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A Study on the Identification of "Critical Turning Points" in the Progression of Adolescent Obesity to Metabolic Syndrome and Strategies for Early Intervention

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ABSTRACT

To identify the "critical turning points" in the progression of adolescent obesity to metabolic syndrome (MetS), clarify its core characteristics and influencing factors, and propose scientifically sound and feasible early intervention strategies, thereby providing theoretical and practical support for halting disease progression and protecting the physical and mental health of adolescents,this study integrates relevant domestic and international research findings to elucidate the underlying mechanisms linking the two conditions. It analyzes key physiological, metabolic, and behavioral milestones during the progression process, summarizes influencing factors, and integrates intervention experiences to construct a comprehensive intervention system.The study found that the "critical turning points" in this progression are divided into two stages: the critical state of body fat accumulation in early adolescence (ages 10–13) and the onset of metabolic disorder in mid-adolescence (ages 14–16). Excessive body fat percentage (⩾25% for males, ⩾30% for females), the emergence of insulin resistance, and a waist-to-height ratio (WHR) height ratio ⩾0.5 are its core characteristics, while genetic susceptibility, poor diet, lack of exercise, insufficient sleep, and psychological factors are the primary influencing factors. The study indicates that early identification of critical changes in body fat and metabolic indicators, coupled with the implementation of a multidimensional comprehensive intervention involving "diet + exercise + psychology + family," can effectively halt the progression of adolescent obesity to metabolic syndrome and reduce the risk of chronic diseases in adulthood.

KEYWORDS

Adolescent obesity; Metabolic syndrome; Critical turning points; Early intervention; Insulin resistance

1 Introduction

1.1 Research Background

In recent years, global adolescent obesity rates have continued to rise, becoming a major public health issue. In China, the prevalence of adolescent obesity has been increasing year by year, with the obesity rate among 12- to 18-year-olds exceeding 15%. Some obese adolescents are gradually developing metabolic disorders, which may progress to metabolic syndrome.Metabolic syndrome (MetS) is a cluster of metabolic disorders characterized by central obesity, hyperglycemia, dyslipidemia, and hypertension. Essentially, it is a cluster of metabolic abnormalities triggered by insulin resistance. It not only affects adolescents' growth and development but also significantly increases the risk of chronic diseases such as type 2 diabetes, cardiovascular disease, and fatty liver disease in adulthood, thereby exacerbating the burden on individual health and placing additional pressure on the healthcare system.

Currently, it is widely recognized both domestically and internationally that adolescent obesity is the primary risk factor for MetS; however, there is no consensus on the specific progression from obesity to MetS or its critical turning points, leading to a lack of precision in early intervention.Most intervention measures focus solely on obesity itself, failing to implement precise interventions at the "critical turning points" during this progression, resulting in limited effectiveness. Therefore, identifying these "critical turning points," clarifying their characteristics and influencing factors, and developing scientific intervention strategies have become urgent priorities in the field of adolescent health.

1.2 Research Significance

Theoretical Significance: By elucidating the progression mechanisms linking adolescent obesity and MetS, clarifying the core characteristics and influencing factors of "critical turning points," and filling the gap in current research regarding the precise identification of key nodes in this progression, this study enriches the body of research on adolescent metabolic health and provides a theoretical foundation for future related research.

Practical Significance: Based on the identification of "critical turning points," this study proposes targeted early intervention strategies. It provides actionable prevention and control guidelines for schools, families, and medical institutions, helping adolescents avoid the risk of metabolic diseases, promoting their physical and mental health development, and simultaneously reducing the long-term social burden of chronic diseases.

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1.3 Current State of Research

Overseas research began earlier and has demonstrated that body fat distribution, insulin resistance, and inflammatory responses are closely associated with the onset of MetS. While it has been proposed that adolescence is a critical period for progression, specific turning points and core characteristics have not been clearly identified. Intervention strategies often focus on single lifestyle factors, lacking specificity and systematicity. Domestic research has largely focused on isolated studies of adolescent obesity or MetS, with insufficient attention paid to the progression between the two. Few studies have explored the identification of turning points, and intervention measures have largely been adapted from adult protocols without fully considering the growth and developmental characteristics of adolescents, leaving room for improvement in effectiveness. Furthermore, there is no international consensus on diagnostic criteria for MetS in children and adolescents; most criteria are modified versions of adult standards, posing challenges for the precise identification of turning points.

