Human Reproduction Update, Vol.7, No.3 pp. 287–291, 2001

Trends in pubertal development in Europe

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The secular changes in growth and maturation can be seen as indicators of socio-economic and health status. In most European countries the age of onset of puberty and of menarcheal age has been decreasing during the past few decades. The duration of puberty seems also to decrease, though few studies provide sufficient data to support this postulation. The four Dutch nationwide growth surveys are useful examples assessing the secular trend in pubertal development over the past 45 years. Genetic and environmental factors contribute to the secular changes. Environmental factors seem to be the most important. Recently, attention has been given to substances with oestrogen-like actions that are present in nutrients. The possible role of these substances in growth and maturation is discussed.

Key words: menarche/onset of puberty/phyto-oestrogens/secular trend

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Introduction

Secular changes in growth and development should be regarded as indicators of socio-economic and socio-hygienic condition and of a population's state of health. The term 'secular trend' is often used to describe a slowly continuing change in growth and development over successive generations living in the same territories. Since these changes can be positive, nil or negative, the term 'secular changes' is preferred (van Wieringen, 1986), but both terms will be used interchangeably in this text.

During the course of the past two centuries a striking increase of mean stature and an earlier sexual maturation has been observed in all countries in Europe (Bodzsar, 1998). However, this has not occurred during the same period in every European country. Both genetic and environmental factors result in population differences. The same environmental factors will not affect all children in the same manner, as their genetic sensitivities will differ (Susanne and Bodzsar, 1998). These secular changes towards a taller stature, heavier body weight and earlier maturation are predominantly linked to improvements in nutrition and health (Susanne and Bodzsar, 1998). Therefore, the growth of a population can be described as 'a mirror of conditions in society' (Tanner, 1992). However, secular changes may slow down and even become reversed. Indeed, negative trends have been observed in periods of socio-economic problems, for example during the second world war.

Observations of no change in the tempo of growth might be explained by cessation of improvement of environmental conditions, or that these already allowed the genetic potential for growth to be fully expressed.

In The Netherlands, in 1955, 1965, 1980—and recently also in 1997—several large cross-sectional nation-wide growth studies have been carried out (de Wijn and de Haas, 1960; van Wieringen *et al*., 1968; Roede and van Wieringen, 1985; Fredriks *et al*., 2000a). In these studies, next to growth data, reference curves for menarcheal age and the stages of secondary sex characteristics were estimated. In the following sections these data will be compared with the secular changes in several European countries, and potential mediators of the process of secular trend highlighted.

Secular trend in the onset of puberty

The onset of puberty is mediated by the increase in pulsatile LH release by the pituitary, resulting in the production of male or female sex steroids that initiate the secondary sexual characteristics. There are many hypotheses regarding the primary event that causes activation of the hypothalamic gonadotrophin-releasing hormone (GnRH) pulse generator. An interesting hypothesis is that leptin, produced by human adipocytes, interacts

via several neuropeptides as a permissive factor for the onset of puberty (Flier, 1998), thus connecting an aspect of body composition with the onset of puberty.

During the Middle Ages in Europe pubertal onset occurred around the age of 14 years, and became delayed until a markedly older age (17–18 years) at around the turn of the 19th century (Backman, 1948). In the last century the onset of puberty progressively shifted back towards younger ages in several European countries, with a levelling off in the last decades. A comparison of average age at the onset of puberty [breast stage 2 (B2) in girls and genital stage 2 (G2) in boys according to published standards (Tanner and Whitehouse, 1976)] in various European studies is shown in Table I.

In The Netherlands, comparison of the results of the fourth nation-wide growth study with those of the three previous studies shows that the mean height of Dutch children, adolescents and adults (who in 1980 were already among the world's tallest) has further increased during the past 17 years (Fredriks *et al*., 2000a) (Table II). Usually, a positive secular growth change is accompanied by an advance of sexual maturation. However, in the Dutch boys the median age at G2 tended to increase during the past 30 years. In girls, the age of onset of puberty (age at B2) declined between 1955 and 1980, but tended to occur slightly later in the most recent study (Table I). The pubertal stages of Stockholm schoolchildren in 1980 were reported and compared with two earlier studies in the same area (Table I) (Lindgren, 1996). The girls in the 1980 study were somewhat earlier in terms of breast and pubic hair development than those investigated in 1970 and 1975, while the boys studied in 1980 entered G2 earlier than those studied in 1970. Thus, during the last decades the tendency of an earlier start of puberty levelled off or even came to a halt in some European countries.

