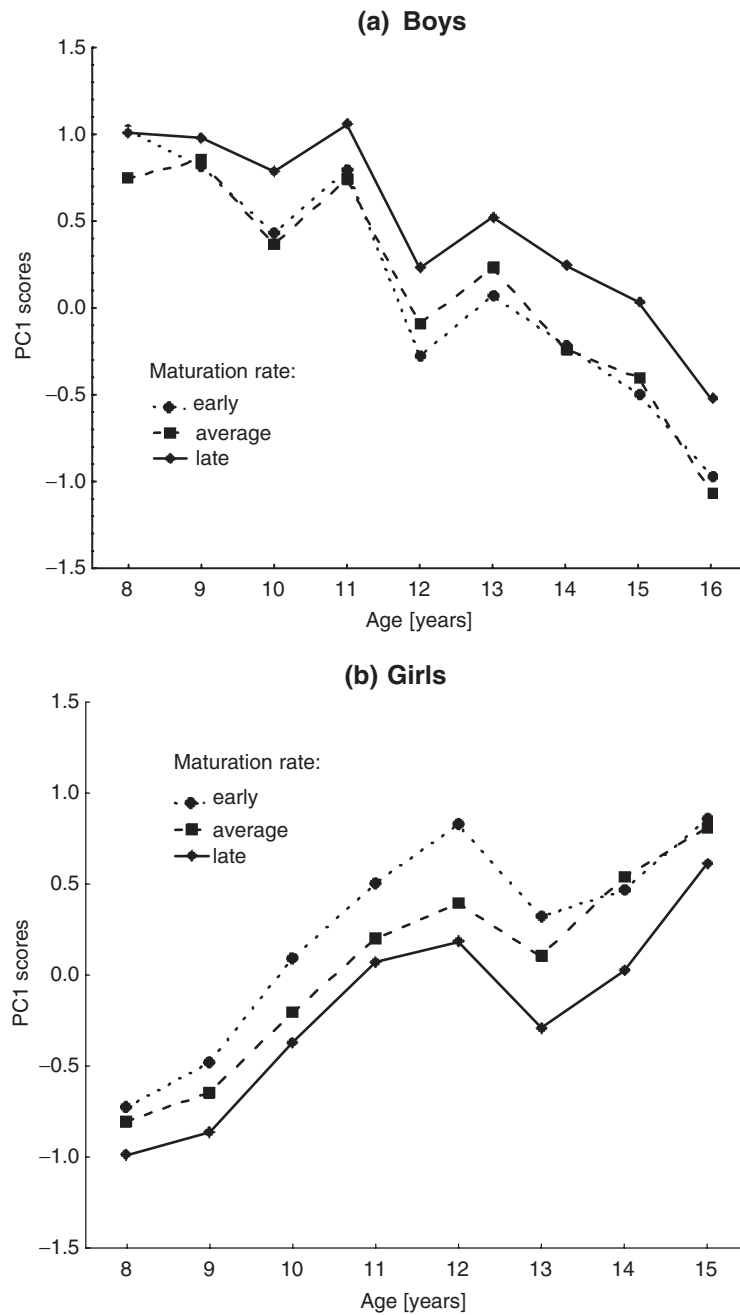


Figure 1. Mean PC1 scores of boys (a) and girls (b) of contrasting maturity status within age groups.

(Figure 1a). The maturity-associated differences are due to higher PC1 scores among late maturing boys; early and average maturing boys do not differ in PC1.

PC1 scores increase from 8 to 12 years in girls and then show a temporary decline at 13 years (Figure 1b). In contrast to boys, PC1 scores differ among the three maturational timing groups from 8 through 13 years of age: early > average > late maturing girls.

