Eur J Pediatr (2001) 160: 163–167 © Springer-Verlag 2001

ORIGINAL PAPER

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Canalisation in human growth: a widely accepted concept reconsidered

Received: 25 July 2000 / Accepted: 11 October 2000

Abstract According to the concept of canalisation, infants and children stay within one or two growth channels, and therefore, any crossing of height centiles always warrants further evaluation. In view of evidence against this concept we re-investigated the variability of individual growth in the First Zürich Longitudinal Growth Study. The investigation is based on height measurements of 232 children (112 females, 120 males) measured at annual intervals during childhood and half-yearly during adolescence. Height data were transformed into height standard deviation scores (SDS) and *canalisation* defined by the width of an individual's growth channel, i.e., by the differences between maximum and minimum height SDS, in the individual series of measurements. Many subjects of the First Zürich Longitudinal Growth Study crossed numerous centiles with patterns that often seemed to show characteristic features. For approximately two thirds of the subjects, the SDS channel during the whole growth process covers more than one SDS. In childhood, between the age of two and age of minimal height velocity, only about one fourth of the subjects have an SDS channel below 0.5, indicating acceptable canalisation. During childhood, growth in boys appeared slightly more canalised than in girls ($P = 0.02$).

Conclusion The present investigation does not support the concept of strict canalisation of individual growth. We suggest to consider crossing of centiles a normal event in child development, though in a clinical setting crossing centiles should still be taken seriously, at least at first until a medical cause for this has been excluded.

Key words Child growth · Canalisation · Growth velocity · Longitudinal growth

Introduction

"Typically, infants and children stay within one or two growth channels. This *canalization* attests to the robust control that genes exert over body size" (Nelson, Textbook of Pediatrics, p. 58, 1999 [1]). The idea of growth *canalisation* or *parallel-to-centile* growth is not new, and was first published by Tanner [8] who showed that the correlation between adult height and heights of the same individuals as children, ranges between 0.7 and 0.8 [8]. Only during the first two years of life, infants are allowed to "cross centiles" and to search for their later individual growth channel. Thereafter, "children normally grow with remarkable fidelity relative to the normal growth curve", and physicians are supposed to note "abnormal height velocity" since it "always warrants further evaluation" (Williams, Textbook of Endocrinology, p. 1430, 1998 [10]). Even when illness or starvation temporarily interrupts the process of normal height acquisition, catch-up growth usually seems to compensate for these losses [2] leading stature back to the original centile. Catch-up growth has been considered one of the strongest examples of developmental canalisation in man [7].

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Yet, there is substantial evidence against this concept. Children with accelerated or retarded developmental tempo may deviate considerably from average height [9], and cyclic changes of growth velocity have been observed during pre-puberty [3]. Since most growth standards are derived from cross-sectional studies and show a much broader and plumper pubertal section than for most individuals, it is obvious that during puberty artificial deviations from centiles appear when plotting the individual stature measurements onto cross-sectional centiles. But, the same effect is already noticeable before puberty, and particularly obvious in advanced and in delayed children who during several years tend to cross the reference centiles. Most clinicians are aware that healthy children often cross height centiles without any apparent medical reason. These and other more anecdotal observations have encouraged us to re-investigate the variability of individual growth, and we have chosen the data of the First Zürich Longitudinal Growth Study [4–6].

Material and methods

The present investigation is based on height measurements of 232 children (112 females, 120 males) of the First Zürich Longitudinal

