Value of Mediterranean Diet in Adolescent Obesity Management

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Abstract. In recent decades, there has been a significant global increase in overweight and obesity rates among the 5-19 age group, with adolescent obesity prevalence surging more than sixfold in certain nations. Adolescent obesity not only predisposes individuals to health complications such as fatty liver disease, respiratory dysfunction, and skeletal developmental abnormalities, but also poses significant long-term health risks. In light of the escalating global public health challenge posed by adolescent obesity, this paper first examines the diagnostic criteria, salient characteristics, and primary causative factors of youth obesity. Building upon this foundation, it systematically explores how the Mediterranean diet (MD), with its natural and balanced nutritional composition, provides both theoretical foundations and practical guidance for the scientific prevention and management of adolescent obesity. Multiple controlled trials and longitudinal data analyses demonstrate that MD significantly reduces waist circumference and visceral adipose tissue area, while effectively attenuating the annual increase in body mass index. The underlying mechanism involves polyphenols modulating the PPARγ pathway to inhibit adipocyte differentiation, ω-3 fatty acids alleviating adipose tissue inflammation, as well as dietary fiber and magnesium enhancing insulin sensitivity and energy metabolism. Furthermore, the synergistic effect of diet and exercise can further increase muscle mass and improve body composition. Home-implemented MD demonstrates significant efficacy in reducing obesity rates. Additionally, it fosters the natural development of healthier eating habits among children by leveraging the interplay between their living environment and daily behaviors. This not only provides robust evidence but also offers practical strategies for addressing weight-related issues in adolescents.

Keywords: Mediterranean Diet, Adolescent management, Disease Prevention.

1. Introduction

With the advancement of society, adolescent obesity has emerged as a global public health crisis. In recent years, the mean body mass index (BMI) and prevalence of obesity among children and adolescents from 5 to 19 years old have exhibited a persistent upward trend globally. The age-standardized obesity prevalence has risen from 0.7% to 5.6% in girls and from 0.9% (0.5–1.3) to 7.8% in boys. This phenomenon is particularly pronounced in regions such as Asia and Africa [1]. Obesity not only predisposes adolescents to manifestations of metabolic syndrome—such as hypertension, insulin resistance, and dyslipidemia—but also elevates their long-term risks of developing cardiovascular diseases and type 2 diabetes in adulthood. Concurrently, it may contribute to a range of psychological issues. Therefore, it is crucial to maintain physical and mental well-being through scientifically supported approaches. While physical activity is one viable strategy for weight management, relying exclusively on exercise often leads to unsustainable outcomes and a high likelihood of weight regain. In contrast, adopting a rationally designed dietary plan is even more pivotal, particularly when viewed from the perspective of nutrition as an integral part of daily life. Among various health-promoting dietary patterns, the Mediterranean Diet model, originating from the Mediterranean region, has gained global popularity in recent years and received extensive acclaim from nutrition experts. The Mediterranean Diet represents a traditional eating pattern centered on health principles. It emphasizes high consumption of vegetables, fruits, whole grains, nuts, and olive oil, moderate intake of fish and poultry, and limited consumption of red meat, processed foods, and sweets. This dietary pattern is rich in monounsaturated fatty acids, dietary fiber, antioxidants, and features a well-balanced fatty acid profile [2].

A growing body of evidence suggests that the Mediterranean diet may help mitigate obesity risk in adults, however studies on its application among adolescent populations are still lacking. Although early findings indicate that this dietary pattern may have a beneficial effect on BMI, blood glucose, and lipid profiles in obese adolescents, its long-term efficacy, cross-cultural applicability, and specific mechanisms of action are not yet fully understood. Consequently, this study focuses on the Mediterranean diet, conducting an in-depth analysis of its mechanisms and practical efficacy in weight management and metabolic indicators among overweight and obese adolescent populations. This study aims to establish scientific theoretical foundations and provide practical references based on the Mediterranean dietary pattern for this demographic group, with the objective of addressing the increasingly severe epidemic of adolescent obesity and exploring effective dietary interventions for its prevention and control.

2. Diagnostic Criteria for Adolescent Obesity

The international standard for diagnosing adolescent obesity primarily employs age-specific BMI percentile classification. The specific criteria are as follows: A comparison is made between the adolescent's BMI and age- and sex-matched reference populations. Obesity is diagnosed when the BMI is≥95th percentile, while a BMI between the 85th and 94th percentiles is classified as overweight [3]. This standard is established based on the WHO Growth Reference Standards and demonstrates strong universal applicability. However, three critical considerations must be noted: Firstly, BMI cannot differentiate between adipose and muscle tissue, potentially leading to misclassification for individuals with high muscularity. Secondly, concurrent presence of growth retardation (annual growth velocity <4cm) or developmental abnormalities necessitates investigation of endocrine disorders such as growth hormone deficiency. Thirdly, clinical assessment of body fat distribution patterns is essential, particularly given that central obesity carries higher metabolic risks. Furthermore, for adolescents in the rapid growth and development phase, it is recommended to monitor BMI percentile trends every three months. When BMI approaches the threshold value, body fat percentage measurement should be incorporated as a supplementary diagnostic criterion (with ≥20% for males and ≥25% for females). Finally, it should be noted that variations exist in body fat distribution across different ethnic groups, necessitating the application of ethnicity-specific standards when required.