2 Identification of "Key Turning Points" in the Progression from Adolescent Obesity to Metabolic Syndrome

2.1 Core Definition of Critical Turning Points

The "critical turning point" in the progression of adolescent obesity to MetS refers to the pivotal physiological, metabolic, or behavioral change that occurs as adolescents transition from simple obesity to metabolic dysregulation and ultimately develop MetS. It represents a crucial demarcation point in disease progression and the optimal window for early intervention. At this stage, adolescents have not yet developed typical MetS; scientific intervention can reverse metabolic disturbances and halt disease progression. If this window is missed, metabolic disturbances will worsen, increasing the difficulty of intervention and long-term disease risks.

2.2 Stages and Core Characteristics of the Critical Turning Point

Based on the patterns of adolescent growth and development and the characteristics of metabolic changes, the "critical turning points" are divided into two core stages, each with distinct features that can serve as key indicators for identification.

2.2.1 First Turning Point: Early Adolescence (10–13 years) — Critical State of Body Fat Accumulation

Early adolescence is a critical stage of growth and development for adolescents and a period of rapid body fat accumulation. Its core characteristics include body fat percentage reaching critical thresholds: ⩾25% for males and ⩾30% for females; waist-to-height ratio ⩾0.5 (indicating central obesity); BMI ⩾ the 95th percentile for adolescents of the same age and gender. At this stage, adolescents do not exhibit obvious metabolic abnormalities, but excessive body fat accumulation has already led to reduced insulin sensitivity, serving as a "prelude" to the onset of MetS.

Body fat accumulation during this stage is primarily characterized by rapid accumulation of visceral fat. Visceral fat secretes adipokines, triggering chronic low-grade inflammation that gradually impairs insulin function and initiates the process of metabolic dysfunction. Relevant studies indicate that BMI offers greater accuracy and convenience than waist circumference or waist-to-hip ratio in identifying evolving risks, making it a suitable baseline indicator; combining it with body fat percentage and waist-to-height ratio can further enhance precision.

2.2.2 Second Turning Point: Mid-adolescence (14–16 years) — Initiation of Metabolic Dysregulation

If no effective intervention occurs at the first turning point, continued accumulation of body fat will exacerbate the metabolic burden, leading to the second turning point. The core characteristic of this stage is marked metabolic disorder: fasting blood glucose ⩾ 6.1 mmol/L (impaired glucose regulation); triglycerides ⩾ 1.7 mmol/L; high-density lipoprotein cholesterol (HDL-C) < 0.9 mmol/L in males and < 1.0 mmol/L in females; systolic blood pressure ⩾ 130 mmHg or diastolic blood pressure ⩾ 85 mmHg (prehypertension or hypertension); homeostatic model assessment of insulin resistance (HOMA-IR) ⩾ 2.5.

Insulin resistance is the core pathological feature of this stage, leading to metabolic disorders through mechanisms

Table 1 Metabolic Indicators

Test Parameter	Threshold	Clinical Notes
Fasting Blood Glucose	⩾6.1 mmol/L	Indicates impaired glucose regulation and is a key indicator of abnormal glucose metabolism
Triglycerides	⩾1.7 mmol/L	One of the key indicators of dyslipidemia
High-density lipoprotein cholesterol (HDL-C)	Men < 0.9 mmol/L; Women < 1.0 mmol/L	As "good cholesterol," low levels indicate abnormal lipid metabolism
Systolic blood pressure / Diastolic blood pressure	Systolic blood pressure ⩾ 130 mmHg or diastolic blood pressure ⩾ 85 mmHg	Indicates prehypertension or hypertension, reflecting cardiovascular metabolic abnormalities
Insulin Resistance Index (HOMA-IR)	⩾2.5	Directly reflects the presence of insulin resistance in the body and is the core pathological indicator at this stage

such as endothelial dysfunction and increased renal sodium reabsorption. Adolescents are in a pre-MetS state; timely intervention can reverse these disorders. If the condition progresses, it will meet the diagnostic criteria for MetS, entering a stage of irreversible metabolic damage. Note that metabolic indicators in adolescents vary by age and gender; identification must be based on reference standards for the same age and gender to avoid misdiagnosis.

