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Review Article

Early Puberty and Modern Lifestyles: A Comprehensive Review of Emerging Risk Factors

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ABSTRACT

Physical, hormonal, psychological, and social changes occur during puberty, a significant developmental stage. There may be a tendency for girls to reach puberty earlier, according to recent data. Numerous interrelated factors, such as obesity, eating habits, physical activity, sleep, psychosocial stress, environmental exposures, and genetic or biological factors, affect when puberty occurs. The hypothalamic-pituitary-gonadal axis is the primary regulator of pubertal development. While peripheral precocious puberty happens through mechanisms unrelated to the normal activation of this axis, central precocious puberty can be caused by premature activation of this hormonal pathway. Lifestyle factors and childhood obesity have drawn a lot of attention as potential causes of early puberty.Although results are not entirely consistent, environmental endocrine-disrupting chemicals have also been studied. Early and precocious puberty may have social and psychological repercussions in addition to physical ones, such as reduced adult height potential and advanced bone maturation. Thus, appropriate clinical evaluation and customized treatment are crucial. The evidence on normal puberty, early and precocious puberty, epidemiology, hormonal mechanisms, lifestyle factors, environmental exposures, genetic factors, health consequences, prevention and management, and current research gaps is compiled in this review.

Keywords: Girls; Obesity; Physical activity; Early or premature puberty; Hormones; Puberty

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INTRODUCTION

Biological, hormonal, physical, psychological, and social changes occur during puberty, a significant period of human development. Breast development, growth acceleration, pubic and axillary hair development, and finally menarche are all aspects of pubertal developmentin girls.Over the past few decades, there has been a shift in the timing of puberty, with several studies showing earlier pubertal development in girls. Genetic, dietary, environmental, and lifestyle factors are likely to interact to cause this trend. Pubertal timing changes have been linked to obesity, dietary changes, physical inactivity, and exposure to chemicals that disrupt hormones.[1, 4]Because early pubertal development can impact not only physical growth but also psychological and social well-being, it is clinically significant. For the purpose of early detection and suitable treatment, it is crucial to comprehend the factors linked to early and precocious puberty.

Normal Puberty in Girls

A coordinated neuroendocrine process underlies normal puberty. One of the earliest obvious indications of puberty in girls is typically the development of the breasts, which is followed by the development of pubic and axillary hair, increased growth velocity, and menarche.The hypothalamic-pituitary-gonadal (HPG) axis is primarily responsible for controlling the process. Hypothalamic activity is largely inhibited during childhood. Gonadotropin-releasing hormone (GnRH) pulsatile secretion rises with the onset of puberty. Follicle-stimulating hormone (FSH) and luteinizing hormone (LH) are released by the pituitary gland in response to GnRH

stimulation. These hormones encourage the production of sex steroids, especially estrogen by stimulating the ovaries. [16, 17]The ensuing hormonal shifts cause growth acceleration, reproductive maturation, and the emergence of secondary sexual traits.

Definition and Classification of Early/Precocious Puberty

The term "precocious puberty" describes the emergence of secondary sexual traits before the anticipated age. Precocious puberty is traditionally defined as the emergence of secondary sexual traits before the ages of eight for girls and nine for boys. [16, 17, 18]

There are three main types of precocious puberty:

- **Central Precocious Puberty**: Premature activation of the HPG axis causes central precocious puberty, which is gonadotropin-dependent. In most cases, the normal order of pubertal development is preserved. [17, 18]
- **Early Puberty in the Periphery**:Gonadotropin is not necessary for peripheral precocious puberty. Excessive production or exposure to sex steroids from the ovaries, adrenal glands, or other sources may cause it. [17, 19]
- **Inadequate Early Puberty:** Premature thelarche and premature adrenarche are examples of incomplete forms. These disorders don't always lead to full precocious puberty and could be variations of normal development. [2].