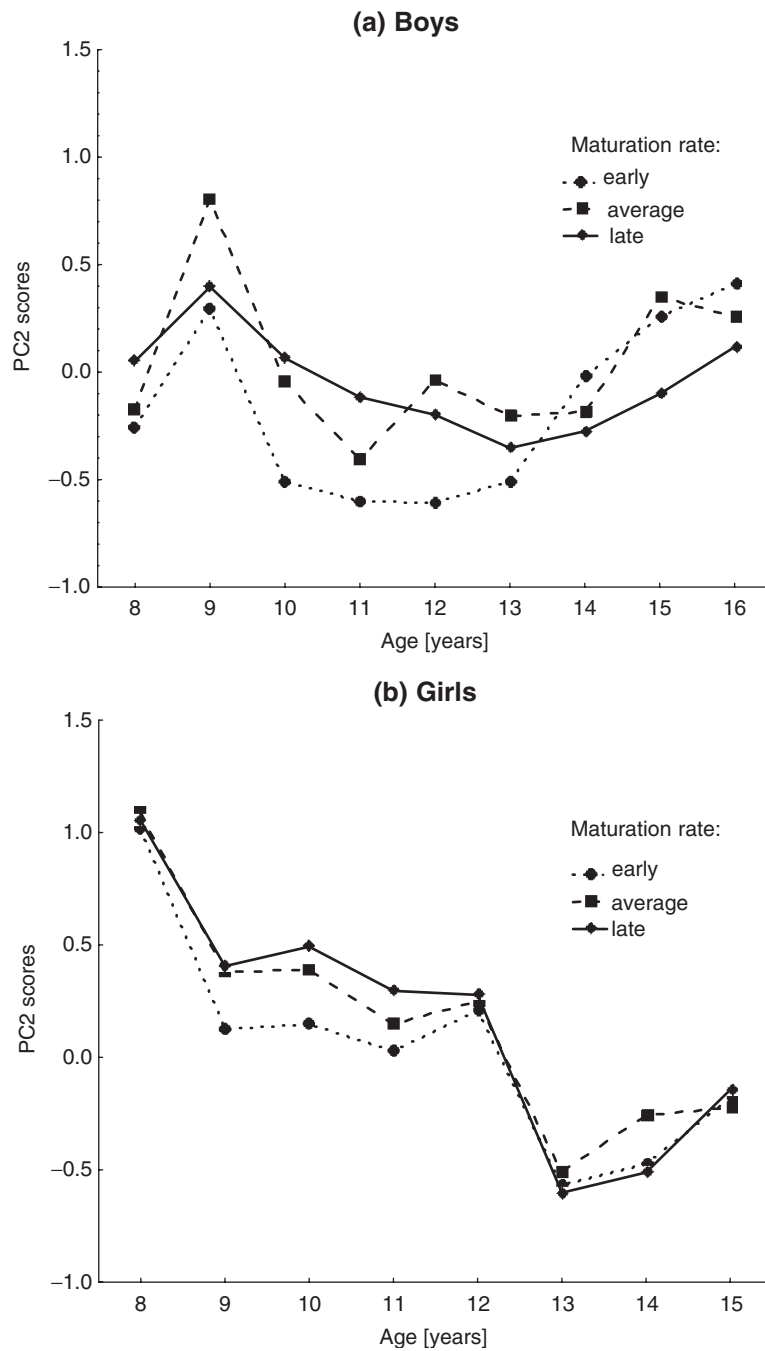


Figure 2. Mean PC2 scores of boys (a) and girls (b) of contrasting maturity status within age groups.

Differences in PC2 associated with variation in maturational timing present a very irregular pattern across the age range in both sexes (Figure 2a, b). None of the differences in PC2 among maturity groups of girls are significant, while corresponding differences among maturity groups of boys are significant at only three ages: 10, 12, and 15 years.

PC2 scores decline with age from 9 to 13 years in boys and then increase (Figure 2a) and also decline with age from 8 to 13 years in girls and then increase (Figure 2b).

