

Age at menarche in girls and the Developmental Origin of Health and Diseases

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Abstract

The researchers express their attitude concerning a chapter in the book by Victor Preedy entitled 'Handbook of Anthropometry: Physical Measures of Human Form and Disease' written by Polish researchers, anthropologists concerning the age at menarche in Polish girls after World War II. The authors question the arguments explaining the phenomenon of acceleration of pubertal timing in girls in recent decades described in the scientific literature. In their opinion, the phenomena of acceleration or delay of pubertal onset in girls cannot be explained solely by the living conditions. According to them, it is necessary to consider in these analyses the hypothesis of Developmental Origin of Health and Diseases (DOHaD). The researchers are of the opinion that this is rather a mismatch in the conditions of individual development, mainly nutrition, between critical developmental periods (critical windows) and later conditions that play a role in the acceleration or delay of the age at menarche in girls. They draw attention to the fact that the age at menarche in girls is an indicator of life span programmed in the early developmental periods. They consider that the effect of these relationships is susceptibility to civilisation chronic diseases in adulthood.

Key words

girls, menarche, health, diseases

On average, the first menstruation in girls occurs approximately one year after the pubertal spurt. This is a sign in individuals of the female gender of the human species of the reproductive capability, dependent on hormonal balance. Together with the onset of puberty – menarche – in girls there begins the hypothalamic control of the gonadotropic activity of the pituitary gland and, in consequence, also of cyclic excretory ovarian function. In the majority of reports and handbooks published, it is commonly believed that acceleration of menarche in girls is a sensitive indicator of the socioeconomic situation of the population. In Victor Preedy's 'Handbook of Anthropometry: Physical Measures of Human Form and Disease' [1] in the chapter written by Polish researchers, it is plainly stated that the age at menarche in girls in an individual population is a 'litmus paper reacting to the slightest changes in living conditions'. Hulanicka directly asserts that an improvement in socioeconomic conditions exert a more significant effect on the age at menarche than the conditions of the chemical and physical environment [2]. Also, other scientific reports published recently state that girls who are well nourished, develop in good living conditions, from higher income families, achieve reproductive capabilities earlier, which is reflected by the age at menarche [3]. The meaning of this statement unequivocally indicates that this situation is a causative agent of acceleration of the age at menarche. The above-mentioned opinions must be corrected against the hypothesis of the developmental origins of adult disease [4, 5], which has been undertaken in publications presented in this journal. It is true that the age at menarche decreases in the populations undergoing a rapid economic, social and political transition [6]. On this

background, one also cannot agree with the thesis that in girls good nutrition and good living conditions accelerate the occurrence of the first menstruation, and associated with it, reproductive capabilities, and that the above-mentioned living conditions are the cause of this. Against the hypothesis of the DOHaD, the truth is just opposite. The organism of a girl, who in the foetal period developed in conditions poor in nutrients or oxygen deficiency has been programmed towards being born alive, the possibility of survival; however, not necessarily towards long life in good health [7, 8]. According to the above-mentioned theory, which is currently common in the scientific centres and even in documents by international health organizations [9], epigenetic changes related with gene expression and genotyping match the phenotype of the developing organism to the development and functioning in these non-optimum and unfavourable conditions [10]. The process of these epigenetic changes takes place in so-called 'critical windows' of human individual development, which are: the periconceptual and foetal periods, childhood, until the period of puberty [11, 12]. This epigenetic programming of human individual development in the situation of deficiency throughout the entire future life assume that the newly-created organism will struggle with unfavourable situations for the entire adult life. The reproductive capabilities of the developing organism are also programmed. An organism programmed for survival and not for a long life span in good health 'adjusts' its reproductive capabilities exactly to these unfavourable conditions. Thus, in female offspring, there occurs acceleration of the first menstrual period, which is aimed at giving birth by them as early as possible, which serves the survival of the species. This happens even when the environmental conditions after birth are clearly better than during the period of intrauterine life. Even worse, the living conditions after birth, which are clearly different from those during the intrauterine period, lead to

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the phenomenon of so-called mismatch [13], which increases the risk of occurrence of civilisation chronic diseases, such as cardiovascular diseases (mainly arterial hypertension), type 2 diabetes, metabolic syndrome, mental disorders and many neurological perturbations [14, 15, 16, 17], and are also presented in the results of scientific studies published in AAEM [18]. The above-mentioned health perturbations in adulthood result in a reduced life span.