Table 1: Etiology of Precocious Puberty

PRECOCIOUS PUBERTY	ETIOLOGY
Central precocious puberty	• Idiopathic • CNS pathology/lesion • Hypothalamic hamartoma • Tumors (astrocytoma, glioma etc.) • Congenital- hydrocephalus, arachnoid cysts, meningo-myelocele. • Acquired-CNS Irradiation, trauma, infection • International adoption • Secondary to peripheral precocious puberty
Peripheral precocious puberty	• Ovarian causes -estrogen secreting tumors (granulosa cell tumor) androgen secreting tumors (arrhenoblastoma, sertoli-leydig cell tumors) • Adrenal causes- adrenal tumors, • Congenital adrenal hyperplasia, Cushings syndrome • McCune Albright syndrome (MAS) • Longstanding hypothyroidism • Incomplete precocious puberty

Table 2: Evaluation of Precocious Pubrty

Precocious Puberty	Evaluation
History	• Age of onset, sequence and progression of events • Time of onset of puberty in mother and siblings • Past history of any neurological disease/trauma/infections • Exposure to exogenous sex steroids in food, facial creams, drugs etc. • Social history- child sexual abuse, • international adoption
Physical Examination	• Height, Weight, Body mass index, growth velocity [cm/yr] • Tanner staging of pubic hair and breast • Examination of skin-cafe au last spots [McCune Albright syndrome] • Abdominal examination- any palpable abdominal mass • Opthalmoscopic examination fundoscopy, visual fields • Neurological examination • Signs of virilisation - hirsutism, clitoromegaly, deepening of voice
Biochemical investigations	• Basal gonadotropin (LH, FSH) levels. • GnRH stimulation tests • Estradiol/testosterone levels. • Adrenal steroids- DHEA-S, 17OH progesterone, androstenedione • (raised in adrenal tumors, congenital adrenal hyperplasia) • ACTH stimulation tests - congenital adrenal hyperplasia

EPTDEMIOLOGY

There have been reports of earlier pubertal development in girls across various populations. Cheng et al.'s review of the evidence shows that girls are still trending toward earlier puberty.[1, 4, 16]Girls are significantly more likely than boys to experience precocious puberty. According to Pallavee and Samal's clinical review, girls are more likely than boys to experience idiopathic central precocious puberty. [17, 18]Population characteristics, nutritional

status, body composition, socioeconomic circumstances, environmental exposures, and genetic background can all have an impact on variations in pubertal timing.Because higher BMI has been linked to earlier pubertal development in girls, the rising incidence of childhood obesity has also drawn attention.