Discussion

The results suggest that the redistribution of subcutaneous fat from extremities to trunk during adolescence is mainly driven to lower parts of the trunk. In addition, the association between maturational timing and the accumulation of abdominal subcutaneous adipose tissue depends to some extent on chronological age *per se*. The influence of variation in maturational timing on upper extremity–lower trunk subcutaneous adipose distribution appears to increase with age in boys whereas the corresponding influence in girls is greatest closer to the age at PHV (about 10–13 years) and then diminishes.

The principal components protocol reduces the influence of overall or absolute fatness on relative subcutaneous fat distribution. The computation of principal components from raw, i.e. unstandardized, skinfold data biases the results towards the measurement with the greatest variance (Mueller and Reid 1979). In the present analysis, the logarithms of ratios were used to compute the principal components and in this way avoided the problem of differences in variance between measurements. Thus, two derived components are the measure of subcutaneous fat distribution between particular skinfold sites independent of overall fatness. Moreover, the resulting principal components can be biological interpreted.

The present results provide some insight into factors that influence changes in relative extremity–trunk subcutaneous fat distribution in association with maturational timing. Age at PHV is a highly heritable characteristic (Hauspie et al. 1994; Malina et al. 2004), and those who attain PHV early differ in relative subcutaneous fat distribution compared with those who attain PHV later. On the other hand, the genetic variance in the extremity and trunk skinfolds appears to be lower (Beunen et al. 1998) than that for age at PHV. Moreover, the genetic variance for skinfolds is generally higher in girls than in boys while that for relative fat distribution is lower (Beunen et al. 1998).

The influence of early maturation on relative fat distribution may be mediated by the sex steroid hormones. Serum testosterone is associated with an increase in subcutaneous trunk fat in pubertal males, while the higher concentration of oestrogen in early pubertal girls is associated with a gynoid distribution of body fat (Malina 1996; Roemmich and Rogol 1999). The relationships among steroid hormones adiposity and relative fat distribution are complex and may also be mediated by sex steroid-stimulated growth hormone release (Roemmich and Rogol 1999). Elevated growth hormone during the adolescent spurt may contribute to the decreasing thickness of the triceps skinfold during male adolescence. It was shown that the estimated velocity of triceps skinfold in age classes relative to age at PHV tended to increase in girls, especially after the age at PHV, whereas in boys this velocity between 1 year before and after age at PHV was negative (Malina et al. 1999). The underlying hormonal mechanism is not consistent and seems to be complicated. In one study performed in a large group of normal-weight girls serum insulin-like growth factor-I (IGF-I) was not related to BMI, triceps skinfold thickness, waist-to-hip ratio, weight and height. In others elevated free IGF-I concentrations have been reported in obese children (Malecka-Tendera and Molnar 2002).

Most previous studies of relative subcutaneous fat distribution were carried out with cross-sectional samples, and the observed trend toward greater central fatness with age usually was generally interpreted as a redistribution effect of subcutaneous fat from the extremities to the trunk during adolescence (Malina 1996). Only a few studies investigated the longitudinal samples. In the Leuven longitudinal study (Beunen et al. 1994),

three groups of contrasting maturity status based on the age at PHV (early, average or on time, and late) differed in a trunk/extremity skinfold ratio not only during adolescence but also in adulthood. Late maturing boys had proportionally less subcutaneous fat on the trunk compared with early and average maturing boys and the differences among maturity groups persisted until 30 years of age.

In the Amsterdam longitudinal study (van Lenthe et al. 1996), variation in maturational timing (age at PHV) and rate (skeletal age) was not associated with a trunk-oriented pattern of relative fat distribution in both sexes. Attaining menarche earlier than average, however, was associated with a centripetal fat distribution in adolescence and young adulthood. These findings contrast to observations in the present study. The differences may reflect different methods of estimating biological maturation, skinfolds considered, and analysis. Indicators of maturational timing, i.e. age at PHV, age at menarche, age as attaining specific secondary sex characteristics, and age at reaching a specific skeletal age, are highly inter-related (Bielicki 1975, Bielicki et al. 1984). In contrast, the use of the difference between skeletal and chronological ages to classify individuals as early or late maturing provides an indication of maturity status at a given age rather than maturational timing.