Thus, in accordance with this line of thought, these better living conditions after birth and in childhood are not the causative agent of acceleration of menarche in female offspring, but rather the conditions of their development in the earliest periods of life, mainly intrauterine, when epigenetic programming took place. According to the DOHaD thesis, better environmental conditions after birth may additionally strengthen this process of acceleration of menarche. Therefore, Hulanicka in one of her reports is right to claim that good living conditions may be an *a priori* cause of acceleration of the capabilities for reproduction [2]. The authors of the discussed chapter of the handbook provide other examples of situations which may accelerate the age at menarche in girls, such as stress associated with the lack of a father and family conflicts however, do not explain the mechanism of their relationships [1]. This may be simply explained by the DOHaD hypothesis. Stressful situations in so-called critical windows in individual development (which is also the period of puberty, especially the early period), and associated with this, the uncertainty of care on the part of parents, may lead to the programming of the organism of the daughter in the direction of early achievement of independence from the family, which probably stimulates the hormone system to accelerate the reproductive capabilities. Thus, one cannot agree with the statement that 'lack of psychological stimulation inhibits puberty' [19]. These are rather stressful situations which disturb the sense of safety that accelerate the age at menarche and reproductive capabilities, while the lack of such 'stimulations' results in the normal course of puberty without perturbations. The period of childhood and early period of puberty are also 'critical windows', when the epigenetic programming of the organism takes place for the entire later individual life. Also, the cases of disability among girls quoted [19, 20, 21, 22, 23] as causes of acceleration of the age at menarche may be easily explained by the above-mentioned hypothesis. Disability is the factor which is usually responsible for reduction of the human life span, therefore, it is understandable that in this case there must occur an early reproductive capability in order to produce offspring for the survival of the human species. Tobacco smoking is the factor which disturbs epigenetic processes at each stage of foetal life, mainly by hypoxia. The offspring of women who smoke in pregnancy are born smaller, in a worse condition, and characterized by a higher risk of contracting chronic diseases in adulthood. For these reasons, it is burdened with a higher risk of shorter life span and living in poorer health. Thus, an acceleration of the occurrence of menarche in daughters of mothers who smoked in pregnancy is aimed at an earlier production of offspring, which serves primarily the survival of the species in an evolutionary sense. Thus, the opinions that tobacco smoking has been the causative agent of acceleration of the occurrence of the first menstrual period are inaccurate [24, 25]. The problem of tobacco smoking by pregnant women and its negative effect on the course of pregnancy, type of delivery, state of the newborn after birth, and increase in the

risk of contracting chronic diseases in adult life is undertaken in many scientific publications, including those presented in this journal [26]. The foetus developing in the uterus of a pregnant, smoking mother is exposed to oxygen deficiency, not to mention the harmfulness of the chemical substances present in tobacco smoke [27, 28, 29]. In this unfavourable situation, epigenetic programming of the organisms occurs during the period of intrauterine development, adjusting it to these unfavourable conditions [30]. An insufficient amount of oxygen is directed to the organs which decide about survival, e.g. the brain, heart, adrenal glands, at the cost of others, such as the kidneys, pancreas, intestines, and muscles [4]. Growth and development of these important organs is secured on the minimum level which guarantees survival at the cost of others. In consequence, during the postpartum period, especially in adulthood, there occur pathological perturbations, e.g. type 2 diabetes, arterial hypertension, or metabolic syndrome, resulting from underdevelopment of the functions and metabolism of organs underdeveloped at early stages of foetal life. Due to this fact, the risk of earlier death is higher. Also for this reason there occurs acceleration of reproductive capabilities by the acceleration of the age at menarche. These phenomena are also explained by the DOHaD hypothesis [31], which is presented in the report in AAEM [32].