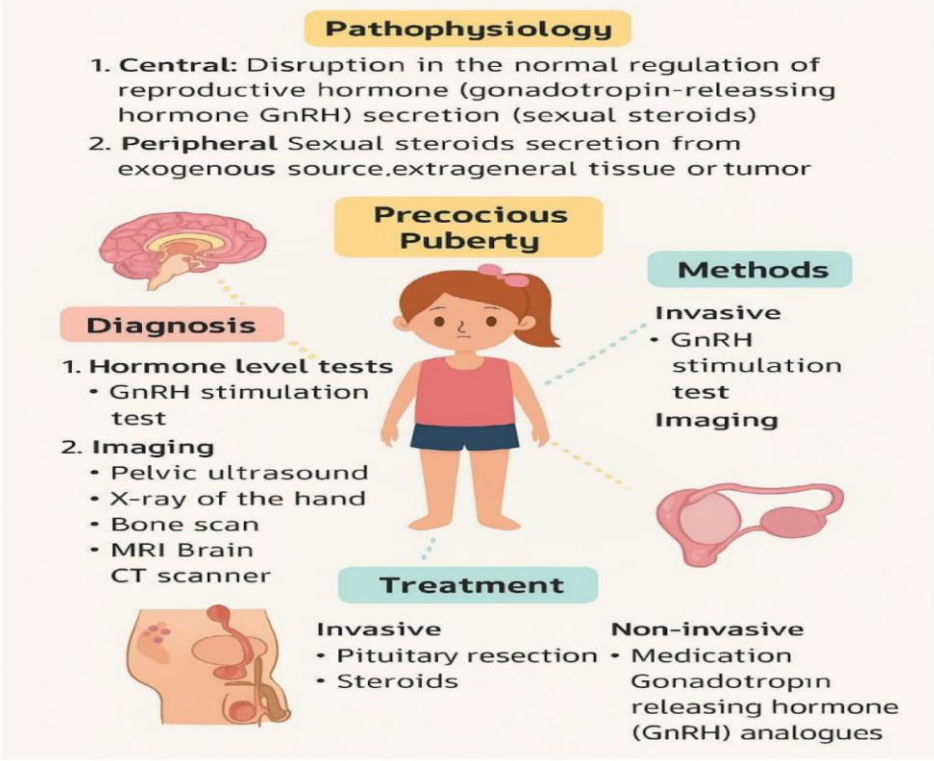


Figure 1: Overview of Precocious Puberty

Hormonal Mechanism

The control of puberty is largely dependent on the HPG axis. The anterior pituitary is stimulated to release LH and FSH by the hypothalamus's pulsatile release of GnRH. These hormones stimulate the production of estrogen by acting on the ovaries.The HPG axis is prematurely activated in central precocious puberty. Increased gonadotropin secretion follows, leading to the emergence of secondary sexual traits. [17, 18]Pubertal development takes place in peripheral precocious puberty without the HPG axis being prematurely activated. The gonads, adrenal glands, or outside sources may be the source of excess sex steroids. [17, 18]Clinical examination, hormonal testing, GnRH stimulation testing, bone-age assessment, and suitable imaging studies may all be used to evaluate suspected precocious puberty.[17]

Lifestyle Factors

Variations in pubertal timing may be caused by lifestyle factors. Important factors discussed in the reviewed literature include body weight, diet, physical activity, sedentary behavior, sleep and psychosocial stress.These elements shouldn't always be taken into account separately. For example, reduced physical activity may contribute to increased body weight, while prolonged screen exposure may be associated with sedentary behavior and changes in sleep patterns.As a result, lifestyle should be viewed as a collection of interrelated behaviors.

Obesity

One of the most often discussed factors linked to early puberty in girls is childhood obesity.Numerous studies have linked earlier development to higher BMI and increased adiposity.[14, 15]

Leptin and other hormones and signaling molecules are produced by metabolically active adipose tissue. Adiposity variations may have an impact on neuroendocrine pathways related to pubertal development.Because childhood obesity and overweight have become more prevalent, the connection between obesity and early puberty is especially significant. However, because pubertal timing is influenced by a variety of biological and environmental factors, obesity cannot account for all cases of early puberty

Diet

Dietary patterns may influence pubertal timing through their effects on energy balance, body composition and metabolic health.High-energy dietary patterns, frequent consumption of sugary drinks and certain processed or fried foods have been investigated in relation to childhood obesity and pubertal development.The available literature suggests that diet should be considered together with body weight and overall nutritional status rather than as an isolated cause of early puberty. [20]

Physical Activity

Physical activity is an important component of healthy childhood development. Reduced physical activity and prolonged sedentary behavior may contribute to increased adiposity and metabolic changes. [36, 40]The reviewed literature considers physical activity as one of several

lifestyle factors potentially associated with pubertal timing. Increased sitting time has also been observed among some groups of girls with obesity who had entered pubertal development.Regular physical activity may therefore have an indirect role through its effects on body composition and general metabolic health.

Sleep

Another lifestyle factor that has drawn more attention in connection to pubertal development is sleep.

Circadian rhythms may be impacted by irregular sleep schedules and excessive screen time in the evening. It has been suggested that alterations in circadian rhythm and sleep patterns may interact with hormonal pathways.Nevertheless, the evidence that is currently available does not prove that sleep disturbance is the only direct cause of early puberty. To fully understand this relationship, more long-term studies are needed.

Stress

Developmental endocrine pathways may interact with psychosocial stress. The psychological experience of puberty may be influenced by social relationships, school environments, and family situations.Because children may go through physical changes earlier than their peers, early puberty itself can also cause psychological stress.Early pubertal timing has been linked to anxiety, emotional problems, and a lower emotional quality of life, according to a 2026 scoping review. Positive school environments and social support from parents and peers may help lessen these detrimental effects. [4]

Environmental and Endocrine-Disrupting chemicals

Substances known as endocrine-disrupting chemicals (EDCs) have the potential to disrupt normal hormone function. They might have an impact on signaling, metabolism, hormone synthesis, or receptor activity. [5–13]Pesticides, phthalates, bisphenol A (BPA), and other industrial chemicals are a few examples covered in the literature. These chemicals can enter the body through consumer goods, food, water, air, or skin contact.Changes in pubertal timing have been suggested to be caused by environmental exposure. [5–13]The evidence isn't entirely consistent, though. Certain chemical exposures have been linked to pubertal development in some studies, but not in others. Therefore, rather than being a single proven cause, EDC exposure should be viewed as one part of a multifactorial explanation.