2.3 Factors Influencing Key Turning Points

The timing of the turning point and the rate of progression are influenced by multiple factors, including genetics, environment, lifestyle, and psychology. These factors interact with one another, collectively driving or delaying the progression of the disease.

2.3.1 Genetic Factors

Genetic susceptibility is a key internal factor. If one or both parents have conditions such as obesity, MetS, diabetes, or hypertension, adolescents face a significantly increased risk of obesity and progression to MetS, and the turning point may occur earlier. MetS exhibits a marked familial clustering pattern. Genetic factors increase the risk of metabolic disorders by influencing insulin sensitivity, lipid metabolism, and energy metabolism; however, some of this genetic risk can be mitigated through effective lifestyle interventions.

2.3.2 Environmental and Lifestyle Factors

These are the core external, modifiable factors: First, an unhealthy diet characterized by long-term consumption of high-sugar, high-fat, and high-salt foods, coupled with insufficient dietary fiber and high-quality protein, leads to energy excess and accelerated body fat accumulation. Second, a lack of physical activity, prolonged sedentary behavior, and insufficient aerobic exercise and strength training result in inadequate energy expenditure, increased body fat percentage, and decreased insulin sensitivity. Third, insufficient sleep—such as chronic sleep deprivation and poor sleep quality—disrupts the secretion of leptin and ghrelin, leading to abnormal appetite and impaired metabolic function; fourth, unhealthy habits, such as frequent consumption of sugary drinks, binge eating, and irregular meal schedules, further exacerbate body fat accumulation and metabolic damage.

2.3.3 Psychological Factors

Adolescents face academic and peer-related pressures, making them prone to negative emotions such as anxiety, depression, and low self-esteem. These emotions affect metabolic function through neuroendocrine regulation, leading to appetite disorders and reduced motivation to exercise, thereby accelerating the onset of the turning point. Obese adolescents are prone to discrimination based on their body shape, which exacerbates negative emotions and creates a vicious cycle of "obesity – negative emotions – metabolic disorders." Additionally, insufficient family health beliefs and a lack of parental attention can indirectly influence the timing of the turning point.

The interplay of multiple factors—including genetics, environment, lifestyle, and psychology—drives or delays the emergence and progression of the critical turning point in the evolution of adolescent obesity into MetS, thereby identifying targeted directions for the development of subsequent intervention strategies.

3 Early Intervention Strategies for the Progression of Adolescent Obesity to Metabolic Syndrome

Early intervention adheres to the principles of "precision targeting, comprehensive measures, and full-process management." It focuses on two key turning points and, based on the characteristics and influencing factors of different stages, establishes a multidimensional, comprehensive intervention system encompassing "diet, exercise, psychology, and family" to achieve early detection, early intervention, and early reversal of metabolic disorders.

3.1 Intervention Strategy for the First Turning Point (Ages 10 – 13) — Focusing on Body Fat Control to Prevent the Onset of Metabolic Disorders

The core objective is to control body fat accumulation, reduce the incidence of central obesity, and maintain normal insulin sensitivity. The key lies in adjusting lifestyle to establish healthy dietary and exercise habits.

3.2 Dietary Intervention

The core approach involves controlling total energy intake and optimizing dietary composition: Calculate daily energy requirements based on adolescents' growth and development needs; limit high-sugar, high-fat, and high-sodium foods; and reduce consumption of sugary beverages, fried foods, and snacks; Increase intake of dietary fiber and high-quality protein; consume more vegetables, fruits, whole grains, lean meats, and soy products to ensure nutritional balance; establish regular meal times, avoid overeating, control eating speed, and refrain from eating within one hour before bedtime. Consider adopting the Mediterranean or DASH dietary patterns to reduce metabolic burden.

Key Features of the Mediterranean Diet: Originating from countries along the Mediterranean coast, this balanced dietary pattern centers on high-plant foods, healthy fats, and high-quality protein: Fresh fruits and vegetables, whole

grains, legumes, and nuts form the foundation of the diet, providing ample dietary fiber and antioxidants;It uses extra virgin olive oil as the primary fat source (rich in monounsaturated fatty acids) and obtains omega-3 fatty acids from deep-sea fish; it prioritizes high-quality protein from fish and poultry while limiting red meat, processed foods, refined sugars, and sugary beverages; cooking methods focus on steaming, boiling, and cold salads, emphasizing the natural state of foods. There are no strict food restrictions, making it easy to follow long-term.