Anthropologists state that slim girls achieve menarche later than their contemporaries with a fat body build. Łaska-Mierzejewska calculates that this delay is 1.8-2.58 [33]. This is actually true, and can also be explained by the hypothesis of DOHaD. According to this hypothesis, when an organism 'programmed' for development in unfavourable conditions encounters different (most often pejoratively understood as 'better') living conditions, it is affected by the phenomenon of so-called mismatch, which increases the risk of occurrence of chronic diseases in adult life. There also occurs a compensatory body weight increase – catch-up growth (mainly of fatty tissue) in the period of infancy or early childhood, which also increases the risk of occurrence of the above-mentioned diseases in later life. Thus, the organism of a developing individual accelerates its reproductive capabilities by accelerating age at menarche, in order to produce offspring as early as possible, rear it, and in this way provide the survival of the human species. The studies show that an increase in fat weight by 1 kg in girls accelerates menarche by 13 days [1]. At present, it is considered that in the process of occurrence of menarche in girls there participate fat cells in which androgens are converted into estrogens, which initiates menarche. The agent which mediates the interaction between the moment of menarche and body structure (especially the pattern of its fatness and its intensity) in girls is leptin. It is assumed that an increase in the level of leptin in blood serum by 1 ng/mL accelerated menarche in girls by 1 month [1].

It is commonly considered that physical activity is another factor which exerts an effect on the acceleration of the occurrence of the first menstrual period in girls [34]. An excessive physical effort related with practising sports and intensive training transfers in time the moment of menarche [35]. The transferring of the age at menarche in girls who perform physical exercises is probably due to a lower percentage of fatty tissue in the body, compared to non-training girls. This secular trend consisting in intergenerational acceleration of the occurrence of the first menstrual period in girls has been observed in the human population for about 150 years.

Within this time, the occurrence of menarche in girls in the developed countries decreased by approximately 3 years, and is 0.2 years, on average, per each decade [1]. In the handbook by Victor Preedy [36] it is mentioned that this fact is related with a higher standard of living and hygiene, urbanization, and the amount of animal proteins consumed, referring to scientific reports [3]. According to the DOHaD hypothesis, this is probably due to a change in the human life style. From the aspect of evolution, 200 years ago humanity underwent an industrial revolution, which totally changed the style of life of an average inhabitant of our planet. First of all, humans started to consume industrially processed food products and changed their style of work in relation with industrialization. Industrialization decreased the amount of physical labour performed by workers by replacing their work with machines. Until then, the inhabitants of our planet were dependent on weather conditions indispensable for agricultural production, and thus periods of hunger were intermingled with periods of eating to the full. The types of food products consumed were seasonal because of the lack of storage conditions. This inclined their organisms to collect energy in the form of reserve of abdominal fat [37]. It is considered that the currently recommended level of physical activity of approximately 2.1 MJ is adequate for the genetic construction of contemporary man. Interestingly, this level is very similar to the standards for our ancestors from before the Paleolithic Period [38]. This is confirmed by observations carried out on contemporary pickers-hunters [39, 40]. According to the DOHaD hypothesis, in each subsequent generation there occurred the state of mismatch in living conditions between intrauterine conditions and those after birth. As mentioned in the discussed handbook on which the authors of the presented report express their opinion, in each generation an increase was observed in the body weight of girls, compared to the generation of their mothers. Thus, a compensatory body weight increase took place after birth, which resulted in an increased risk of the occurrence of chronic diseases in adulthood, and the organism of an offspring was epigenetically programmed for a shorter life span. Admittedly, during the last hundred years the average life span has also increased; nevertheless, it should be taken into consideration that this was mainly due to the improvement of sanitary conditions, consequent control of infant death rates, and the possibilities of curing many diseases in relation with technological progress in medicine. Thus, it cannot be unequivocally stated that the causative agent of acceleration of menarche in the subsequent generations were factors associated with an improvement of living standard. On page 1,332 of the handbook discussed, Antoszewski and Sitek claim that in the 1950s in Poland there occurred acceleration of the age at menarche in girls by 0.51 years (6.12 months), explaining this by an improvement of living conditions, especially in large cities. However, it is enough to analyze the history of the life of the girls who experienced menarche in the 1950s. They were born at the time of the Nazi occupation in Poland (1939-1945). Thus, it appears that the intrauterine period when the organisms of these girls developed, when very rapid process of epigenetic programming took place, was the time of World War II. During this period, food in Poland was rationed on a very low level, and pregnant women were forced to perform hard physical labour. According to the sources, from the beginning of World War II, with respect to nutrition, the situation of

