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Review Article

Exploring societal and environmental influences on decreasing menarcheal age: a comprehensive review

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ABSTRACT

Menarche typically occurs between the ages of 10 and 16 years, although the timing can vary widely among individuals and populations due to genetic, environmental, and socioeconomic factors. The onset of menstruation reflects the complex interplay between biological, psychosocial, and environmental factors that influence pubertal development. Environmental factors such as nutrition, exposure to endocrine-disrupting chemicals (EDCs), and socioeconomic status (SES) play critical roles in determining menarcheal age. Psychosocial factors such as stress, family dynamics, and cultural norms also influence menarcheal age. This narrative review tries to explore the factors responsible for decreasing menarcheal age.

Keywords: Menarche, Environmental, Psychosocial, Socioeconomic status, Genetic, Pubertal maturation

INTRODUCTION

Menarcheal age refers to the age at which a female experiences her first menstrual period, marking the onset of reproductive capability and the transition from childhood to adolescence. It is a significant milestone in a woman's life, representing the activation of the hypothalamic-pituitary-ovarian (HPO) axis and the initiation of the menstrual cycle.[1] Menarche typically occurs between the ages of 10 and 16 years, although the timing can vary widely among individuals and populations due to genetic, environmental, and socioeconomic factors.[2]

The significance of menarcheal age in reproductive health stems from its role as a key indicator of pubertal maturation and hormonal regulation. The onset of menstruation reflects the complex interplay between biological, psychosocial, and environmental factors that influence pubertal development.[3] Understanding menarcheal age is essential for assessing reproductive health outcomes, predicting fertility potential, and identifying individuals at risk of reproductive disorders and health complications.

FACTORS INFLUENCING MENARCHEAL AGE

Biologically, menarcheal age is influenced by factors such as genetics, hormonal signalling, and adiposity. Genetic factors contribute to variations in pubertal timing, with certain gene variants associated with earlier or later onset of menarche.[4] Hormonal regulation, particularly the secretion of gonadotropin-releasing hormone (GnRH) from the hypothalamus and the subsequent release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) from the pituitary gland, plays a central role in initiating menstruation.[5] Adiposity, represented by body mass index (BMI) and body fat distribution, also influences menarcheal age, with higher adiposity levels associated with earlier onset of menstruation due to increased leptins secretion and hormonal stimulation.[2]

Psychosocial factors such as stress, family dynamics, and cultural norms also influence menarcheal age. Chronic

stress can disrupt the hypothalamic-pituitary-adrenal (HPA) axis and alter hormonal balance, potentially accelerating pubertal maturation.[6] Family dynamics, including parental relationships, sibling interactions, and care giving practices, can shape a child's psychosocial environment and affect their pubertal timing. Cultural norms and societal expectations regarding femininity, body image, and sexual development may influence perceptions of menarche and its significance, impacting the psychosocial experience of adolescent girls.[7]

Environmental factors such as nutrition, exposure to endocrine-disrupting chemicals (EDCs), and socioeconomic status (SES) also play critical roles in determining menarcheal age. Nutrition, including dietary intake and micronutrient status, influences hormonal regulation and reproductive maturation, with inadequate nutrition potentially delaying menarche.[8] Exposure to EDCs, found in plastics, pesticides, and personal care products, can disrupt hormonal signalling pathways and affect pubertal timing.[9] Socioeconomic disparities, characterized by differences in income, education, and access to resources, contribute to variations in menarcheal age, with lower SES associated with earlier onset due to factors such as limited access to healthcare, higher psychosocial stress, and poorer nutrition.[10]

TREND OF DECREASING MENARCHEAL AGE

Over the past century, there has been a noticeable trend towards a decreasing age at menarche, the onset of menstruation in females, in many parts of the world. This phenomenon has attracted significant attention from researchers, healthcare professionals, and policymakers due to its implications for adolescent health and reproductive outcomes. Understanding the factors contributing to this trend is essential for promoting reproductive health and well-being among adolescents.

The observed trend of decreasing menarcheal age reflects changes in various societal, environmental, and biological factors that influence pubertal development. Historically, menarcheal age has been influenced by factors such as nutrition, socioeconomic status (SES), psychosocial stressors, and environmental exposures. However, shifts in these factors over time have contributed to the observed decline in menarcheal age across generations.