The abdominal skinfold thickness may not reflect overall abdominal adiposity including both subcutaneous and visceral or intra-abdominal fat. Moreover, skinfolds and the ratio of skinfolds measured at different bodily sites do not necessarily reflect visceral adiposity. The ratio of trunk to extremity skinfolds, for example, explains only 62% of the variation in abdominal visceral fat in children (Goran and Malina 1999) and is not related to abdominal visceral fat in adolescent girls (de Ridder et al. 1992). The use of a combination of skinfold thicknesses and circumference may provide a reasonable estimate of abdominal visceral fat in the absence of direct measurement with imaging techniques.

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Résumé. Des données longitudinales complètes de 136 garçons âgés de 8 à 16 ans et de 124 filles âgées de 8 à 15 ans ont été utilisées pour évaluer l'association entre chronologie de la maturation et distribution relative du tissu adipeux sous-cutané sur le tronc. L'âge à la vitesse de pic de croissance (VPS) de la stature est l'indicateur de maturation et trois plis cutanés (triceps, subscapulaire, abdominal) sont les indicateurs de la graisse sous cutanée. Une analyse en composantes principales des trois plis a été utilisée pour identifier les indicateurs de la distribution du tissu adipeux sous cutané. L'âge à la VPS et l'âge chronologique influencent significativement les scores du premier facteur de l'analyse qui indique une répartition centripète de la graisse. Les données suggèrent que les sujets à maturation précoce accumulent plus de tissu adipeux sous cutané dans la partie inférieure du tronc que ceux de même sexe qui ont une maturation tardive.

Zusammenfassung. Vollständige longitudinale Daten von 136 8-16-jährigen Knaben und 124 8-15-jährigen Mädchen wurden verwendet, um die Beziehung zwischen dem Stand der Reifeentwicklung und der relativen Verteilung von subkutanem Fettgewebe, insbesondere ein rumpfbetontes Verteilungsmuster, zu untersuchen. Alter bei maximaler Wachstumsgeschwindigkeit (peak height velocity, PHV) wurde als Indikator für den Stand der Reifeentwicklung und die drei Hautfettfalten (Trizeps, subskapular, abdominal) als Indikatoren für Subkutanfett gewählt. Hauptkomponentenanalysen der drei Hautfettfalten wurden verwendet, um Indikatoren für die relative subkutane Fettgewebsverteilung zu identifizieren. Das Alter bei PHV und das chronologische Alter beeinflussten den Ausprägungsgrad der ersten Hauptkomponenten signifikant, der auf ein zentripetales Fettverteilungsmuster hindeutete. Die Daten weisen darauf hin, dass frühreife Jugendliche mehr subkutanes Fettgewebe im Bereich des unteren Rumpfes anreichern, als gleichgeschlechtliche Altersgenossen, die sich später entwickeln.

Resumen. Se utilizaron los datos longitudinales completos de 136 chicos de entre 8 y 16 años de edad, y de 124 chicas de 8 a 15 años, para evaluar la asociación entre la edad de maduración y la distribución relativa del tejido adiposo subcutáneo, en concreto, el patrón de distribución troncal. La edad al pico de crecimiento puberal (PHV) fue el indicador de la edad de maduración, y tres pliegues de grasa subcutánea (tríceps, subescapular y abdominal) fueron los indicadores de la grasa subcutánea. Se utilizó el análisis en componentes principales de los tres pliegues para identificar los indicadores de la distribución relativa del tejido adiposo subcutáneo. La edad al PHV y la edad cronológica influían significativamente en las puntuaciones de los primeros componentes principales, que representaban el patrón de grasa centripeto. Los datos sugieren que los sujetos con una maduración temprana acumulan más tejido adiposo subcutáneo en la parte inferior del tronco que los maduradores tardíos del mismo sexo y edad.