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Clinical standards for growth in height of Belgian boys and girls, aged 2 to 18 years

The present paper presents the first clinical standard for growth in height of Belgian boys anf girls, based on purely longitudinal data. Growth charts are provided with centiles of height for age along with growth curves of the typical early, average and late maturing child in the population. These new standards show the classical features of cross-sectional standards, but above that, they also provide information about the variability in individual growth patterns, as a result of variation in maturation. Average adult height is 176.6 cm (SD = 6.3 cm) in boys and 163.3 cm (SD = 5.7 cm) in girls.
The representativity of these new standards with respect to the actual Belgian population has been by comparison with recent cross-sectional data, collected on a large number of subjects. These standards should be applied in all situations where interest lies in the evaluation of the normality of a child's growth pattern over some length of time and will therefore find their usefulness in clinical follow-up studies of growth.

Key words: Growth standards, longitudinal growth study, maturation.

Introduction

Population standards for growth are generally based on cross-sectional surveys in which children have been measured only once. Provided that they are constructed on a correctly designed and possibly stratified sample, cross-sectional standards give a representative estimate of mean height and some measure of the distribution of height at each age in the population (centile lines, for example). Therefore, the use of such standards should be limited to answering questions like: «Is a child's height at a particular age within the limits of normal variation of the population which he comes from?». They are also perfectly apt to check if the average growth pattern differs among various populations. However, problems arise when a physician wants to follow a child's growth over some length of time. Indeed, cross-sectional standards suffer from the fact that certain characteristics of the individual growth pattern are smoothed out. This is especially true for the adolescent growth spurt (Tanner, 1962), because there is a population variation of about 4 years in the age at which this phenomenon occurs among children of the same sex. By the fact that cross-sectional surveys cannot adjust for this phase-difference effect in timing of growth, it results that none of the centile lines, obtained in this way, are representative for the growth pattern of any of the children in the population (Tanner et al., 1966a, b). On the contrary, it would be rather abnormal if a child's growth pattern at puberty would exactly fit one of the centile lines. It was shown by Tanner (1951) that, particularly at adolescence, the correlation between height, measured at a particular age, and height, measured one year later diminishes.

Dynamic aspects of growth, such as individual growth patterns or changes in growth rate as a response to illness or subsequent treatment, can only be analyzed correctly, by using longitudinally-based standards, which, moreover, have been constructed in an appropriate way such as to show the variability in the true shape of children's growth curves. Longitudinal growth standards of that type have been published for the British (Tanner and

Whitehouse, 1976; Tanner et al., 1966a, b) and more recently for the American (Tanner and Davies, 1985) and Polish population (Susanne et al., 1987).

The aim of the present study is to present longitudinally-based standards of growth in height for Belgian boys and girls, together with some estimate of the variability in growth pattern at adolescence. These charts are meant to be used whenever interest lies in the evaluation of serial measurements of height, and hence will find applications in follow-up studies of children in a clinical context. As a matter of fact, since the charts also show the conventional centiles of height for age, they can also be used for purpose of health screening in the population. The representativity of the present standards is tested by comparison with recent data on height growth on the Belgian population (Vercauteren, 1984). Standards for growth velocity, based on the same longitudinal data are published by Hauspie and Wachholder (1987).

Material and Methods

The data of the present study comes from the Belgian Growth Study of the Normal Child (Graffar, 1958), which was part of a series of longitudinal growth surveys, in London, Paris, Stockholm, Zurich and Brussels, co-ordinated by the International Children's Centre in Paris (Falkner, 1961). The actual study was conducted between 1955 and 1975 and started with 259 boys and girls. All children were of Belgian nationality and were born in Brussels between 1955 and 1958. They belonged to representative distribution of socio-economic strata of the Belgian population. Detailed description of the socio-economic background of the sample was given by Graffar et al. (1956, 1961, 1962, 1965).