NUTRITIONAL FACTORS

One significant factor contributing to the decreasing age at menarche is improvements in nutrition and overall health.[11] A balanced and nutritious diet is essential for normal growth and development, including the onset of puberty. Dietary patterns rich in fruits, vegetables, whole grains, and lean proteins provide the necessary nutrients for healthy hormonal regulation and reproductive function. On the other hand, diets high in processed foods, sugar, and unhealthy fats may contribute to metabolic disturbances and hormonal imbalances, potentially affecting menarcheal age. Advances in healthcare, sanitation, and food availability have led to better nutrition and higher caloric intake among populations, supporting optimal growth and development during childhood and adolescence. Adequate nutrition, particularly in terms of protein, vitamins, and minerals, is essential for hormonal regulation and reproductive maturation. As access to nutritious foods has increased, especially in urban and industrialized settings, girls are reaching puberty earlier due to improved overall health and nutritional status. As societies transition from agrarian to industrialized economies, dietary habits shift towards higher caloric intake and more diverse food choices, supporting optimal growth and development during childhood and adolescence. This improved nutritional status contributes to earlier onset of puberty and menarche among girls.

One key aspect of changing dietary habits is the shift towards a diet characterized by higher energy intake, increased consumption of processed foods, and higher levels of animal protein and fats. This dietary pattern, often associated with Westernized diets, has been linked to earlier onset of puberty and menarche.[12] Increased intake of calorie-dense foods may lead to higher body fat accumulation, which can trigger hormonal changes and advance the timing of puberty. Additionally, higher consumption of animal protein may contribute to elevated levels of insulin-like growth factor 1 (IGF-1), a hormone associated with pubertal development.

Several studies have highlighted the relationship between socioeconomic status (SES) and nutritional intake in relation to menarcheal age. Lower SES is often associated with inadequate nutrition, which can delay menarche due to insufficient body fat accumulation. Conversely, higher SES is linked to better access to nutritious food, promoting earlier menarche. Research suggests that certain dietary patterns may be associated with earlier or delayed menarche. Diets high in fast food and sugary beverages have been linked to earlier onset of puberty.[13] Higher intake of sugar and processed foods, which are common in modern diets, may promote insulin resistance and inflammation, potentially accelerating puberty.

Micronutrients such as iron, zinc, calcium, and vitamin D play crucial roles in reproductive health and hormonal regulation.[14] Deficiencies in these micronutrients can disrupt normal physiological processes, potentially impacting menarcheal age. Iron deficiency is commonly associated with delayed menarche due to its role in hemoglobin synthesis and oxygen transport, which are essential for reproductive function. Similarly, inadequate intake of calcium can impair bone health and delay puberty. Some studies have shown that low levels of vitamin D were associated with earlier onset of puberty in girls.[15] Addressing micronutrient deficiencies through supplementation or dietary interventions may help promote optimal reproductive health and normalize menarcheal age.

Obesity is a significant risk factor for early puberty and menarche.[16] Excess adipose tissue in obese individuals can lead to increased production of estrogen through aromatization of androgens in adipocytes, thereby accelerating the onset of puberty. Furthermore, obesity-related insulin resistance and inflammation can disrupt hormonal regulation, contributing to early menarche. Numerous studies have demonstrated a strong association between obesity and early menarche. A meta-analysis published in Pediatrics concluded that obesity significantly increases the risk of early puberty in girls, with each unit increase in body mass index (BMI) associated with a higher likelihood of early menarche.[17] Addressing obesity through lifestyle modifications such as diet and exercise interventions may help prevent early puberty and normalize menarcheal age.

Beyond macronutrient composition and micronutrient intake, modern dietary habits also expose individuals to a variety of environmental contaminants and endocrine-disrupting chemicals (EDCs) present in processed foods, packaging materials, and agricultural products. Exposure to EDCs, such as bisphenol A (BPA) and phthalates, has been associated with altered hormonal signaling and reproductive development, potentially influencing menarcheal age.[18]

SOCIETAL AND ENVIRONMENTAL FACTORS

Socioeconomic factors also play a critical role in shaping menarcheal age. Higher socioeconomic status (SES) is generally associated with later menarche, as individuals from more affluent backgrounds tend to have better access to healthcare, education, and resources.[19] However, with increasing urbanization and socioeconomic development, there has been a shift towards earlier menarche in many populations. Urbanization brings changes in lifestyle, dietary habits, and environmental exposures that may accelerate pubertal maturation. Additionally, socioeconomic disparities persist, with lower SES individuals experiencing earlier menarche due to factors such as limited access to healthcare, higher psychosocial stress, and poorer nutrition.[20]

The impact of socioeconomic status (SES) on pubertal development is a multifaceted and complex and it intersects biology, psychology, and sociology. SES encompasses various factors such as income, education, occupation, and social status, all of which can influence a young person's physical and psychological development during puberty.[21] Higher SES families generally have better access to nutritious food and healthcare services, which can contribute to optimal growth and development during puberty. Adequate nutrition is crucial for the production of hormones essential for puberty, such as estrogen and testosterone.[22] Conversely, lower SES individuals may experience food insecurity and limited access to healthcare, which can potentially delay puberty or lead to irregularities in hormonal levels.

