Development and Tracking of Central Patterns of Subcutaneous Fat in Adolescence and Adulthood: The Amsterdam Growth and Health Study

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Background. A central pattern of body fat is recognized as a risk indicator of cardiovascular diseases in adulthood. The development of this body fat pattern from childhood into adulthood however, remains to be explored.

Methods. The development of two trunk skinfolds (subscapular; supra-iliac), two extremity skinfolds (biceps; triceps), and three trunk-extremity skinfold ratios for males (n = 71) and females (n = 84), were described over a period of 17 years from 13 to 29 years of age. In addition, tracking of the skinfolds and the skinfold ratios was investigated over this period. Data for this study came from the Amsterdam Growth and Health Study, an ongoing longitudinal study in the Netherlands that started in 1977.

Results. In adolescence, a decrease was seen in extremity skinfolds for men but not for women. For both sexes, the trunk skinfolds increased over the entire period of study. An increase was found in trunk-extremity skinfold ratios in males, but not in females. Tracking coefficients, calculated as Pearson correlation coefficients between the initial measurement and subsequent measurements, were about 0.4 for the single skinfolds between 13 and 29 years of age for both men and women. For the skinfold ratios, these correlation coefficients were about 0.55. Longitudinal tracking coefficients, measuring the association between the initial measurement and all follow-up data simultaneously, were about 0.65 for both men and women.

Conclusions. A central pattern of body fat, mainly seen in males, seems to start in adolescence. From a preventive point of view, tracking coefficients were too low to be of predictive value. In order to conclude that the roots of a central pattern of body fat are in adolescence, careful search for determinants of change of this body fat pattern is needed.

Keywords: fat distribution, longitudinal, tracking, adolescence
with fat on the extremities. It was the aim of this study to describe the development of two trunk skinfolds and two extremity skinfolds in a healthy population of Dutch males and females over a period of 17 years between 13 and 29 years of age. Trunk-extremity skinfold ratios were constructed and their development was shown over the same period of time. In addition, the existence of tracking of the skinfolds and the trunk-extremity skinfold ratios was investigated. Data were available from the Amsterdam Growth and Health Study, a longitudinal study which started in 1977 in the Netherlands.9

### METHODS

#### Population

The Amsterdam Growth and Health Study is a longitudinal observational study. The primary aim of the study was to investigate the development of indicators of growth and health in a cohort of Dutch adolescents.10 For that purpose, subjects were recruited from the first and second form of a secondary school in Amsterdam (the Netherlands). Informed consent was obtained from the children and their parents and all subjects agreed to participate in the study.

In order to obtain information on the socio-economic status of the participants, the professional occupations of the parents were subdivided into seven categories. The distribution of the professions over the categories was compared to that of a representative sample of the Dutch population in 1977. More parents were involved in administrative and commercial jobs. Parents also showed higher mean levels of education compared to the average in the Dutch population and their incomes were higher. Therefore it was concluded that the mean socio-economic status of the participants at the start of the study was slightly higher compared to the average in the Dutch population.10

The first measurement was in 1977 with the subjects (boys n = 148; girls n = 159) having a mean age of 13 years. Follow-up measurements were performed annually between 1978 and 1980. For different reasons, i.e. leaving school or moving out of town, 31.1% of the boys (n = 46) and 17.6% of the girls (n = 28) dropped out of the study during this 4-year period. Three additional measurements were performed in 1985, 1991 and 1993 with the subjects having a mean age of 21, 27 and 29 years. Of the remaining subjects in 1980 another 30.4% (n = 31) of the males and 35.9% (n = 47) of the females dropped out of the study between 1980 and 1993.

Student’s t-tests were used to investigate whether differences existed in the means of the skinfolds and the skinfold ratios between those who remained and those who dropped out of the study between 1977 and 1993. The results are presented in Table 1.