Children were measured at birth and then, regularly until 15 years of age, at their birthdays and in some periods also at half-birthdays. Most of those, seen at age 15, were remeasured at age 18 and some again in their late twenties. As in all longitudinal surveys, we also suffered from a considerable amount of drop-outs, so that we ended up with only 48 boys and 50 girls, who had enough data to determine their complete growth pattern with certainty. Measurements of height until the age of 18 years were taken according to standardized techniques (Falkner, 1961) and the growth curves were analyzed by using a mathematical model (see Appendix for details about methodology).

Results

The height for age centiles are given in Table 1 for boys and in Table 2 for girls. The growth charts are shown in Figure 1 for boys and in Figure 2 for girls. The boys' average height at age 18 years is 176.0 cm (SD = 6.5 cm), which is slightly below adult height as estimated by the mathematical model (176.6 cm with SD = 6.3 cm). The girls height at age 18 years is 163.3 cm (SD = 5.7 cm), which is equal to adult height as estimated by the mathematical model. So, it seems that by the age of 18 years, girls have in the average stopped growing, while boys still increase in length by about half a centimeter beyond that age. The average adult height of the 12 male subjects for whom additional data were collected in their late twenties, was 174.8 cm (S.D. = 7.5), which is not statistically significantly different from the above mentioned estimate of adult size.

The solid lines on the boys' and girls' charts correspond to the height for age centiles, which were obtained by cross-sectional analysis of our longitudinal data. They provide, as any other cross-sectional standards, some measure of the variability of height at each age

TABLE 1 - *Centiles of height (cm) for age (years), BOYS (Belgian Growth Study of the Normal Child, 1986).*

Age	P3	P10	P25	P50	P75	P90	P97
2.0	80.0	81.7	83.4	85.3	87.3	89.1	90.8
3.0	87.9	89.9	91.9	94.2	96.6	98.6	100.6
4.0	95.0	97.3	99.6	102.2	104.9	107.2	109.5
5.0	101.4	104.0	106.6	109.5	112.4	114.9	117.4
6.0	107.3	110.1	112.9	116.0	119.2	121.9	124.6
7.0	112.6	115.6	118.6	122.0	125.3	128.3	131.2
8.0	117.4	120.6	123.8	127.4	130.9	134.1	137.2
9.0	121.8	125.2	128.6	132.4	136.1	139.5	142.8
10.0	125.9	129.4	133.1	137.1	141.1	144.7	148.3
11.0	129.7	133.6	137.5	141.8	146.3	150.2	154.2
12.0	133.7	138.0	142.3	147.1	152.0	156.5	160.9
13.0	138.6	143.3	148.1	153.5	158.9	163.8	168.7
14.0	145.2	150.2	155.3	160.9	166.5	171.5	176.4
15.0	153.1	157.8	162.6	167.9	173.1	177.8	182.4
16.0	159.3	163.5	167.8	172.6	177.4	181.7	186.0
17.0	162.4	166.4	170.5	175.0	179.5	183.6	187.7
18.0	163.6	167.5	171.5	176.0	180.4	184.4	188.4

TABLE 2 - *Centiles of height (cm) for age (years), GIRLS (Belgian Growth Study of the Normal Child, 1986).*

Age	P3	P10	P25	P50	P75	P90	P97
2.0	78.7	80.5	82.5	84.7	86.9	88.9	90.8
3.0	87.0	89.3	91.6	94.1	96.6	98.8	101.1
4.0	94.5	97.0	99.5	102.3	105.1	107.6	110.1
5.0	101.1	103.8	106.6	109.6	112.6	115.4	118.1
6.0	106.9	109.9	112.9	116.1	119.4	122.3	125.2
7.0	112.1	115.3	118.5	122.0	125.5	128.6	131.7
8.0	116.8	120.2	123.6	127.4	131.2	134.5	137.9
9.0	121.1	124.8	128.5	132.7	136.9	140.6	144.3
10.0	125.4	129.4	133.6	138.3	143.0	147.2	151.4
11.0	130.1	134.6	139.2	144.4	149.6	154.3	159.0
12.0	135.9	140.8	145.6	151.0	156.3	161.0	165.8
13.0	142.7	147.2	151.6	156.6	161.5	165.9	170.2
14.0	148.2	152.0	155.8	160.2	164.6	168.5	172.4
15.0	151.0	154.5	158.0	162.0	166.1	169.7	173.3
16.0	152.0	155.5	159.0	162.8	166.7	170.2	173.7
17.0	152.4	155.8	159.3	163.2	167.0	170.4	173.8
18.0	152.5	156.0	159.4	163.3	167.1	170.5	173.9

and are, as such, perfectly appropriate to determine the relative position of a child's height at a particular age with respect to the population distribution in stature. Indeed, even if a child's height lies within the 3rd and 97th centile, that does not necessarily mean that the child's growth process is progressing normally. To be able to examine this latter aspect of growth, we need regular measurements of a child's height during his growth, in the way it is