Psychosocial factors play a significant role in pubertal development. Adolescents from lower SES backgrounds may experience higher levels of stress due to economic hardships, family instability, or neighborhood violence. Chronic stress can disrupt the hypothalamic-pituitary-adrenal (HPA) axis, affecting the release of hormones involved in puberty.[23] This may result in early puberty for some or delayed puberty for others, depending on individual responses to stress.

Adolescents from affluent families may be exposed to different societal expectations regarding body image, sexuality, and gender roles compared to those from lower SES backgrounds. Media portrayal of idealized body images and peer pressure to conform to certain standards can impact self-esteem and body image perception, influencing pubertal development trajectories. Access to education and information about puberty varies across socioeconomic groups. Higher SES families may have the resources to provide comprehensive sex education and open communication about puberty-related changes, fostering a supportive environment for adolescents. In contrast, lower SES individuals may lack access to accurate information about puberty, leading to misconceptions and anxiety surrounding bodily changes.

Marginalized communities often face additional challenges related to systemic inequalities, which can exacerbate the impact of SES on pubertal development. Racial disparities in healthcare access and socioeconomic opportunities can compound the effects of poverty on pubertal outcomes among minority adolescents.

Socioeconomic disparities in housing and living conditions can affect exposure to environmental pollutants such as air and water contaminants. Individuals living in low-income neighborhoods or areas with high levels of industrial pollution may experience higher levels of exposure to toxic substances, which can disrupt hormonal regulation and accelerate pubertal timing. Additionally, overcrowded or substandard housing conditions may contribute to psychosocial stressors that impact pubertal development, such as family dysfunction and neighborhood violence.[24]

Income level can indirectly affect menarcheal age through its influence on nutrition and overall health. Higher income families typically have better access to nutritious food, healthcare services, and living conditions. Girls from lower income households may experience malnutrition or food insecurity, which can delay menarche due to insufficient energy reserves. Conversely, girls from higher income families may reach menarche earlier due to improved nutritional status and overall health.

EDUCATIONAL STATUS

Education plays a significant role in shaping menarcheal age through its association with socioeconomic status and access to information. Girls from families with higher

levels of education often have access to comprehensive sex education and reproductive health knowledge. They may be better informed about puberty and menstruation, which can positively influence their attitudes and perceptions towards these biological changes.[25] In contrast, girls from families with lower levels of education may lack access to accurate information about menstruation, leading to misconceptions or anxiety surrounding menarche. Additionally, educational attainment is often correlated with delayed childbearing, which can indirectly influence the timing of menarche.

ACCESS TO RESOURCES

Access to resources such as healthcare, sanitation, and hygiene products can also impact menarcheal age.[26] Girls who have access to adequate healthcare are more likely to receive timely medical attention and support for reproductive health issues, which can positively influence the onset of menstruation. Additionally, access to sanitary products such as pads or tampons is essential for managing menstruation comfortably and hygienically. Lack of access to these resources, which is more common among disadvantaged populations, can lead to stress and discomfort surrounding menstruation, potentially impacting menarcheal age.[27]

Girls from higher SES families are more likely to have access to regular healthcare check-ups and comprehensive sex education, which can positively impact reproductive health outcomes, including menarcheal age. Conversely, girls from lower SES backgrounds may face barriers to accessing healthcare services and accurate information about puberty and menstruation, potentially leading to delayed or irregular menarche.