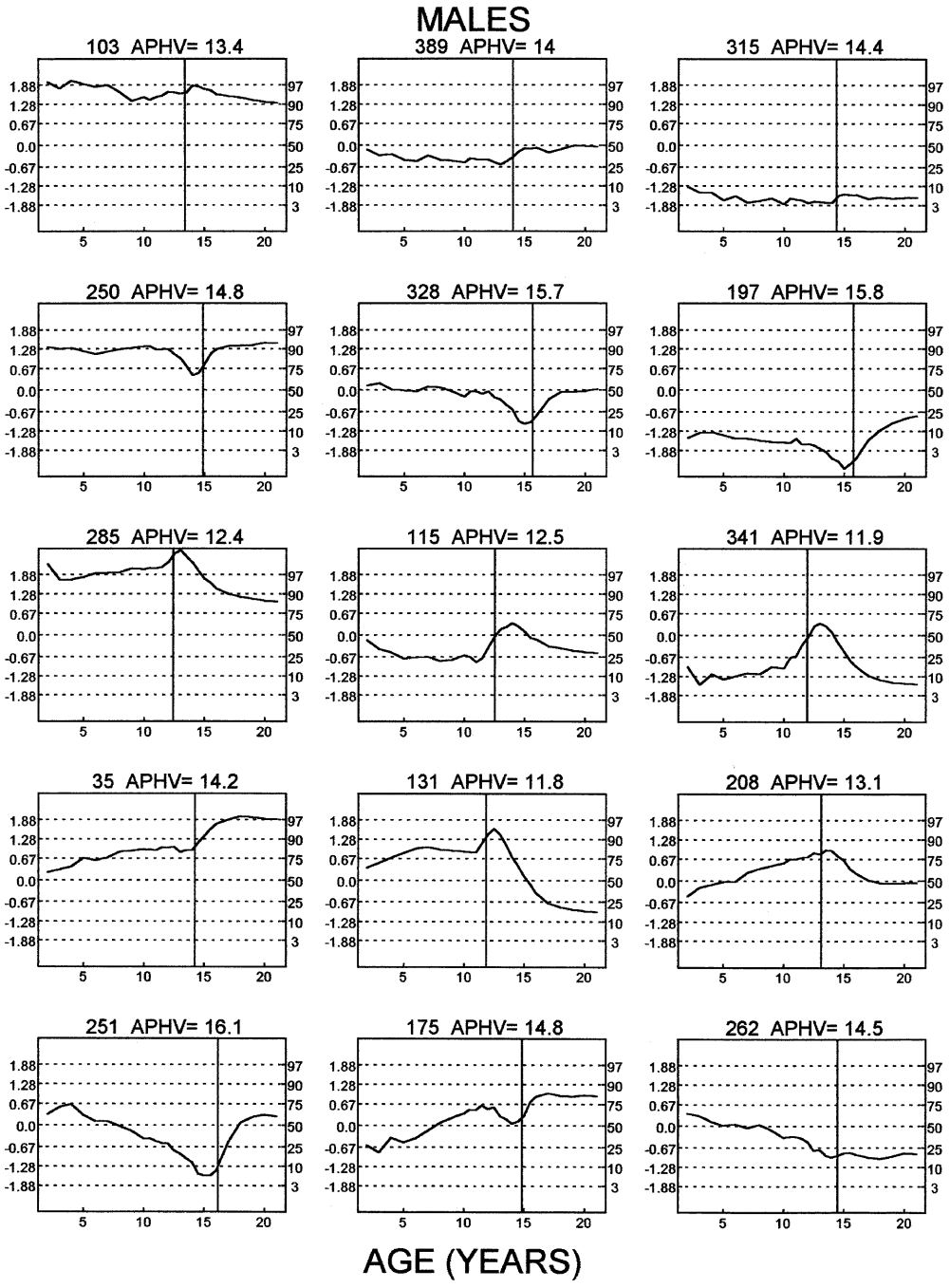


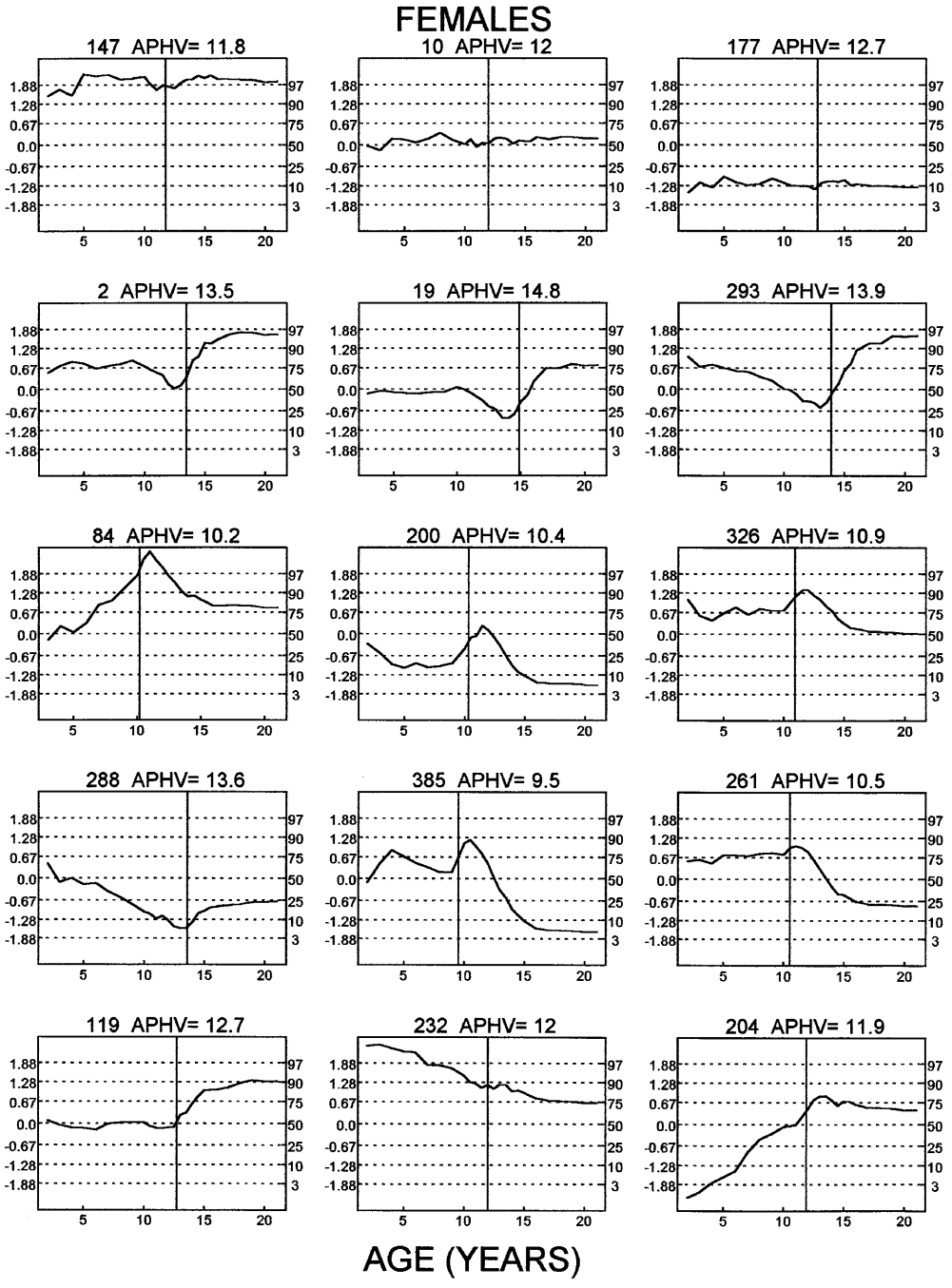
Fig. 1 Height SDS (numbers on the left) and height centiles (numbers on the right) of a selection of 15 male and 15 female individuals of the First Zürich Longitudinal Growth Study [6]. The numbering refers to the original numbering of the study cohorts. Ages at peak height velocity (APHV) are indicated by vertical bars, and given in decimal years

Growth Study. The children were measured at birth, and at 1, 3, 6, 9, 12, 18, and 24 months of age. Thereafter, measurements were made at annual intervals up to the age of 9 (girls) or 10 years (boys) (childhood). Half-annual measurements were obtained afterwards (adolescence), until yearly increments in stature had fallen below 0.5 cm, when yearly measurements were resumed and continued until the height increment was less than 0.5 cm in two years. The height data were transformed into height SDS (SDS = standard deviation score, SDS of a stature measurement is calculated by dividing the difference between the measurement and the corresponding population mean by the population standard deviation, at any given age) using table of means and standard deviations provided in Prader et al. [6]. Thus, 232 series of height SDS were obtained. Because canalisation of growth is supposed to occur after the age of two, we limited the investigation to the age range from 2 to adulthood.

Prepubertal SDS are understood to cover, individually, the period between age 2 and Age of Minimal Height Velocity (AMHV) as presented in Gasser et al. [4].

Since the term *growth channel* has never been satisfactorily explained, we defined *canalisation*, by the width of an individual's growth channel, i.e., by the differences between maximum and minimum height SDS in the individual series of measurements. For example, when an individual's body height ranged between SDS = −0.86 and SDS = +0.26, the width of his/her growth channel is 1.12 SD. Standard Deviation Scores and their change reflect better the position of a subject and his/her change of position within the reference, than percentiles. It must be noted, that an SDS channel of 1 implies, for a child of average size, a crossing of about 40 centiles and of up to 30 centiles for tall and short subjects.