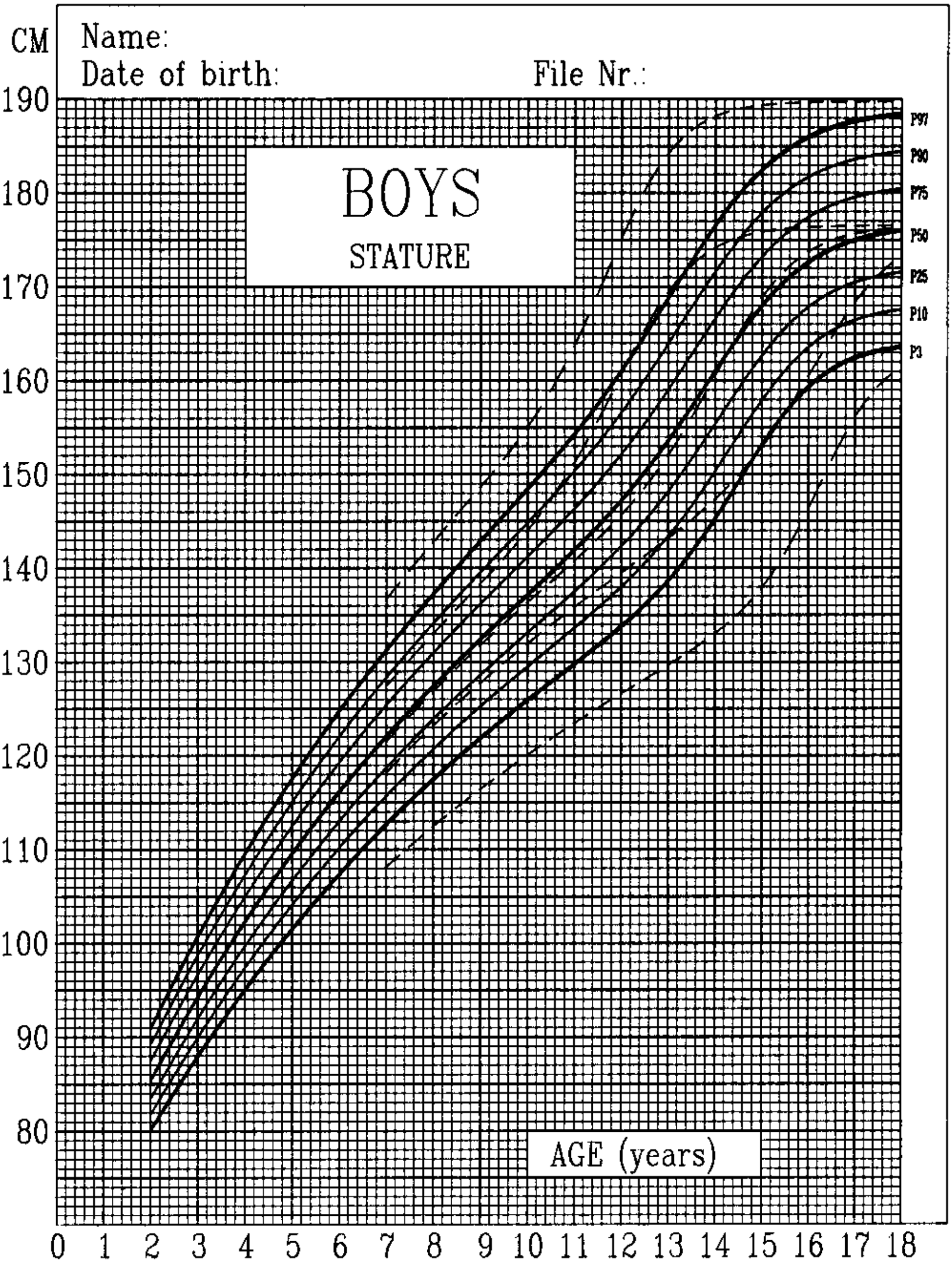

Fig. 1 - Centiles of height for age in Belgian BOYS (solid lines). The three inner dashed lines represent the typical early, average and late maturing child in the population. The upper and lower dashed lines correspond respectively to the P97 for early and P3 for late maturing boys.