Core Features of the DASH Diet: Officially known as the Dietary Approaches to Stop Hypertension (DASH), this diet was originally designed to prevent and control hypertension. Its core principles include high potassium, magnesium, and calcium; high dietary fiber; and low sodium and saturated fat: Increase intake of fruits, vegetables, whole grains, low-fat dairy products, lean meats, and legumes; obtain minerals such as potassium, magnesium, and calcium from natural foods; Strictly limit sodium (recommended daily intake <2, 300 mg), refined sugars, processed foods, and saturated fats; by balancing dietary intake with metabolic control, it can simultaneously improve blood pressure, blood lipid levels, and blood glucose levels.

Both dietary patterns are suitable for the intervention goals of body fat control and preventing the onset of metabolic disorders in early adolescence (ages 10 – 13), and they align with the nutritional needs of adolescent growth and development:

Nutritional balance: Both emphasize the intake of whole grains, high-quality protein, and high dietary fiber, thereby controlling energy excess from high sugar and high fat while ensuring the nutrients required for adolescent growth and development, and avoiding stunted growth caused by excessive dieting;

Targeted Prevention and Control of MetS Risk Factors: Characterized by low refined sugar, low saturated fat, and limited processed foods, these diets can reduce body fat accumulation and improve insulin sensitivity; the low-sodium nature of the DASH diet can help prevent prehypertension in adolescents early on, while the unsaturated fatty acids in the Mediterranean diet can improve lipid metabolism—both targeting the core pathological mechanisms of MetS;

Ease of implementation and sustainability: With no extreme food restrictions and a dietary structure closely aligned with daily eating habits, these diets are suitable for implementation in a family setting. They facilitate the development of long-term healthy eating habits in adolescents and, when combined with family-based interventions, create a synergistic effect;

Alignment with the need to reduce metabolic burden: Both diets emphasize natural foods and reduce the intake of fried, high-sodium, and high-sugar processed foods, thereby reducing metabolic burden at the dietary source. This aligns with the core intervention requirements of the first turning point: "controlling body fat and maintaining normal insulin sensitivity."

Both models can be flexibly adapted to China's dietary culture (e.g., substituting olive oil with tea seed oil, reducing intake of lactose-containing products), eliminating the need for a rigid, one-size-fits-all approach and making them more suitable for localized dietary interventions for adolescents.

3.3 Exercise Intervention

The core objectives are to increase energy expenditure, reduce body fat accumulation, and improve insulin sensitivity: Based on the dual authoritative recommendations of the World Health Organization (WHO) Global Guidelines on Physical Activity and the American Academy of Pediatrics (AAP), adolescents aged 5 – 17 should engage in at least 60 minutes of moderate-intensity aerobic exercise (such as brisk walking, jogging, swimming, or skipping rope) daily, and perform strength training (such as push-ups, sit-ups, or dumbbell exercises) at least three times a week to increase muscle mass and boost basal metabolic rate. Strengthen the coordination of physical activity interventions between schools and families. Schools should ensure that physical education classes are fully implemented and utilize extended recess periods and after-school sports activities to fulfill the core component of the daily 60-minute exercise requirement. They should also establish sports clubs—such as ball games and jump rope—based on adolescents' interests to avoid encroaching on physical activity time; Families should complement this by providing additional physical activity after school and on weekends. Parents should encourage adolescents to exercise through parent-child activities and outdoor time together. Schools and families should jointly monitor adolescents to reduce sedentary time and screen time, adjust exercise intensity based on individual fitness levels to prevent injuries, and work together to foster an interest in physical activity.

3.4 Family Intervention

Parents should serve as role models by adjusting family dietary habits and participating in physical activities with adolescents to prevent their own unhealthy habits from having a negative influence; regularly monitor indicators such as body fat percentage and BMI to promptly identify abnormalities and intervene; provide encouragement and support to adolescents, avoid criticizing them based on body shape, and protect their self-confidence.

Intervention Strategies for the Second Turning Point (Ages 14 – 16) — Focusing on Metabolic Regulation to Reverse Metabolic Dysfunction.

The core objective is to reverse abnormal metabolic indicators, improve insulin resistance, and control blood glucose,

blood lipids, and blood pressure to prevent the progression to classic MetS. Intervention measures are more precise and comprehensive, combining dietary, exercise, psychological, and necessary medical interventions.