Fig. 1 (Continued)



Results

Figure 1 exhibits a selection of 15 female and 15 male series of height SDS. The variability of individual patterns is evident. In order to better observe the influence of the developmental tempo, APHV is added. The first row contains growth patterns of children who keep their centiles during the whole growth process; these children obey the traditional view of *parallel-to-centile* growth, but they are the exception. The next two rows show children, who cross the centiles downwards, usually due to a late pubertal spurt, or upwards, because of an early spurt; most of these children tend to regain their childhood centile. The last two rows contain miscellaneous patterns, with irregular centile crossing and permanent deviations from the initial centile. Particularly the latter demonstrate growth patterns not interpretable by simple deviations in the timing of puberty.

Table 1 shows the absolute number of girls and boys distributed according to the width of their SDS growth channel, considered first over the whole growth period, and during childhood. For about two thirds of the subjects, boys and girls, the SDS channel during the whole growth process covers more than one SDS. Between the age of two and AMHV, only about one fourth of the subjects have an SDS channel below 0.5, indicating acceptable canalisation.

During childhood, growth in boys appeared slightly more canalised ($P = 0.02$, Wilcoxon and Chi-square test).

Discussion

In view of evidence against the traditional concept of *canalisation in child growth*, we re-investigated height growth between 2 years of age and adolescence in 232 children of the First Zürich Longitudinal Growth Study. First, we had to define the terms *canalisation* and *growth channel*. These terms appear to be used synonymously with growth parallel to a population centile or height SDS line, but they have never been precisely defined. We decided to describe *canalisation*, by the width of an individual's growth channel, i.e., by the differences between maximum and minimum height SDS that occurred in the corresponding series of measurements. This implies that we describe longitudinal growth mainly by parameters derived from cross-sectional data. This is not unproblematic. Due to the large inter-individual variability in growth tempo, this causes artefacts, particularly during puberty. Height SDS of children with early onset of puberty (APHV at an early age), tend to shift upwards when their pubertal growth spurt starts, and to decline later (2nd row of Fig. 1a, b). Height SDS of children with late onset of puberty (APHV at a late age), tend to drop, but often catch up when their pubertal growth spurt starts (3rd row of Fig. 1). This was described previously [9], but the magnitude of this phenomenon remained unclear.

We decided to describe growth channels by height SDS rather than by centiles. The importance of centiles and centile crossings depends on whether a child shows average height, or whether it is tall or short. Stature crossing from the 60th down to the 40th centile is certainly different in terms of clinical importance, than crossing from the 21st down to the 1st centile though the width of the growth channel is 20 centiles in both cases. If an individual's height is close to average height, centiles tend to magnify the aberration from *parallel-to-centile* growth; whereas in tall or short individuals (e.g., male subjects #103, #315 and female subject #177 in Fig. 1), they tend to underestimate this aberration, as the growth pattern becomes *compressed* at either end of a centile distribution. This is different when using height SDS that more clearly depict aberration from *canalised* growth also in the tall and in the short child.

The present investigation does not support the general opinion about canalisation of individual growth. Most Zürich children, all of them healthy, crossed many height SDS and centile lines, not only during adolescence, but also before, with little evidence for strict canalisation of growth. The extent to which these deviations from canalised growth are caused by genetic mechanisms, and/or merely reflect environmental changes requires a more detailed analysis of the incremental pattern of human growth.

In conclusion, we consider crossing centiles a normal event in child development, though in a clinical setting crossing centiles should still be taken seriously, at least at first until a medical cause for this has been excluded.

Table 1 Number of girls and boys distributed according to the width of their SDS growth channels, between the age of 2 years and adulthood, and prepubertally

Height SDS	Age 2 to adulthood		Age 2 to AMHV	
SDS	Girls	Boys	Girls	Boys
< 0.5	0	4	21	36
0.5–0.99	39	42	68	65
1.0–1.49	45	51	17	16
1.5–1.99	18	18	5	3
2.0–2.49	7	4	1	0
2.5–2.99	2	1	0	0
3.0 and more	1	0	0	0
Median SDS	1.1	1.1	0.71	0.63
	ns		$P = 0.02$	

Acknowledgements This study was kindly supported by Deutsche Gesellschaft für Auxologie. This work was supported by the Swiss National Science Foundation (Grant No. 3200-045829.95-2).

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