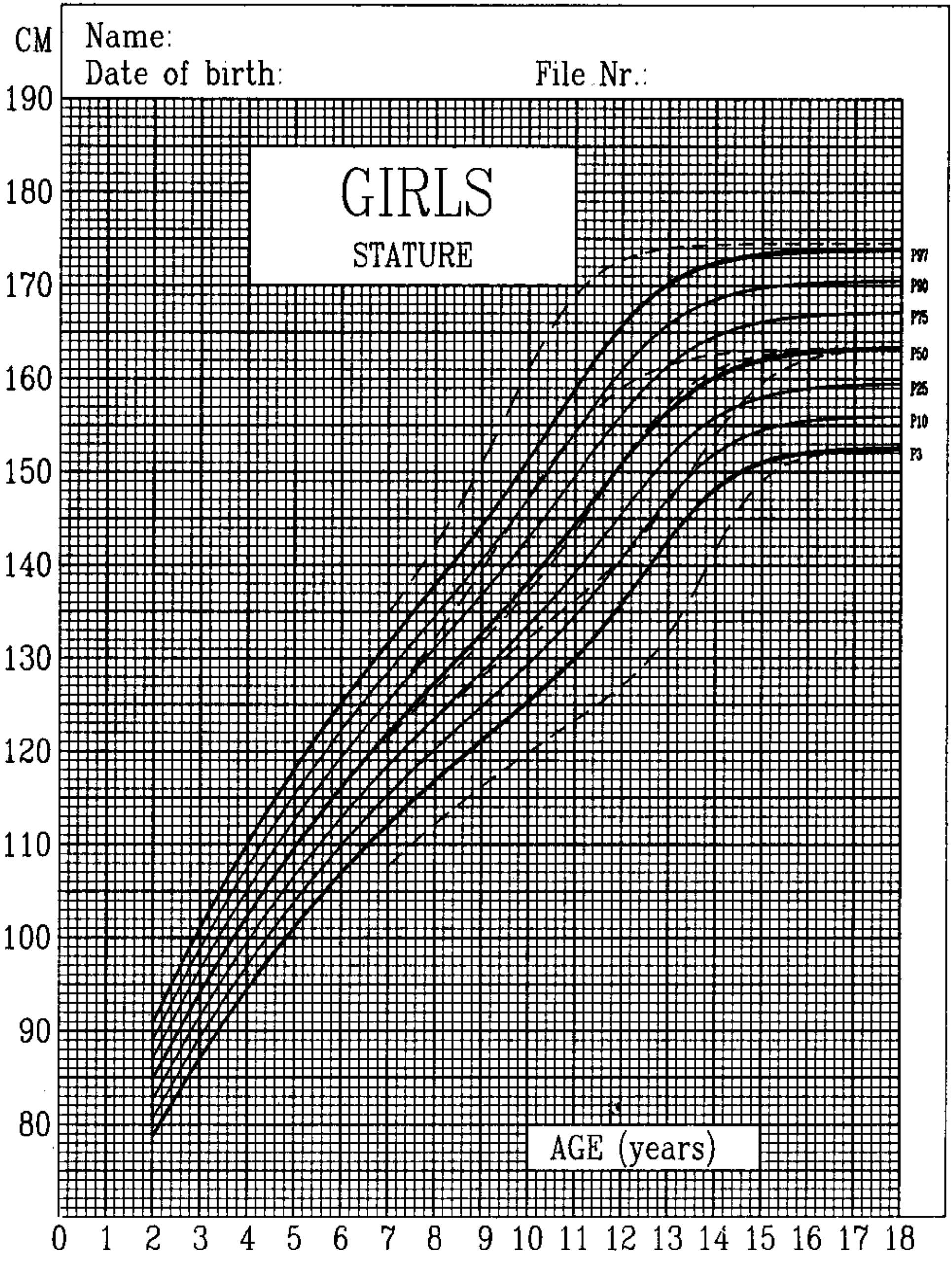

Fig. 2 - Centiles of height for age in Belgian GIRLS (solid lines). The three inner dashed lines represent the typical early, average and late maturing child in the population. The upper and lower dashed lines correspond respectively to the P97 for early and P3 for late maturing girls.

actually done in pediatric medical practice in Belgium (Pediatricians, Belgian National Child Organisation, School Health Centers). Normality of growth should be considered in terms of changes in size over time, rather than in terms of a static picture of a dynamic process. If, on the basis of the pattern of height for age on the distance charts, one observes important deviations from the centile lines, then one should examine the child's growth rate. Indeed, only detailed analysis of changes in growth rate on the basis of standards of growth velocity allow to answer that sort of questions (Hauspie and Wachholder, 1987).

Since all children have their own rythym or tempo of growth, they are for a particular chronological age not all at the same stage of their development process towards full maturity. Nevertheless, early maturers have in the average the same adult size as late maturers (Lidgren, 1976; Tanner, 1962), since their shorter growth period is largely compensated by a slightly higher prepubertal growth rate and a more intense adolescent growth spurt. Therefore, early maturers are in the average taller than late maturers during childhood as well as during adolescence.

In order to help interpreting this variability in the shape of individual growth curves, due to differential maturation, we have added to the charts the growth curves, of the typical early, average and late maturing child (the three inner dashed lines), who have their adult size equal to the population average. Applying methods, similar to Tanner and Davies (1985), we have constructed the typical early and late maturity curves with ages at peak velocity, respectively 2SD below and above the population average, i.e. 11.9 and 16.1 years of age in boys and 9.5 and 13.6 years of age in girls (see Appendix for details about methodology). They include about 95% of the variability in growth patterns of children who differ in maturation, but who are average in adult size. In addition, we have also drawn the 97th centile of the typical early and the 3rd centile of the typical