Secular trend in tempo of puberty and age of menarche

Tempo of puberty

The duration of puberty can be defined in several ways, for example as the interval between B2 and menarche or B5 stage in girls, and between G2 and G5 stages in boys. In this review we use for girls the period between B2 and B5, and for boys between G2 and G5. It should be noted that data from cross-sectional studies result in longer intervals than compared with data from longitudinal studies.

From the different surveys it becomes clear that the secular trend towards earlier onset of puberty is accompanied by a decrease in the duration of puberty. Few studies show all stages of sexual maturation from the onset of puberty to the last stage; thus we included only those studies providing complete data. A summary of maturation data from four countries in northern Europe is shown in Table I.

From Table I it can be concluded that there is a secular trend towards a higher tempo of sexual maturation in girls. A similar trend can be assumed in boys, but only the Dutch data support this assumption. Minimal data exist on pubertal development in boys due to the lack of a marked indicator, as is menarche in girls. Only a few studies used spermarche as indicator for male puberty (Susanne and Bodzsar, 1998). Some reports are available on peak height velocity (PHV) in boys, but it is difficult to estimate these data from cross-sectional studies; consequently, a comparison to estimate a secular change can be assumed to be inaccurate (Hauspie *et al*., 1996). Factors that determine the tempo of puberty are not known. Clinical observations in children on growth hormone (GH) treatment and in several forms of early pubertal development suggest a role of the GH–insulin-like growth factor (IGF) axis (Fontoura *et al*., 1989; Rekers-Mombarg *et al*., 1999).

A shorter duration of puberty can, in theory, cause less pubertal height gain, unless growth velocity is higher during that shorter period (Bourguignon, 1988).The data on the secular increase in final height in the same periods as in which duration of puberty decreases, however, do show that either a higher stature at start of puberty or sufficient pubertal growth in a shorter period is obtained. It was reported that the largest part of the secular increase in adult height was established in childhood and was due to an increase in leg length (Hauspie *et al*., 1997).

Methodological aspects of the assessment of age at menarche

In order to compare the different studies on final height and age of

Table I. Pubertal maturation (years) in various European countries

Country/ Year of study	Girls			Boys			Reference
	B2	B5	B2–B5	G2	G5	G2–G5	
Netherlands							
1965	11.0	15.2	4.2	11.0	15.85	4.9	Wieringen *et al*. (1968)
1980	10.54	14.21	3.7	11.33	15.33	4.0	Roede and Wieringen (1985)
1997	10.72	14.34	3.6	11.45	15.30	3.8	Fredriks *et al*. (2000a)
Sweden							
1970	11.0	15.6	4.6	12.2	15.1	2.9	Derived from Lindgren (1996)
1980	10.8	14.8	4.0	11.6	15.1	3.5	Lindgren (1996)
England							
1960	11.2	15.3	4.1	11.6	14.9	3.3	Derived from Lindgren (1996)
1975	0.8	14.0	3.2	–	–	–	Derived from Lindgren (1996)
Switzerland							
1970	10.9	14.0	3.1	11.2	14.7	3.5	Derived from Lindgren (1996)

Most studies do not provide SD or SE, but give percentage ranges.

menarche, some methodological issues should be addressed. First, the quality of the survey in terms of the composition of the study population, its representativeness for the whole population, and a balanced distribution of all age groups should be considered (Fredriks *et al*., 2000a). Second, an assessment of the age of menarche has to be made. In this respect, several methods can be used. One is the 'status quo' method where it is asked whether or not the girl had had her first period; another method is to ask at what age menarche occurred. The latter 'recall method' was compared with the status quo method and resulted in comparable age at menarche (Henneberg and Louw, 1995). The status quo method is preferred in most studies however, as it was shown that the longer the recall period the more inaccurate was the estimation of menarcheal age (Koo and Rohan, 1997).

Changes in age of menarche

Many studies address the age of menarche as a marker for the timing of puberty. It is well known and a worldwide phenomenon that there is a difference between urban and rural regions in menarcheal age, with the urban girls having their menarche earlier than rural girls (Indian Council of Medical Research, 1989; Bielicky and Hulanicka, 1998). In Figure 1 a summary is shown of data from several growth studies providing data on menarcheal age over time. The largest decrease in the age of menarche was observed until the end of the 1970s and in the early 1980s. Thereafter, in some countries there was a continuous small decrease in the age at menarche (The Netherlands, Germany, Bulgaria), while an increase in the age at menarche was seen in Italy and Croatia. Age at menarche has not changed recently in Belgium and Norway (Hauspie *et al*., 1996).

The observation of a decreasing age of menarche should be interpreted with care. The decrease in numbers of late maturers was the most marked change observed (Hauspie *et al*., 1996; Bodzsar, 1998; Fredriks *et al*., 2000a). This phenomenon can contribute to a decrease in mean age and in the variability around the mean. One might speculate that the number of late maturers is a sensitive indicator of the effect of final changes in socio-economic and health status. The cause of the reduction in number of late maturers might be the increasing awareness of delayed puberty and better treatment options available.