For women, a significantly higher mean subscapular skinfold was found for those who dropped out, compared to those who remained in the study. Since this was not found for the other skinfolds, nor for variables not included in this study, as for example physical activity, blood pressure or cholesterol, it was concluded that the drop-out was not selective, thereby resulting in a population containing the most healthy individuals.9,11 Only those subjects who participated in all seven measurements were included in the analysis. Consequently, data were available for 71 men and 84 women.
Body Fat Patterns
Four skinfolds (biceps, triceps, subscapular and suprailiac) were measured to the nearest 0.1 mm with a Harpenden calliper (Holtain, London, UK) at every period of measurement according to the International Biological Program. Two measurements were done and the highest value was used in the analyses. It is known that measurements of skinfolds are susceptible to measurement error. In our study, skinfolds were measured by one person (RV) from 1977 to 1985. During the last two measurement periods a second examiner WvM was responsible for skinfold measurements. Both examiners were trained according to the guidelines of the International Biological Program. The longitudinal design of the study made it possible to get information on the reproducibility of skinfold measurements. Therefore, all possible correlation coefficients were calculated between skinfolds measured at two different measurement periods. Linear regression analysis was performed with these correlations (inter-period correlation coefficients, IPC) as the dependent variables and the number of years between the measurements as the independent variables. The intercept of the linear regression reflected the correlation coefficient between two skinfold measurements when the time between the measurements was zero. Since the intercepts were about 0.8 or higher, it was concluded that the reproducibility of the skinfold measurements was high.

As indicators of a central pattern of body fat the following ratios, contrasting subcutaneous fat on the trunk with fat on the extremities, were used:

\[
(s/t) \text{ ratio:} \quad \frac{\text{subscapular}}{\text{triceps}} \\
(s/st) \text{ ratio:} \quad \frac{\text{subscapular}}{\text{subscapular + triceps}} \\
(ss/ssbt) \text{ ratio:} \quad \frac{\text{subscapular + supra-iliac}}{\text{biceps + triceps + subscapular + supra-iliac}}
\]

Obviously, from the available skinfolds many more ratios could be constructed contrasting subcutaneous fat on the trunk with that on the extremities. Biologically however, they are all indicators of the same concept, a central pattern of body fat. The development of the median of ratios, including the biceps and the suprailiac skinfolds, was as expected, to a large extent comparable to the development of the medians of the ratios presented in this report. The choice of the presented ratios was therefore based on the ability to compare the results of this study with results presented in the literature.

Data Analysis
Prior to the final analysis, the possible existence of cohort effects was tested. From the multiple longitudinal design, three cohorts, consisting of individuals born in 1962, 1963 or 1964, could be identified. MANOVA for repeated measurements was performed to test for differences in the development of the mean of the skinfolds and the skinfold ratios between the cohorts. Considering \( P < 0.01 \) as statistically significant, no cohort effects were found.

Using different cohorts, it was possible that individuals with identical chronological ages were measured in different years. A difference in the mean of an indicator between individuals with the same chronological ages, but measured in different years, is known as a period or time of measurement effect. MANOVA for repeated measurements was used to test for significant time of measurement effects for the skinfolds and the trunk-extremity skinfold ratios, which were not found \( (P < 0.01) \). Due to the absence of cohort and time of measurement effects, the development of the skinfolds and the skinfold ratios were presented according to the years of measurement.

Methodologically, a large variety exists in tracking studies, correlation coefficients being amongst the most frequently used. Several studies defined the tracking coefficient as the correlation between indicators measured at the first and at a subsequent period of measurement. These coefficients refer to the predictability of future high risk values, based on the first measurement. In this report, correlation coefficients were calculated between indicators of a central pattern of body fat at the initial measurement (mean age 13 years) and the same indicators at the mean ages of 16, 21, 27 and 29 years.

A disadvantage of this technique, however, is that only data from two periods of measurement can be used. When the time period between two follow-up measurements becomes large, fluctuations in the age- and sex-specific distribution can easily occur but cannot be taken into account in the correlation coefficient. A tracking coefficient based on data from all available follow-up measurements would therefore provide a more accurate estimation of tracking. In the past decade, major steps forward were made in longitudinal data analyses, making available techniques that allow inclusion of data from all periods of measurement in statistical analyses. Recently, Twisk et al. developed a longitudinal tracking coefficient, measuring the association between an indicator at the first period of measurement and the same indicator at all other periods of measurement, using the generalized estimating equations (GEE) technique.
coefficient of tracking is expressed by $\beta_1$ in the following formula:

$$ Y_{it} = \beta_1 Y_{it_1} + \beta_2 t + \epsilon_{it} $$

where

- $Y_{it} =$ observations of individual $i$ from $t_2$ to $t_m$ (where $m =$ the number of measurements).
- $Y_{it_1} =$ initial (first) observation of individual $i$ at $t_1$.
- $\beta_1 =$ standardized regression coefficient interpreted as longitudinal tracking coefficient.
- $t =$ time.
- $\beta_2 =$ regression coefficient of time.
- $\epsilon_{it} =$ measurement error of individual $i$ over $t_2$ to $t_m$ (where $m =$ the number of measurements).