the Polish population was very difficult. In 1941, the average Polish inhabitant consumed 930 kilocalories, while the food rations for the Jewish inhabitants of the Warsaw Ghetto were approximately 186 kilocalories [41]. Therefore, the organisms of foetuses at that time developed in conditions of nutritional deficiencies, in addition to the excessive physical effort among pregnant women related with the necessity to work beyond their powers. These factors were intensified by the stress of occupation. In these unfavourable conditions the supply of food components to individual organs of the developing foetus was rationed, resulting in epigenetic programming towards enabling the survival of the offspring at the cost of life span after birth. This, in turn, according to the DOHaD, for the survival of the human species, accelerated menarche took place in female offspring in order to produce the subsequent offspring as soon as possible. In my opinion, this is the explanation for the phenomenon of the acceleration of menarche in Polish girls in the 1950s. It is enough to analyze from this aspect the incidence of cardiovascular diseases 30 years later, i.e. in the 1980s, and number of deaths in Poland due to these diseases. In the 1980s, many males and females born during World War II contracted cardiovascular diseases, and often died due to these diseases. For the female population who during that time contracted this type of diseases in numbers, the period of intrauterine development was during wartime, whole menarche occurred in the 1950s. The 1980s in Poland was also the time of shortening of the life span both of males and females. This is confirmed by studies by Prof. Zatonski [42]. According to the DOHaD, the population of pregnant women during the Nazi occupation was exposed to unfavourable environmental conditions, mainly associated with food deficiency or simply hunger. Intrauterine programming of the offspring foetuses was aimed only at their survival and being born alive; however, at the cost of risk of contracting chronic diseases, including cardiovascular diseases, which was to result in the shortening of the life span [43]. The 1980s were the peak of morbidity and premature deaths due to these chronic diseases, mainly cardiovascular in Poland. This also speaks for the use of the hypothesis of DOHaD in the analysis of the causes of acceleration of menarche in Polish girls during the 1950s, and the necessity to analyze the phenomena of menarche acceleration in combination with developmental conditions in the earliest periods of individual development, from the periconceptional period, intrauterine development, to the termination of growth. The slowest pace of acceleration of menarche among girls living in rural areas should be explained by the fact that after delivery they lived in the same conditions as during the intrauterine period, i.e. also in conditions of nutritional deficiency. This, in this case the phenomenon of mismatch did not occur, which was related with obligatory food supplies to the cities, and often it was difficult to feed the family. By the end of the 1950s, not fulfilling the imposed standards for food supplies to the cities was punishable by imprisonment. To confirm the above-mentioned fact, it is enough to quote the phenomenon of comparisons of the state of health of the Dutch population, who survived the period of Winter Hunger 1944-1945, and the siege of Leningrad during World War II.

After a short period of hunger in winter 1944-1945, the inhabitants of Holland were nourished normally (affluently), the same as before the crisis. The offspring from mothers who survived hunger while being pregnant, more frequently

fell ill with chronic diseases in adulthood. In this case, the phenomenon of mismatch occurred between the conditions of development of individuals during the intrauterine period and affluent environmental conditions after birth. An extreme example is the siege of Leningrad, when the offspring born during the siege, for many years developed in conditions of food insufficiency. After the war, no increased risk of civilization diseases was noted in the offspring born during that period. In turn, in this case there occurred the phenomenon of match, i.e. conformity between the postnatal conditions and those before birth [44].

The Dutch population, for whom the intrauterine period occurred at the time of hunger, in adulthood more frequently suffered due to chronic diseases than other citizens of this country. In the population of Leningrad, such a relationship was not observed, because after birth which took place during the starvation period of the siege, for many years the offspring still lived in conditions of nutritional deficiency. Following this line of thought, the rural population in occupied Poland lived in conditions not so very different from those before the period of occupation, which resulted in the fact that the phenomenon of mismatch did not occur and did not result in increased morbidity due to civilization diseases, as well as the risk of premature death due to these reasons. In turn, the urban population encountered a slightly more comfortable life, which was guaranteed, for example, by the certainty of permanent employment and a salary in newly constructed factories, in relation with the dynamic industrialization of Poland. Therefore, this population was not exposed to the deficiency of food and resources for the maintenance of families. Frequently, this was a population who had formerly lived in the rural areas and had migrated *en masse* to the cities. In this case, the phenomenon of mismatch was observed between the actual foreseen deficiency during the period of intrauterine growth and development (during the occupation), and the actual conditions after birth and in adulthood. According to the DOHaD hypothesis, this fact intensified the morbidity risk due to chronic diseases and shortened of life span. For this reason, in 1955, among girls from large cities the mean age at menarche was by nearly 1 year earlier than among rural girls (13.41 in cities of over 500,000 vs. 14.28 in rural areas) [1, 33, 45, 46]. In the analyzed chapter of the handbook by Preedy [1], Antoszewski and Sitek report that during the period 1971-1975 an acceleration of the age at menarche in rural girls was observed by 0.48 years, i.e. by 5.76 months. The researchers stated that this occurred as a result of the dynamic development of the agricultural sector in Poland and an improvement of living conditions in the rural areas. The causes of this phenomenon cannot be explained in this way. It is enough to mention that in these years, rural girls reaching the age of menarche were born in the years 1959-1962, when the living conditions in the rural areas were relatively difficult, as a result of previously described food deficiencies in consequence of mandatory supplies of food to the cities. Women who were pregnant in the years 1959-1962 consumed an insufficient amount of nutrients, exposing the foetuses to the same deficiencies. The process of intrauterine programming adjusted the developing foetuses to the situation of deficiency during the foetal period and childhood. However, after birth these conditions radically improved with respect to the access to food, the phenomenon of mismatch occurred and increased together with the risk of chronic diseases and shorter life span. This was the cause