Although the age at menarche is falling, it appears that individual size at menarche (based on body weight) underwent only minor changes (Foster and Nagatani, 1999). This may lead to the hypothesis that the earlier occurence of menarche is the result of the optimalization of growth so that the minimal body size (needed for menarche) is achieved at an earlier age. This may explain why the decreasing age of menarche is not accompanied by a decrease in final height, as happens in case of precocious puberty (Sigurjonsdottir and Hayles, 1968)

Table II. Final height, menarcheal age and change in menarcheal age per decade in Dutch girls by year of growth study

	1955	1965	1980	1997
Final height (cm)	163.0	166.3	168.3	170.6
Menarche age (years)	13.75	13.40	13.28	13.15
Observed shift per decade (years)	–	–0.35	–0.08	–0.08

Mediators in secular change in timing and progression of puberty

The age at onset of puberty and menarche is determined by genetic and environmental factors (Treloar and Martin, 1990). The relative contribution of each of these is difficult to assess. Most likely, the secular trend towards earlier occurrence of pubertal onset and menarche is mainly due to environmental factors (Lindgren, 1998) such as increasing socio-economic conditions, better health care and prevention (Hauspie *et al*.,

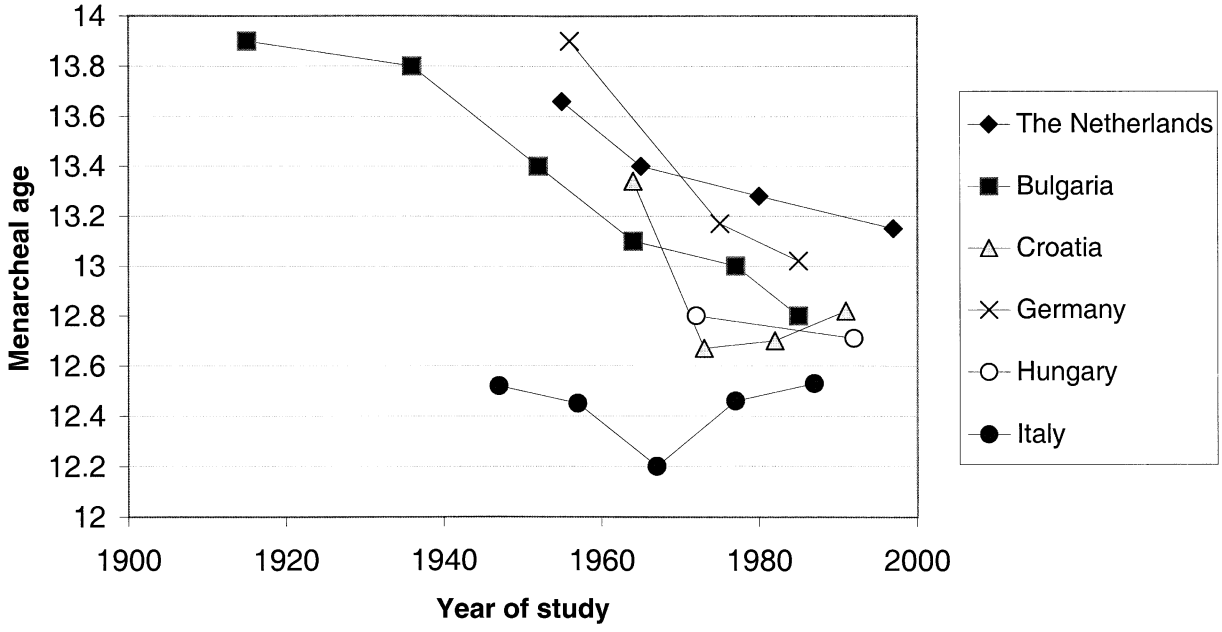

Figure 1. Secular trend in menarcheal age. Data from Bodzsar and Susanne (1998) and four Dutch national growth surveys referred to in the text.

1996). Because of improvements in general living conditions (which favour the lower social groups in particular), growth and maturation differences diminish between social groups (Lindgren, 1998). The effect of racial mixing might also contribute to the secular changes (Roche, 1979). However, the phenotypic effect of heterosis remains a controversial issue (Susanne and Bodzsar, 1998); thereby, gene–environment interactions do occur. In particular, periods of more intense change are more prone to undergo modifications under the effect of external agents. Some factors that may contribute to secular change are summarized in Table III.