late children (the two outer dashed lines). The typical average child has a growth pattern which is at all ages close to the 50th centile line, but with a definitely steeper slope in his growth curve at age 14.0 years in boys and 11.6 years in girls, which are the population averages for age at peak height velocity for both sexes. The 97th centile of the 2 SD early and the 3rd centile of the 2 SD late maturing children correspond to limits beyond which only 0.3% of all subjects in the population are situated. From the typical early and late maturity curves, it is clear that individual children do not follow a particular centile line throughout their growth period, but can undergo a shift in their growth pattern of as much as 20 centile units. Children can have their height at the 75th or 25th centile during childhood (pre-pubertal ages), but nevertheless reach the same adult height, simply because they are respectively very early or very late maturers. Deviations from centile lines are most marked during adolescence (pubertal ages) and are also more pronounced in boys than in girls. On the other hand, if a child is during childood at the 75th centile, but he is an average maturer, then he is likely to end up with an adult size close to the 75th centile as well. In such a situation the child is tall because he is constitutionally tall and most probably has tall parents. So, it is of utmost importance for a physician, to know what a child's maturational stage is, in order to be able to evaluate his growth retardation or advancement at a particular age, or to interpret the shape of his growth pattern. Evaluation of the development stage of the secondary sex characteristics during adolescence (Marshall and Tanner, 1969, 1970; Tanner 1962; van Wieringen et al., 1971) or the dental maturation during childhood (Demirjian et al., 1973) can be very informative. By far the most interesting measure of maturation, applicable throughout the entire period, is skeletal maturation, usually based on the osseus development of several bone centers, as seen in an X-ray of the hand and wrist (Greulich and Pyle, 1959; Tanner et al., 1975). By evaluating a child's growth in height with respect to his developmental age, like bone age for example, rather than in relation to his chronological age, it is possible to explain a great deal of the variation in his growth, which is due to his