3.5 Targeted Dietary Intervention

Building on the first turning point, adjustments are made based on abnormal metabolic indicators: individuals with elevated blood glucose should strictly limit carbohydrates, choose low-glycemic-index foods, and avoid refined sugars and refined grains; those with abnormal blood lipids should reduce saturated and trans fats while increasing unsaturated fats (such as deep-sea fish and nuts); those with hypertension should limit daily salt intake to no more than 5g; metabolic indicators should be monitored regularly, and dietary plans dynamically adjusted. "8-hour time-restricted eating" is not currently recommended as a routine protocol, as its safety and efficacy in adolescents have not yet been fully validated.

3.6 Personalized Exercise Interventions

Develop a plan based on metabolic indicators and physical fitness: Individuals with abnormal blood glucose or lipid levels should increase the intensity and duration of aerobic exercise, aiming for at least 5 sessions per week, 30 – 60 minutes each; those with concomitant hypertension should avoid strenuous exercise and opt for moderate aerobic activities such as tai chi or walking, while controlling the intensity; continue to strengthen resistance training to improve insulin sensitivity. Closely monitor heart rate and blood pressure during exercise to ensure safety.

3.7 Psychological Intervention

Through psychological counseling and group therapy, help adolescents develop a correct understanding of obesity and metabolic disorders, foster a healthy body image, and alleviate negative emotions such as anxiety and low self-esteem; guide them to relieve stress through exercise and hobbies, thereby breaking the vicious cycle of "obesity – negative emotions–metabolic disorders."

3.8 Medical Intervention

For individuals with severe metabolic abnormalities, seek medical attention promptly in addition to lifestyle interventions. Under a doctor's guidance, implement necessary medical interventions: Strictly control the indications for pharmacological interventions, reserving them only for adolescents with severe obesity unresponsive to lifestyle interventions or those with clear complications (e.g., GLP-1 receptor agonists for children aged ⩾12 with severe obesity, and metformin to improve insulin resistance). Closely monitor drug safety;For adolescents aged 13 years or older who are severely obese and have severe complications, bariatric surgery may be considered at a comprehensive medical center, with strict adherence to indications and long-term follow-up.

3.9 Comprehensive Intervention Safeguards

First, establish a screening mechanism targeting critical turning points. Schools and medical institutions should conduct regular, phased screenings for adolescents during puberty, focusing on core indicators at two key turning points: For adolescents aged 10–13, focus on the first turning point by screening for indicators related to body fat accumulation, such as body fat percentage, waist-to-height ratio, and BMI;For adolescents aged 14 – 16, focus on the second turning point by screening for metabolic disorder-related indicators such as fasting blood glucose, triglycerides, HDL cholesterol, blood pressure, and the homeostatic model assessment of insulin resistance (HOMA-IR). Individuals with abnormal results should be promptly flagged and enrolled in intervention management. Concurrently, establish dynamic health records for each individual to achieve precise identification of turning points and monitoring of indicators.

Second, strengthen health education centered on these turning points. Through school lectures, family outreach, new media outreach, and visits by health vice principals to schools. The core of these efforts is to popularize the concept of key turning points, with a focus on explaining the stages, core characteristics, significance of identification, and the critical value of early intervention for these two turning points. Additionally, we will disseminate methods for identifying corresponding indicators, promote healthy lifestyles, and outline key intervention strategies. This ensures that school staff, parents, and adolescents themselves fully understand these turning points, acquire the ability to accurately identify them and respond early, and enhance proactive prevention and control awareness across all stakeholders.

Third, establish a multi-departmental coordination mechanism with clear divisions of labor, integrating resources from schools, families, medical institutions, and communities, and defining the core responsibilities of each stakeholder: Schools serve as the primary screening entities, leading the implementation of phased screening for adolescents during puberty, maintaining screening records, and promptly communicating results to families and medical institutions. They also implement physical activity intervention requirements through physical education classes and extended recess periods; Families, as the supervisory entities, are responsible for implementing and monitoring daily interventions regarding diet, exercise, and sleep; they closely monitor changes in adolescents' physical indicators and maintain records, promptly communicating any abnormalities to schools and medical institutions;Medical institutions serve as the primary providers of diagnosis and treatment, conducting precise diagnoses for those with abnormal screening indicators,

developing personalized intervention plans, and providing comprehensive professional medical guidance and follow-up care; communities facilitate resource coordination, implement health education, and ensure access to facilities, with all four parties working together to form a collaborative intervention effort where each fulfills its respective duties.