The levelling off of menarcheal age in some countries is either the effect of a ceasing improvement of environmental factors, or of reaching the genetically determined limits of normality in menarcheal age (Hauspie *et al*., 1996).

Differences in terms of nutrition still exist between rural and urban populations in some European countries, with more vegetables and fruit, meat and milk-based products generally being consumed in the urban areas (Susanne and Bodzsar, 1998). In The Netherlands, the general wealth of the population has increased considerably over the past 42 years, and at present virtually all children have easy access to food. With regard to the quality of food, a clear rise in the consumption of animal protein and saturated fat was observed between 1936 and 1975 in The Netherlands, and the present consumption of diary products is one of the highest in the world (Fredriks *et al*., 2000a). Recently, emphasis has been placed on food substances that have oestrogen-related physiological effects such as phyto-oestrogens and lignans. These materials act as either agonists or antagonists of oestrogens, and are found in vegetables, fruits, seeds and grains as substantial constituents of our daily food (Mazur, 1998). Studies in rats have shown that feeding lignan-rich food (e.g. flaxseed) during pregnancy had dose-dependent hormonal effects in the offspring, such as earlier age and lighter weight at onset of puberty (Tou *et al*., 1998). Although it is often stated that soy-based formulae (containing relatively high concentrations of isoflavonoids) do not affect the timing of puberty, there are no reported studies of sexual maturation in relation to the type of infant feeding (Klein, 1998). In women, the intake of some phyto-oestrogens was shown to be related to a reduction in breast cancer risk (Ingram *et al*., 1997). In contrast, there is a theoretical (albeit disputed) increase in breast cancer risk as an effect of an earlier start of oestrogen exposure in women with a history of early menarche (Herman-Giddens *et al*., 1997; Rockhill *et al*., 1998). However, no data are available regarding the net effect on breast cancer risk should women with early puberty ingest greater quantities of phyto-oestrogens. The early onset of puberty in many children adopted from developing countries and now living in Europe (Oostdijk *et al*., 1991; Proos *et al*., 1991) raised the question of whether exposure to low levels of oestrogenic chemicals in the environment (xeno-oestrogens) may lead to higher expression of oestrogen-regulated genes in children who were used to vegetarian diets (F.Mengarda, unpublished data). A possible role of intra-uterine growth retardation can also be postulated in these children (Persson *et al*., 1999). With regard to diet, however, published data suggest that the composition of the diet is a less important determinant of pubertal events than is the attainment of a certain body size or fat mass at which pubertal onset is permitted (Meyer *et al*., 1990; Maclure *et al*., 1991; Kiess *et al*., 1999).

Another potential explanation for the decreasing age of onset of puberty might be the increasing prevalence of obesity both in the United States and Europe. The relationship of obesity with earlier onset of puberty may be due to the postulated minimal body mass being reached at an earlier age (Morrison *et al*., 1994; Kaplowitz and Oberfield, 1999; Fredriks *et al*., 2000b).

Table III. Possible mediators explaining secular trend in timing and progression of puberty

Genetic	
Migration:	gene flows
	phenotypic effect of heterosis[a]
Environmental	
Improvement of:	socio-economic conditions
	hygiene conditions
	health service
Growing urbanization	
Reduction of family size	
Changes in nutrition:	increased intake of animal proteins
	phyto- or xeno-oestrogen intake (?)
Environmental pollutants (?)	

[a]Heterosis = the increase in size, strength, etc. often found in a hybrid as compared with inbred plants or animals.

Concluding remarks

During the past century, an earlier start of puberty has been observed in most European countries, though during the past few decades this effect has slowed or even halted, as shown by recent data from The Netherlands (Fredriks *et al*., 2000a).

The shift towards a younger age has also been observed for age at menarche, and still continues in several European countries, though at a slower rate. On occasion—notably during periods of socio-economic instability—age at menarche was found to have shifted towards a later time. From several reports it became clear that the more recent decline of mean menarcheal age resulted mostly from a reduced frequency of late maturers.

Improved socio-economic conditions, together with improved health services and hygiene, changes in nutrition, and growing urbanization are among the most important factors influencing these secular changes. The observation that the earlier maturation slowed down, stopped, or even reversed may indicate either that environmental conditions have ceased to improve, or that these have already allowed the full expression of genetic potential (Hauspie *et al*., 1996).

The striking decrease in age at onset of puberty and menarcheal age as reported from the United States (especially in African-American girls; Herman-Giddens *et al*., 1997) has not been identified in Europe. The magnitude of the decrease is in part due to the comparison with old references from Marshall and Tanner. The possible influences of materials that have oestrogen-related effects have been detailed, and require further study (Herman-Giddens *et al*., 1997).

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Received on July 3, 2000; accepted on February 5, 2001