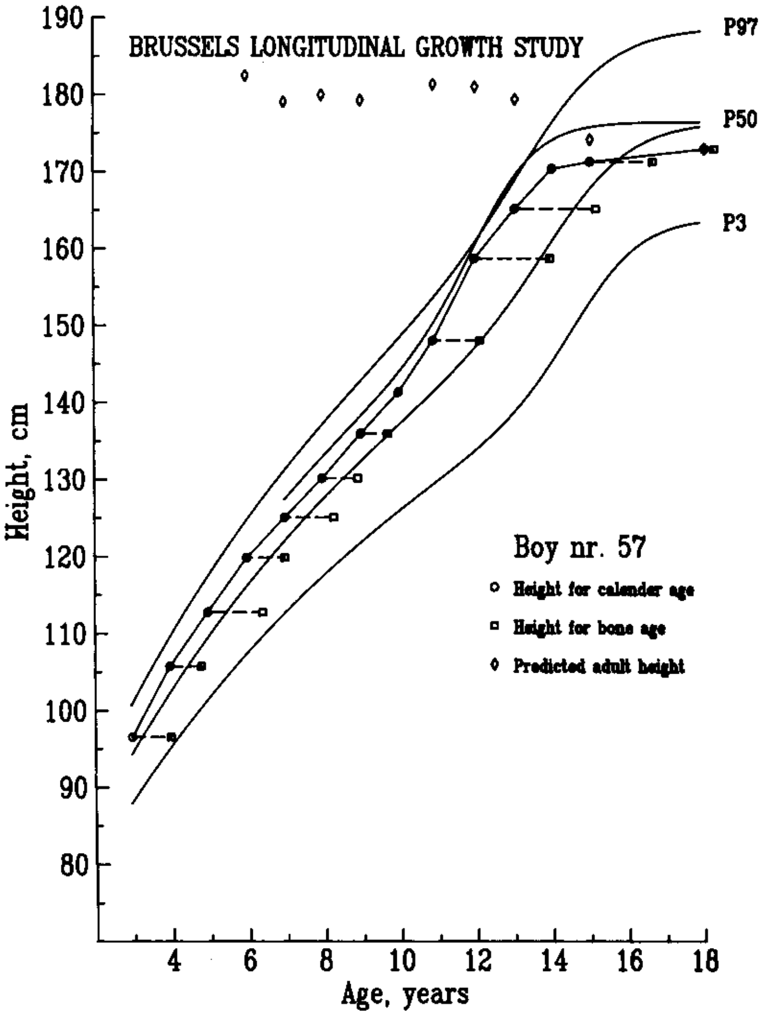

Fig. 3 - Plot of height for calender age and for bone age, prediction of adult height in boy Nr. 57, on a simplified version of the charts. The typical curve of the 2SD early maturing boys is also shown.

particular maturation rate. It is the deviation in growth which remains after removing the effect of maturation which is of importance in decision making about normality of growth.

The relationship between growth in height and maturation rate are clearly illustrated in the case study shown in Figure 3 where the height for age measurements of an early maturing child from our sample (Boy Nr. 57) are plotted (circles) on a simplified version of the charts, including the typical curve for the 2SD early maturing children. Age at peak velocity in this boy was estimated by the Preece Baines model at 11.8 years and happened to be 2SD earlier than the average age at peak velocity in our sample (Hauspie and Waccholder, 1987). His height is constantly above average during pre-adolescent years. At puberty, his growth pattern undergoes an upwards shift and he reaches about the 90th centile line at age 12 years. His growth then decelerates very rapidly and he reaches a body length of 173.0 cm at age 18 years, which is between P25 and P50. The shape of his growth pattern is more similar to the curve of the 2SD early children in the population, than to the 50th centile line. However, although the height of this child was, at almost all ages during his growth cycle, above the 50th centile, it can be seen from the plot of his height for bone age (TW2-bone age, Tanner et al., 1975), that he was not constitutionally tall (squares), but that his greater height is due to the fact that he was about 1 year early in maturation during pre-adolescent years and as much as two years at age 13 and 15 years. His predicted adult height, based on his RUS-bone age (equation 1 of the TW Mark II system, Tanner et al., 1983), fluctuates around 180 cm until 13 years of age. However, beyond that age, rate in maturation seems to progress faster than does growth in height, resulting in a finally lower potential. An analysis of the growth velocity of this boy is given by Hauspie and Wachholder (1987).