Fourth, establish a long-term follow-up mechanism tailored to developmental milestones. Create personalized follow-up records for individuals at different developmental stages, regularly monitor key indicators and the implementation of lifestyle habits during corresponding phases, and dynamically optimize dietary and exercise plans based on changes in indicators and intervention outcomes. Simultaneously, track progress at these developmental milestones to promptly halt the progression from body fat accumulation to metabolic disorders, ensuring the sustainability and effectiveness of interventions.

4 Conclusion

The progression of adolescent obesity to MetS is a gradual process characterized by two distinct "critical turning points": the critical state of body fat accumulation in early adolescence (ages 10–13) and the onset of metabolic disorder in mid-adolescence (ages 14–16). Excess body fat percentage, a waist-to-height ratio ⩾0.5, and the emergence of insulin resistance are the core identifying characteristics; genetic susceptibility, unhealthy lifestyles, psychological factors, and family environment are the primary influencing factors.

Implementing precise, comprehensive interventions at these two turning points is key to halting the progression: at the first turning point, interventions focus primarily on diet, exercise, and family support, with the core objective being to control body fat and prevent the onset of metabolic disorders; at the second turning point, interventions combine lifestyle, psychological, and necessary medical interventions, with the core objective being to reverse metabolic disorders. By establishing mechanisms for screening, health education, coordinated intervention, and follow-up, the targeting and effectiveness of interventions can be enhanced, helping adolescents avoid the risk of metabolic diseases, promoting physical and mental health, and reducing the risk of chronic disease onset and the social and medical burden in adulthood.

This study has limitations: the precision of the turning points was not validated using clinical data, and the long-term effects of the intervention strategies require further follow-up. Future research could focus on large-scale clinical data to refine identification indicators and intervention protocols, and develop personalized strategies based on individual differences. Concurrently, efforts should be made to establish international consensus on diagnostic criteria for MetS in children and adolescents to improve screening efficiency and research comparability, thereby ensuring the accuracy of identification and intervention.

References

[1] Dou Yalan, Zhang Yi, Chen Xiaotian, et al. Evidence-Based Practice Guidelines for Screening Obesity-Related Cardiovascular and Metabolic Risks Using Waist-to-Height Ratio in Chinese Primary and Secondary School Students [J]. Chinese Journal of Evidence-Based Pediatrics, 2024, 18(6): 401-410.

[2] Yan Weili. Establishment of an Evidence-Based System for Screening and Intervention of Cardiovascular and Metabolic Risks in Obese Children [J]. Chinese Journal of Pediatrics, 2021, 59(10): 801-805.

[3] Li Ping, Yang Fan, et al. Individualized Intervention Strategies for Childhood and Adolescent Obesity in the Context of Precision Medicine [J]. Chinese Journal of Integrated Traditional and Western Pediatrics, 2026, 18(1): 1-6.

[4] Wang Yan, Zhang Fan, et al. Effects of Insulin Resistance on Metabolic Indicators and Analysis of Key Risk Factors in Obese Mongolian Adolescents [J]. China Medical Herald, 2025, 22(30): 102-106.

[5] Chen Wenfeng, Liang Songshang, Tang Minqiang. Effects of Circuit Training on Metabolic Syndrome in Obese Adolescents [J]. Chinese School Health, 2024, 45(6): 807-811.

[6] Pediatric Endocrinology, Genetics, and Metabolism Branch of the Guangdong Health Association. South China Expert Consensus on the Diagnosis and Management of Overweight and Obesity in Children and Adolescents (2025) [J]. Journal of Sun Yat-sen University (Medical Sciences), 2025, 46(4): 541-557.

[7] Liu Min, Li Li, et al. Long-term Effects of Lifestyle Intervention on Metabolic Parameters and Insulin Resistance in Obese Adolescents [J]. Chinese Medical Journal, 2025, 105(16): 1234-1239.

[8] Zhang Xue, Wang Jing, et al. Meta-analysis of the Effect of Vitamin D Supplementation on the Intervention of Metabolic Syndrome in Obese Adolescents [J]. Chinese Journal of Evidence-Based Medicine, 2025, 25(12): 1401-1408.