PSYCHOSOCIAL FACTORS

Psychosocial stressors, including family dynamics, peer relationships, and cultural norms, also influence menarcheal age. Early exposure to sexual content in the media, peer pressure, and family stressors can accelerate pubertal maturation, while supportive family environments and positive peer relationships may delay menarche.[28] Cultural norms regarding femininity, body image, and sexual development can also impact perceptions of menarche and influence the timing of pubertal milestones. Structural inequalities and systemic barriers can exacerbate the impact of socioeconomic factors on menarcheal age, particularly among marginalized populations.[29]

Family dysfunction, parental conflict, socioeconomic hardships, and exposure to trauma can significantly impact menarcheal age.[29-31] Chronic stress activates the hypothalamic-pituitary-adrenal (HPA) axis, leading to dysregulation of hormonal pathways involved in puberty. High levels of stress hormones such as cortisol can disrupt the normal timing of puberty, potentially advancing or delaying menarche.[32] Family dynamics, including parental relationships, care giving practices, and familial support systems, play a crucial role in shaping menarcheal age. Positive family environments characterized by nurturing, supportive relationships and open communication about puberty and reproductive health may promote healthy psychosocial development and normal timing of puberty. Conversely, family dysfunction, parental neglect, or absence of care giving support can contribute to stress and emotional disturbances, potentially impacting menarcheal age.[33] family structure and dynamics, such as single-parent households or parental divorce, have been associated with earlier onset of puberty in some studies.[34]

Peer relationships play a crucial role in adolescents' psychosocial development and pubertal experiences. Peer interactions, social dynamics, and peer pressure can influence pubertal timing through various pathways.[35] Adolescents often compare themselves to their peers and may experience pressure to conform to societal norms and expectations regarding puberty and sexual behaviour. Peer relationships can also influence adolescents' perceptions of their own pubertal development, with early-maturing individuals potentially facing social challenges or stigma from peers. Peer relationships provide opportunities for social learning and information exchange about puberty, sexuality, and reproductive health, which can impact adolescents' understanding and experiences of pubertal timing.

With the widespread availability of media and digital technology, adolescents are increasingly exposed to sexual content at younger ages. Exposure to sexual imagery, explicit media content, and online pornography can impact pubertal timing through several mechanisms. Firstly, early exposure to sexual content may accelerate the onset of puberty by triggering hormonal responses through arousal and sexual stimulation.[36] Secondly, exposure to sexual content can shape adolescents' attitudes, beliefs, and expectations about sexuality, potentially influencing their perceptions of pubertal development and sexual behaviour. Early exposure to sexual content may contribute to psychological stress and emotional disturbances, which can disrupt hormonal regulation and pubertal timing.

Chronic stressors such as poverty, discrimination, and social instability can dysregulate the hypothalamic-pituitary-adrenal (HPA) axis and disrupt hormonal balance, potentially advancing or delaying puberty.[37] Moreover, psychosocial stressors may exacerbate the effects of environmental pollutants on pubertal development, leading to compounded health disparities among socioeconomically disadvantaged populations.

ENVIRONMENTAL FACTORS

Environmental factors, such as exposure to endocrine-disrupting chemicals (EDCs), pollutants, and lifestyle changes, have also been implicated in the decreasing age at menarche.[38] EDCs, found in plastics, pesticides, and

personal care products, can interfere with hormonal signalling pathways and affect pubertal timing. Additionally, lifestyle changes associated with urbanization, such as sedentary behaviour, inadequate sleep, and altered dietary patterns, may contribute to earlier onset of puberty. Lifestyle changes associated with urbanization, such as sedentary behaviour, inadequate sleep, and altered dietary patterns, may contribute to earlier onset of puberty. Environmental pollutants, such as air pollution and water contaminants, may also impact hormonal regulation and pubertal development, potentially influencing menarcheal age.

EDCs are substances that interfere with the body's endocrine system, which regulates hormone production, secretion, and function.38 These chemicals can mimic, block, or interfere with hormonal signals, leading to adverse effects on pubertal development. EDCs are found in various everyday products such as plastics, pesticides, personal care products, and food packaging. Exposure to EDCs during critical periods of development, including prenatal and early childhood stages, can have long-lasting effects on pubertal timing and reproductive health. Certain EDCs, such as bisphenol A (BPA), phthalates, and organochlorine pesticides, have been associated with accelerated pubertal development, early onset of puberty, and reproductive abnormalities in both animal studies and human populations.[39] These chemicals can disrupt the normal function of hormones such as estrogen, testosterone, and thyroid hormones, leading to disturbances in pubertal maturation.

Environmental pollutants, including air pollutants such as particulate matter, volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), as well as water pollutants such as heavy metals and industrial chemicals, can also impact pubertal development.[40] Exposure to these pollutants has been linked to alterations in hormone levels, oxidative stress, inflammation, and DNA damage, which can affect reproductive health and pubertal timing.