Careful control of the evolution of height growth in relation to skeletal maturation is an important issue in clinical follow-up studies, because it allows to estimate to what extent a disease or a medical treatment is affecting the child's growth potential.

Discussion

The present charts are based on part of the data that was also used to construct previously published standards for growth in height from age 1 month to 15 years (Emery-Hauzeur et al., 1974; Graffar and Wachholder, 1976; Wachholder, 1976; Waccholder and Graffar, 1973). However, these older standards were based on a cross-sectional analysis of the longitudinal data of all subjects, present in the survey. In that respect these standards were subject to the same limitations as any other cross-sectional growth standards. The advantages of the present standards are that the age range is extended until 18 years and that these new charts provide information about the variability in true individual growth patterns, which are the result of the variation in maturation rate or tempo of growth. The present longitudinally-based standards are unique for the Belgian population.

Since longitudinal growth studies are always based on fairly low numbers of subjects, one needs to carefully check if the actual sample can be considered as representative of the population that it comes from. For that purpose, we have compared the actual data with recent cross-sectional material, which is representative for the Belgian population (Vercauteren, 1984). This latter study is based on an analysis of growth in height of 2093 boys and 2084 girls of Belgian nationality, living in Brussels and measured between 1980 and 1982. Comparison of mean height at each age, by means of t-Student tests did not reveal significant differences between this latter study and the actual longitudinally-based standards. Figure 4 shows the 50th centile for boys and girls from the present study, together with the mean height's from Vercauteren's study, plotted at each age. The average absolute difference in height, calculated over all ages is 3 mm in boys and 5 mm in girls. The differences in adult size are even smaller and also not significant: adult boys in the present study are in the average 2 mm smaller than those observed by Vercauteren, while our adult girls were in the average only 1 mm smaller. Despite the fact that it was shown that there is a significant secular trend towards greater height for age between 1966 and 1984 (Vercauteren and Susanne, 1985), we still find that growth in height in our sample is not significantly different from the actually attained height in Belgium. This might be explained by the fact that the 98 subjects selected for the present study constitute a group of significantly higher socio-economic background than the 259 boys and girls at the start of the longitudinal survey (Corten, 1984; Wachholder, 1976). This shift towards higher socio-economic level among those subjects who stay for a longer period in a longitudinal survey is a rather