of acceleration of menarche in rural girls, in order to obtain reproductive capabilities earlier, producing offspring and continuing the human species. Thus, the statement contained in the chapter of the handbook analyzed, that better living conditions in the rural areas during the period 1971-1975 were the causative agent of acceleration of menarche, is at least imprecise. Similarly, in the years 1971-1975 in small towns, acceleration of menarche was noted by 0.43 years (5.16 months). Explaining this phenomenon also requires consideration of the DOHaD hypothesis. An improvement in the living conditions of the Polish population in the years 1971-1975, from the aspect of evolution, acts rather in a negative way on the anticipated risk of chronic diseases, and consequently, the risk of premature death and shorter life span, while an earlier occurrence of menarche is aimed at survival of the human species. The above-mentioned authors emphasize that in the years 1977-1989 the economic crisis related with rationing of selected products, mainly food, caused a delay in the age at menarche in Poland. They also emphasize that such a delay is a phenomenon not encountered in Poland after World War II. The greatest delay was observed among the population of small towns (by 0.25 years = 3 months), and large cities (0.12 years = 1.44 months), while the age at menarche was the least delayed in the rural areas (0.06 years = 0.72 months). In accordance with the DOHaD, the girls born during the period 1964-1976 developed in the intrauterine period in relatively affluent conditions, and these conditions were similar in the period of infancy, childhood, until the period of puberty. These conditions, to a greater degree, were equivalent with those programmed during the foetal period with respect to large cities, slightly less equivalent in relation to small towns, and the least equivalent in relation to the rural inhabitants. This is understandable, because the parity on behalf of farmers' income in the 1980s was more beneficial, compared to the urban population. Girls born in the 1960s and the first half of the 1970s, their childhood being during the 1980s – the years of prosperity in the rural areas – lived in relatively better living conditions, which were much different from the programmed anticipated living conditions during their intrauterine life, and for this reason, the least visible delay in the age at menarche in girls in these years was observed in the rural areas. The above analyses clearly show that the acceleration of the age at menarche in Polish girls noted during the post-war period was not a positive symptom in the sense of life span. According to the DOHaD, an earlier occurrence of menarche indicates that in critical windows sensitive to epigenetic changes programming the entire human individual development, there were perturbations resulting in the risk of occurrence of chronic diseases in adulthood, which may generally result in a shorter life span. For the survival of the human species from the aspect of evolution, the capability for reproduction is accelerated in the form of earlier age at menarche. Therefore, it seems that the explanation of the phenomenon of developmental acceleration and earlier age at menarche in girls by merely an improvement in the living conditions, is a mistake. The question arises what is meant by 'improvement of living conditions' in the sense of the risk of civilization diseases? An improvement in these conditions may mean only an elimination of the causes of morbidity and deaths due to infectious diseases. This has been observed in Poland in recent decades. However, an improvement in the living conditions

results in an increased risk of morbidity due to civilisation chronic diseases, and consequently, the perspective of a poorer quality of life with a chronic disease: type 2 diabetes, hypertension, metabolic syndrome, which when untreated result in a shorter life span. This aspect should be considered while analysing and commenting on the phenomenon of the secular trend which has been noted among adolescents worldwide and in Poland in recent decades.

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