Repeated measurements of the same individual are likely to be correlated. In order to correct for within-person correlations, GEE requires definition of a correlation structure between the data. For example, an exchangeable structure implies that the correlations between all measurements are equal. An often recognized phenomenon in tracking research however, is the decrease in correlation between measurements with increasing periods of time. Here, the stationary six-dependent structure seemed to be the most appropriate.

In this structure, the same correlation was used for measurements with an identical period of time in between. All data were z-converted. GEE-analyses were carried out using SPIDA, all other analyses were done with SPSS-PC.

In order to avoid confusion, tracking coefficients based on Pearson correlation analysis were called simple tracking coefficients ($r$), while tracking coefficients derived from GEE-analyses were called longitudinal tracking coefficients ($\beta_1$).

**RESULTS**

Figure 1 presents the development of the median ($P_{50}$) of the biceps and triceps skinfolds for men and women. For men, a moderate decrease of the thickness of the biceps was found between 13 and 16 years of age. From the age of 16 to 29 years, the biceps skinfold slowly returned to the thickness at the age of 13 years. Over the entire period of study, the biceps skinfold thickness increased for women. A slight decrease was also seen for the triceps skinfold of men in adolescence. From this period onwards, the thickness of the triceps skinfold remained almost constant. For women, an increase was seen in the triceps skinfold thickness until the mean age of 21 years, after which there was a decrease. The
median of both skinfold thicknesses was higher for women than for men.

Figure 2 presents the development of the median (P50) of the subscapular and supra-iliac skinfold thickness for men and women. For both sexes, a pattern emerged of an increasing subscapular skinfold thickness over the entire period of measurement. The median for women was consistently higher than for men. The same pattern was found for the supra-iliac skinfold thickness between 13 and 21 years of age. From the age of 21 years onwards, the median of the supra-iliac skinfold thickness decreased in women and increased in men.

Figures 3 and 4 present the development of the median of the trunk-extremity skinfold ratios based on the subscapular and the triceps and based on all four skinfold thicknesses respectively between 13 and 29 years of age. Generally, the three ratios showed the same pattern: at the mean age of 13 years equal ratios were found for men and women. From the mean age of 14 years, an increase was found in the ratios for men, indicating a relatively larger increase of the trunk skinfolds compared to the skinfolds on the extremities. For women, only a very moderate increase in the ratios was seen over the entire period of study. Hence, men showed higher skinfold ratios from the mean age of 14 years onwards.

Table 2 presents the simple (correlational) and longitudinal (GEE) tracking coefficients of the single skinfolds and the trunk-extremity skinfold ratios for men and women. For men, the correlations for the single skinfolds between the mean ages of 13 and 16 years varied between 0.70 and 0.81 and for women between 0.77 and 0.83. The correlation coefficients between the measurements at the ages of 13 and 29 years of age varied from 0.35 to 0.54 for men (except for the not significant coefficient for the subscapular skinfold) and from 0.31 to 0.48 for women. For the trunk-extremity skinfold ratios, correlation coefficients between the mean ages of 13 and 16 years of age were found to be between 0.60 and 0.66 in men. For women, these coefficients were almost identical to each other: about 0.80. Both for the single skinfolds and the trunk-extremity skinfold ratios, and in both sexes, decreasing correlation coefficients were found with increasing periods between the measurements. Generally, correlation coefficients were slightly higher for women than for men.

Longitudinal tracking coefficients (β1), indicating the association between indicators at the initial measurement with the indicators at all other periods of measurement, varied from 0.56 to 0.67 in men and from 0.57 to 0.70 in women.
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**FIGURE 3** Development of the median of the (subscapular/triceps) skinfold ratio (dotted lines) and the (subscapular/triceps + subscapular) skinfold ratio (solid lines) for males and females between 13 and 29 years of age.