Genetic and other contributing factors:

In addition to lifestyle and environmental factors, genetic and biological factors also affect the timing of puberty.Individual variations in the age at which puberty begins can be attributed to genetic traits. Other factors that may be pertinent include body composition, metabolic status, maternal pubertal timing, and family history.Environmental and genetic factors may interact, according to the literature. [1, 4, 16]In order to identify children who might be at higher risk of early or precocious puberty, more recent research methods are also looking into the possibility of combining multiple variables, such as BMI, family history, dietary patterns, and lifestyle behaviors.

Health Consequences

Precocious and early puberty can have a number of negative physical effects. Accelerated skeletal maturation is one significant issue. Growth plates may close too soon due to advanced bone age, which could lower the potential for adult height. [17, 18]Additionally, there might be social and psychological repercussions. Children who go through puberty earlier than their peers may struggle with social relationships, emotional adjustment, and body image.Early puberty has been linked to anxiety, emotional issues, and a lower emotional quality of life, according to the reviewed scoping review. Additionally, it noted that while peer and school support may be protective, bullying, peer rejection, and unfavorable social environments could be risk factors.Children's behavioral and emotional outcomes may also be influenced by parenting style and parental stress. Parental stress, parenting style, and behavioral issues in girls with early puberty were linked, according to the review.

Prevention and Management

The type and underlying cause of early or precocious puberty determine how it should be managed.

Medical history, physical examination, pubertal progression assessment, hormonal testing, and bone-age assessment are all common components of clinical evaluation. In certain situations, more imaging might be necessary. [17, 18]GnRHanalogs are a proven treatment for central precocious puberty. They can delay pubertal development and skeletal maturation, as well as suppress premature activation of the HPG axis [17,18].Treatment for peripheral precocious puberty focuses on the underlying cause. Although they might not need special treatment, incomplete forms like isolated premature thelarche or premature adrenarche should be watched for progression. [17, 18, 19].

Maintaining a healthy weight, eating a balanced diet, getting enough exercise, and sleeping well are all important aspects of lifestyle management.Early puberty may have an impact on emotional health and family relationships, so psychological and familial support should also be taken into account.