Research has demonstrated links between exposure to air pollutants such as nitrogen dioxide (NO2) and polycyclic aromatic hydrocarbons (PAHs) and delayed onset of puberty in girls. Similarly, exposure to heavy metals such as lead and cadmium through contaminated water sources or industrial emissions has been associated with delayed pubertal development and hormonal disturbances.[41]

Pesticides and agricultural chemicals used in farming practices can also impact pubertal development through their endocrine-disrupting properties. Exposure to pesticides, herbicides, and fungicides has been linked to alterations in hormone levels, reproductive abnormalities, and adverse effects on fertility and reproductive health.[41]

Certain pesticides, such as organophosphates and pyrethroids, have been identified as EDCs with potential effects on pubertal development. Additionally, residues of these chemicals can be found in food sources, further increasing the risk of exposure among vulnerable populations.

Environmental changes, including climate change, deforestation, pollution, and habitat destruction, can have far-reaching effects on ecosystems and human health. Changes in environmental conditions may influence menarcheal age through various mechanisms. Exposure to air pollutants such as particulate matter and nitrogen dioxide has been associated with early puberty and menarche in some studies.[42,43]

Additionally, environmental disruptions may impact access to clean water, nutritious food, and healthcare services, which are essential for optimal growth and development during puberty. Changes in environmental stressors, such as extreme weather events and natural disasters, may also contribute to psychosocial stress and emotional disturbances, potentially affecting pubertal timing.[44]

LIFESTYLE CHANGES

Sedentary behaviour, characterized by prolonged sitting or low levels of physical activity, has been associated with alterations in hormonal levels and metabolic function, which can impact pubertal timing.[45] Lack of physical activity can contribute to obesity and insulin resistance, both of which are risk factors for early puberty and menarche. Additionally, sedentary behaviour may disrupt the balance of hormones involved in pubertal development, such as insulin-like growth factor 1 (IGF-1) and leptin, potentially advancing the onset of puberty.

Sleep patterns, including duration, quality, and timing of sleep, play a crucial role in regulating hormonal rhythms and pubertal development. Adequate sleep is essential for the secretion of growth hormone, which influences the timing of puberty and reproductive maturation. Disruptions in sleep patterns, such as insufficient sleep or irregular sleep schedules, can disrupt the circadian rhythm and alter the production of hormones involved in pubertal timing, such as melatonin and cortisol.[46]

Exposure to artificial light, particularly in the evening and nighttime hours, can disrupt the body's natural circadian rhythms and melatonin production, potentially influencing pubertal timing. Artificial light exposure from electronic devices such as smartphones, tablets, and computers, as well as indoor lighting, can suppress melatonin secretion and delay the onset of nighttime sleep, leading to disturbances in hormonal regulation and sleep patterns.

Exposure to artificial light at night may be associated with earlier menarcheal age.[47] The disruption of circadian rhythms and melatonin production by artificial light exposure may contribute to alterations in hormonal signalling and pubertal development.

GEOGRAPHIC AND CULTURAL FACTORS

Socioeconomic disparities in menarcheal age can also vary by geographic region and cultural context. Studies have documented differences in menarcheal age between urban and rural areas, as well as among different ethnic and cultural groups.48 Cultural beliefs, norms, and practices surrounding menstruation and puberty vary across different societies and can influence menarcheal age. Cultural attitudes towards menstruation, body image, sexuality, and gender roles shape girls' experiences of puberty and may impact the timing of menarche. Additionally, cultural practices such as puberty rituals, ceremonies, and traditions may serve as markers of social maturity and influence the perception of menarcheal age within specific cultural contexts. Cultural expectations regarding femininity, marriage, and reproductive roles may also influence the timing of menarche within specific cultural contexts. societal messages about beauty ideals, body image, and sexual attractiveness can impact adolescents' self-perceptions and body image satisfaction, which may in turn influence their experiences of pubertal timing.

CONCLUSION

Puberty is a critical period of reproductive development, and disruptions in pubertal timing can have long-lasting effects on reproductive health and fertility. Socioeconomic disparities and environmental injustices contribute to unequal access to resources and opportunities, leading to disparities in pubertal development and health outcomes among adolescents. Socioeconomic factors such as poverty, inadequate nutrition, and limited access to healthcare can increase the risk of early puberty, obesity, and chronic health conditions among adolescents. By addressing socioeconomic and environmental determinants, we can prevent or mitigate the health risks associated with pubertal development, promoting healthier outcomes, optimal reproductive health outcomes and prevent or mitigate the risk factors associated with chronic diseases such as obesity, diabetes, cardiovascular disease, and certain cancers.

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