**FIGURE 4** Development of the median of the ((subscapular + supra-iliac)/(subscapular + supra-iliac + triceps + biceps)) skinfold ratio for males and females between 13 and 29 years of age.
Table 2 Sex-specific tracking coefficients between values at the first measurement (mean age 13 years) and four subsequent measurements of skinfolds and trunk-extremity skinfold ratios

<table>
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<tr>
<th></th>
<th>16 years</th>
<th>21 years</th>
<th>27 years</th>
<th>29 years</th>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>triceps</td>
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<tr>
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<td>0.36</td>
<td>0.27 (ns)*</td>
<td>0.16 (ns)</td>
<td>0.56</td>
</tr>
<tr>
<td>supra-iliac</td>
<td>0.80</td>
<td>0.40</td>
<td>0.30</td>
<td>0.35</td>
<td>0.62</td>
</tr>
<tr>
<td>(s/t) ratiob</td>
<td>0.60</td>
<td>0.53</td>
<td>0.48</td>
<td>0.53</td>
<td>0.63</td>
</tr>
<tr>
<td>(s/st) ratioc</td>
<td>0.61</td>
<td>0.58</td>
<td>0.53</td>
<td>0.58</td>
<td>0.66</td>
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<tr>
<td>(ss/ssbt) ratiod</td>
<td>0.66</td>
<td>0.48</td>
<td>0.37</td>
<td>0.43</td>
<td>0.58</td>
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<td></td>
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<tr>
<td>biceps</td>
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<tr>
<td>triceps</td>
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<td>0.53</td>
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<tr>
<td>supra-iliac</td>
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<td>0.33</td>
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<tr>
<td>(s/t) ratiob</td>
<td>0.80</td>
<td>0.68</td>
<td>0.61</td>
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<tr>
<td>(s/st) ratioc</td>
<td>0.81</td>
<td>0.68</td>
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<tr>
<td>(ss/ssbt) ratiod</td>
<td>0.81</td>
<td>0.63</td>
<td>0.58</td>
<td>0.53</td>
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</table>

* Longitudinal tracking coefficient, derived from GEE-analysis; other coefficients are correlation coefficients.

** DISCUSSION **

In this study, the development of single trunk- and extremity skinfolds and ratios contrasting fat on the trunk with fat on the extremities was described. Ratios of skinfolds, indicating a central pattern of body fat, were equal for both sexes at the mean age of 13 years. During adolescence however, a larger increase in these ratios became apparent in men and at the mean age of 29 years a central pattern of body fat was more pronounced in men than in women. In addition, tracking of the skinfolds and the trunk-extremity skinfold ratios was investigated. Using a technique for longitudinal data analysis, tracking coefficients were found to be about 0.6.

A major point of concern in studies considering a central pattern of body fat is the choice of indicators. Generally, two types of indicator are used: 1) circumference ratios, the waist to hip ratio (WHR) being the best known, and 2) ratios of skinfolds, contrasting subcutaneous fat on the trunk with that on the extremities. The most appropriate indicator can only be found after the pathophysiological mechanism, relating a central pattern of body fat to CVD morbidity and mortality, is clarified. In an often presented hypothesis for this mechanism, the amount of intra-abdominal fat is thought to play a key role. Using computed tomography, it was shown in adults that the WHR correlates slightly better with the amount of intra-abdominal fat than with indicators based on skinfolds. However, the WHR is not yet validated in youth and therefore indicators of subcutaneous fat remain of importance in longitudinal studies of body fat patterns from youth into adulthood.

A point of concern however, in the use of skinfold ratios is their relationship with the level of body fatness. Garn et al. reported a dependence of the ratio (subscapular/triceps) for body mass index (BMI; (weight [kg]/height$^2$ [m]). In order to control for this influence of the level of body fatness, simple tracking coefficients were recalculated as simple partial correlation coefficients between values at the initial and a subsequent measurement, corrected for BMI at the initial measurements. These partial correlation coefficients were only a maximum of 0.1 higher than the simple correlation coefficients for the separate skinfolds. For the trunk-extremity skinfold ratios, these differences appeared to be only a maximum of 0.05 higher. Probably, the influence of the level of obesity is more serious in populations consisting of relatively more obese individuals (for example, a BMI of ≥25.0 was apparent in only 19.2% of the males and 14.8% of females at the mean age of 29 years, which is below the average in the Dutch population).
Skinfold ratios imply an equal contribution of the skinfolds to the ratio, a concept that has the advantage of simplicity, but probably does not reflect the truth. Mueller et al. used a method, principal component analyses, in which loadings were given to the separate skinfolds in order to maximize the percentage of explained variance.\(^{28}\) However, for longitudinal data analyses, as for example tracking analyses, this would mean that tracking of the trunk-extremity component would be done on differently composed indicators. Obviously, this would pose problems in the interpretation of the results.