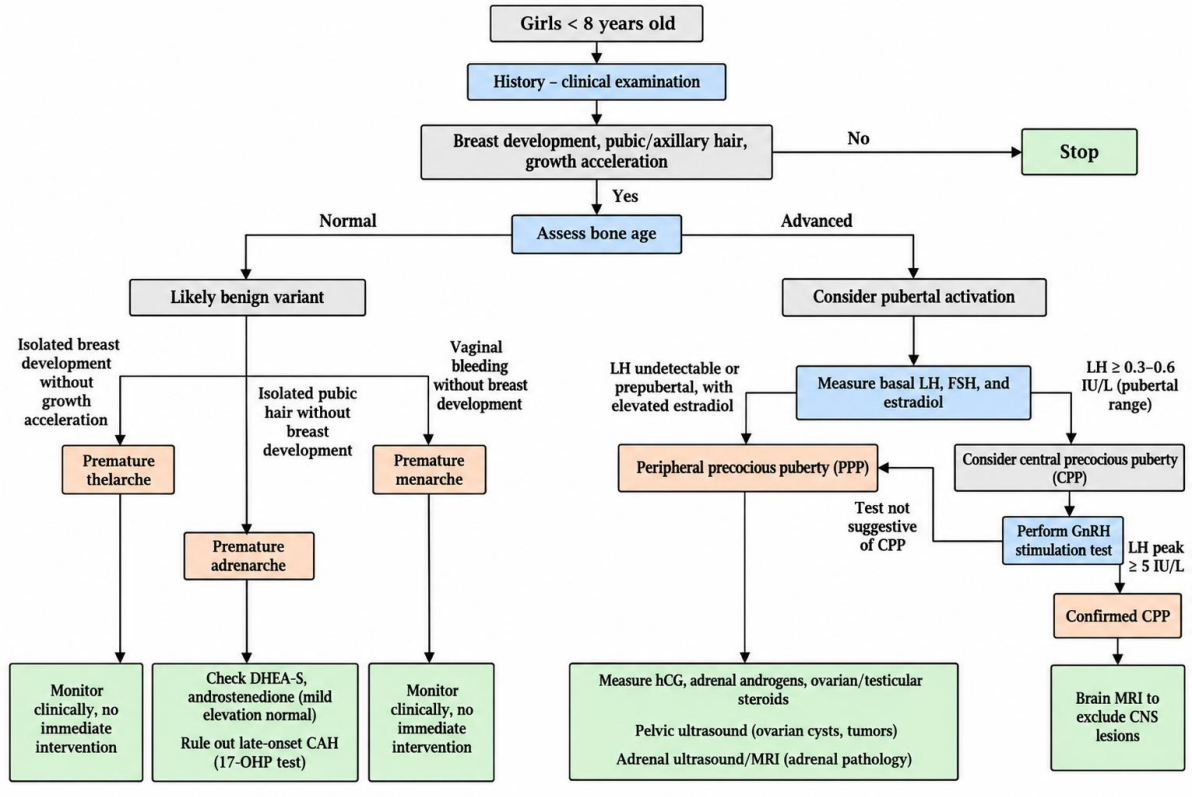
Research Gaps

Pubertal timing has been the subject of extensive research, but there are still a number of unresolved issues.Further research is needed to ascertain the effects of individual chemicals and combined exposures because the association between endocrine-disrupting chemicals and early puberty is not entirely consistent.To separate associations from causal relationships between lifestyle factors and early puberty, more long-term studies are also required.Research involving a variety of populations and cultural contexts is necessary to understand psychological and social effects. In particular, the recent scoping review highlights the need for more advanced methodologies and longitudinal research.Integrating genetic, hormonal, metabolic, environmental, and lifestyle data may be beneficial for future studies. Although constraints like small datasets,

population bias, interpretability, and privacy must be addressed, new technologies like artificial intelligence and longitudinal digital data may offer more chances for risk prediction.

Case study

In girls, isolated vaginal bleeding without breast development should raise suspicion for MAS, which results from a gain-of-function mutation in the GNAS gene.In MAS, PPP is driven by estrogen secretion from functional ovarian cysts, with vaginal bleeding often triggered by cyst involution and subsequent estrogen withdrawal. Additional findings, such as polyostotic fibrous dysplasia and café-au-lait macules with irregular "coast of Maine" borders, further support the diagnosis.



Clinical evaluation and bone age assessment are the first steps in the diagnostic process. tests for hormones, imaging and additional research aid in directing the categorization and suitable handling of each state. 17-OHP stands for 17-hydroxyprogesterone; CAH stands for congenital adrenal hyperplasia; Central nervous system (CNS); central precocious puberty (CPP); and dehydroepiandrosterone (DHEA-S) sulfate; gonadotropin-releasing hormone (GnRH); follicle-stimulating hormone (FSH); human chorionic gonadotropin; luteinizing hormone (LH); magnetic resonance imaging (MRI); peripheral early puberty. To sum up, a careful history and physical examination are still necessary to distinguish between benign and pathological forms of early puberty and directing proper management.

CONCLUSION

Hormonal, genetic, nutritional, lifestyle, environmental, and psychosocial factors all play a role in the multifactorial condition of early and precocious puberty in girls.Premature activation of the HPG axis, which is essential to normal pubertal development, causes central precocious puberty. Physical activity, sleep, and stress may interact with obesity and nutritional factors, which have been extensively studied as potential causes of early puberty.Although the evidence is still conflicting, environmental endocrine-disrupting chemicals are another area of interest.Early puberty can have effects that go beyond physical development, such as delayed bone maturation, diminished potential for adult height, and social or psychological challenges.Thus, appropriate clinical evaluation and customized treatment are crucial.In general, understanding early puberty requires a multidisciplinary approach that incorporates perspectives from the fields of medicine, nutrition, lifestyle, the environment, and psychology. To better understand causal mechanisms and enhance management, early detection, and prevention, more long-term studies are required.

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