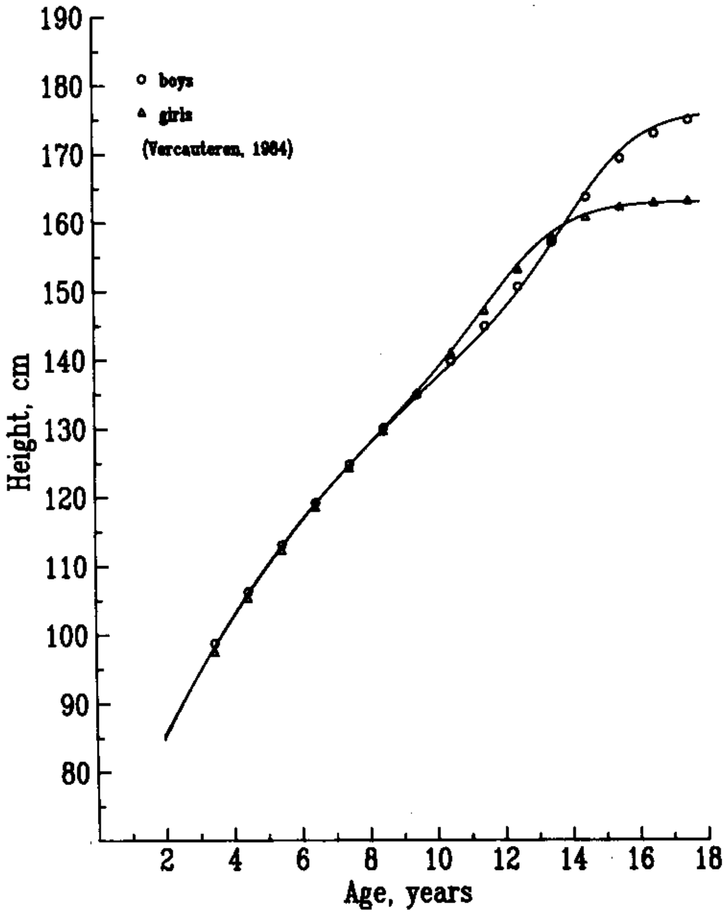

Fig. 4 - Comparison of the 50th centile for height of the present longitudinal standards with the mean heights for age in a recent large-scale cross-sectional growth study (Vercauteren, 1984).

commonly encountered phenomenon. So, it seems that although the children in our sample were examined about a generation ago, they still form a representative group for the actual Belgian population, as far as growth in height is concerned.

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Appendix

Estimation of centiles

The centiles were estimated by calculating cross-sectional means and standard deviations of height at each age. Height at each age was itself estimated by fitting the Preece Baines model 1 function to the serial data of height for age in each individual (Preece and Baines, 1978). The function takes the form:

$$y = h_1 - \frac{2(h_1 - h_\theta)}{\exp\{s_0(t-\theta)\} + \exp\{s_1(t-\theta)\}} ,$$

where y = height (cm), t = age (years) and h_1, h_θ, s_0, s_1, and θ are the five function parameters. It was previously shown that this model describes well the individual growth curve from childhood to adulthood. The Kolmogorov-Smirnoff test (Siegel, 1956) revealed, that in boys as well as in girls, the distribution of height at each age did not show significant departures from normality (Gaussian). Hence, the centiles were calculated parametrically and the 50th centile values also corresponds to the means.

For the purpose of producing smooth centile lines on the charts, we have then fitted the same model to each set of centile values. It was shown by Vercauteren (1984), that Preece Baines model 1 also successfully fitted the average patterns of height for age. All curve- fitting was done by an efficient non-linear least squares technique (Nie et al., 1975). The average residual variance obtained for the fits to the centile values was rather small: 0.06 in boys and 0.01 in girls. The centile values shown in Tables 1 and 2 are Preece Baines model 1 adjusted values.

Typical average and late maturer curves

Our typical curve is in fact the mean-constant curve obtained by feeding in the mean values of the respective function parameters into the model. It is well known that mean-constant curves do not suffer from the smoothing out effect at adolescence that undergo all cross-sectional average growth patterns, but represent the average typical child in the sample, being average for characteristics, such as age, size and velocity at take-off, age, size and velocity at the peak of the pubertal spurt, adult size, etc. (Hausoie, 1986). Therefore, it makes sense to consider the mean-constant curve as a more representative picture of the average growth in the sample than the average cross-sectional growth pattern.

The techniques used to construct the typical early and late maturer curve were derived from the methods recently used by Tanner and Davies (1985). These curves are plots of the Preece Baines model 1 function with parameter values which were obtained through regression of the 5 function parameters on age at peak velocity in the sample of boys and girls respectively. Although h_1 (which is actually adult size) showed a small, but not significant, positive correlation with age at peak velocity, we have set h_1 in early and late maturers equal to the average of h_1 in the sample. This decision was made on the basis of no relationship between tempo of growth and adult size (Tanner and Davies, 1985). The values for the parameters h_θ, s_0, s_1 and θ for the 2SD early and 2SD late maturers were estimated from their regression on age at peak velocity. Values of the 97th centile for early and the 3rd centile for the late maturers were obtained by respectively adding the value of $1.88 \times SD$ to the early maturers curve and subtracting 1 the value of $1.88 \times SD$ from the late maturers curve. The SD's used at each age were those obtained for the cross-sectionally calculated centiles. We have obtained smoothed curves for these latter centile lines by fitting the same model to the calculated yearly centile values.

All calculations were performed at the University of Brussels Computer Center (CDC, Cyber 170/750).