Comparable results in the literature were predominantly available for the period of adolescence. Based on data of several longitudinal growth studies, Cronk et al. reported a small decrease in trunk skinfolds in boys between the ages of 12.5 and 14–15 years.\(^{29,30}\) From this age onwards, increasing trunk skinfold thicknesses were seen while no increase was seen in thicknesses of extremity skinfolds for boys. In an overview of several studies, Malina et al. reported a pattern of increasing trunk-extremity skinfold ratios for males and moderate or no changes in these ratios in females during adolescence.\(^{31}\) This pattern, in agreement with our results, was also found in other studies.\(^{32}\) Hence, there appears to be a sexual differentiation in the development of a central pattern of body fat in adolescence.

Tracking studies of body fat patterns have been performed from childhood into adolescence, and to a lesser extent from adolescence into adulthood.\(^{33–35}\) In the Fels Longitudinal Study, age to age correlations were about 0.7 for adipose tissue thicknesses between the ages of 8 and 16 years.\(^{36}\) Roland-Cacher et al. found correlation coefficients for the ratio (subscapular/triceps) measured at the mean ages of 16 and 21 years of about 0.6.\(^{32}\) Correlations between adult values and measurements at the mean age of 13 years were 0.2 (men) and 0.4 (women).

Adolescence is a period characterized by biological maturation. It has been suggested that advanced skeletal maturation is associated with a more central pattern of body fat in adolescence.\(^{37}\) In the Amsterdam Growth and Health Study however, no effect of rapid or slow skeletal maturation was found on the development of a central pattern of body fat from adolescence into adulthood.\(^{38}\) In that study however, girls with a relatively early menarche showed a more central pattern of body fat compared to girls with a relatively late menarche in adolescence and adulthood. Hence, it seemed possible that differences in the stage of biological maturation would result in an underestimation of the tracking coefficients. Tracking coefficients, adjusted for the skeletal age at the first period of measurement, were a maximum of 0.07 higher for both sexes. Correlation coefficients for girls, adjusted for the age at menarche, were even more equal to the unadjusted correlation coefficients. Consequently, it could be concluded that biological maturation only had a minor effect on tracking of skinfolds and indicators of central patterns of body fat.

For the interpretation of the results of the tracking coefficients, a clear distinction needs to be made in the underlying aims of tracking research.\(^{39}\) From a preventive point of view, stability of a central pattern of body fat implies that individuals at risk can be identified at earlier observations. Hence, the tracking coefficient refers to the degree of success of screening at young ages in order to identify individuals with future risk values. This practical aim requires the measurement of skinfolds and trunk-extremity skinfolds and the subsequent calculation of the tracking coefficient to be done in circumstances similar to screening; without correction for measurement error or any other variable. From the results of this study, it could be concluded that tracking coefficients over the 17-year period of study were too low to emphasize screening of young individuals for a central pattern of body fat.

Drawing conclusions is less easy if tracking coefficients were calculated in order to investigate the natural development of a central pattern of body fat. In that particular situation, the aim of the study is to investigate the stability of the ‘real’ (‘genetic’) development of a central pattern of body fat, independent of measurement error and the influence of variables potentially changing patterns of body fat. Measurement error results in an underestimation of the real tracking coefficient, while the development of variables can either result in an over- or underestimation of the real tracking coefficient.

Suppose a change of body weight causes a change in trunk-extremity skinfold ratios and a high tracking coefficient was found for body weight (near 1.0). This would imply that tracking of a central pattern of body fat was at least partly caused by the stability of the natural development of body weight. Without taking into account the development of body weight, tracking coefficients of trunk-extremity skinfold ratios would be an overestimation of the real tracking coefficient. The opposite could occur for a determinant of change of the trunk-extremity skinfold ratios with a low or moderate degree of tracking. In this situation, the instability of this determinant would result in an unstable pattern of body fat. Not taking into account the development of this determinant of change would result in an underestimation of the real tracking coefficient. Hence, in
tracking analyses aimed at investigating the natural development of a central pattern of body fat, determinants of change of fat distribution should be taken into account. Potential determinants of change of a central pattern of body fat are physical activity, energy intake, smoking behaviour and alcohol intake.

In conclusion, an increase was found in trunk-extremity skinfold ratios in males, but not in females, from adolescence into adulthood. A moderate degree of tracking of patterns of central body fat exists from adolescence into adulthood. A moderate degree of tracking analyses aimed at investigating the natural development of a central pattern of body fat is in adolescence into adulthood. From a preventive point of view, tracking coefficients were too low to be of predictive value. In order to conclude that the natural development of a central pattern of body fat is in adolescence, careful search for determinants of change of this body fat pattern is required.

REFERENCES


(Revised version received June 1996)