3. Characteristics of Adolescent Obesity

Adolescent obesity exhibits a distinct set of physiological and metabolic features that differentiate it from obesity in other life stages. At the physiological level, the most prominent change involves significant hormonal fluctuations, which induce alterations in adipose tissue metabolism. During adolescence, significant hormonal fluctuations occur in estrogen, leptin, and insulin, with leptin resistance and aberrant insulin signaling pathways being particularly prevalent [4]. This metabolic shift thereby promotes the disproportionate buildup of adipose tissue in the abdominal and visceral regions, producing the typical central obesity pattern. At the same time, adipocytes not only are at their highest number but also enlarge considerably, showcasing the unique cellular feature of "concomitant hyperplasia and hypertrophy" [5]. This change links to accelerated differentiation of adipocyte precursor cells and upregulation of lipogenic enzyme activity, and greatly raises the risk of future weight rebound. Moreover, obesity may disrupt the normal timing of puberty, which occurs more often in females and usually appears as premature breast development. This precocious puberty, in turn, worsens adipose tissue accumulation through endocrine feedback mechanisms, creating a self-perpetuating physiological cycle [6].

Metabolically, adolescents with obesity may exhibit early-onset insulin resistance and dyslipidemia, frequently accompanied by elevated serum free fatty acid levels, increased triglyceride synthesis, and a low-grade inflammatory state. Although these early changes in metabolism do not cause obvious symptoms, they gradually increase the risk of type 2 diabetes mellitus and

cardiovascular diseases over time [1]. A major concern is the visceral adipose tissue accumulation often seen in adolescent obesity, which is closely linked to metabolic syndrome. This adipose tissue not only demonstrates high endocrine activity but also systemically disrupts glucose and lipid metabolism through the secretion of various adipokines, thereby significantly elevating the risk of chronic diseases in later life.

From a comprehensive perspective, adolescent obesity manifests not only through distinctive physiological characteristics such as adipose tissue distribution and cellular alterations, but also demonstrates multifaceted metabolic dysfunctions with pathological potential. This condition constitutes a complex health issue involving neuroendocrine regulation, molecular-cellular events, and multi-organ system interactions.

4. Primary Causes of Adolescent Obesity

The development of obesity in adolescents results from the complex interplay between genetic and environmental factors [7]. Genetically, individuals are born with varying degrees of susceptibility to obesity from an environmental perspective, the contributing factors primarily encompass the wave of large-scale urbanization, shifts in modern dietary patterns, reduced physical activity and increased sedentary behaviors among adolescents, maternal obesity during pregnancy, infant feeding practices, adverse childhood experiences, endocrine disorders, medication usage, sleep deprivation, and chronic stress [2].

With the evolving social environment, the impact of environmental factors has become increasingly pronounced. The rapid urbanization process, in particular, has significantly altered the lifestyles of adolescents. The modern dietary structure exhibits a growing proportion of processed foods high in sugar and calories, while physical activity has substantially decreased. Prolonged screen time has led to the widespread prevalence of sedentary behaviors. These factors collectively disrupt the body's energy balance. During adolescence specifically, poor dietary habits or unhealthy lifestyles further elevate the risk of obesity. Furthermore, maternal obesity during pregnancy may also elevate the risk of adolescent obesity. Extensive research has elucidated specific mechanisms, such as glucose and lipid metabolism disorders. A cohort study involving 1,325 pregnant women identified five metabolic subtypes through unsupervised cluster analysis. The study revealed that compared to metabolically normal pregnant women, offspring of mothers in the "insulin resistance-hyperglycemia" subgroup exhibited a significant 4.27% increase in body fat percentage at age 5, with an 8.7-fold higher risk of developing high body fat relative to the control group [8]. Moreover, feeding practices during infancy and early childhood are equally pivotal. A retrospective study involving 1,106 full-term neonates revealed that infants who experienced overfeeding (≥30mL per feeding) on the first postnatal day demonstrated a 5.19-fold increased risk of developing overweight or obesity by age 4 when five out of their first seven feedings were excessive, compared to non-overfed infants. This risk escalated to 7.22-fold when all seven initial feedings exceeded the threshold [9]. In addition, adverse childhood experiences (such as economic adversity, abuse, or neglect) may also contribute to an increased risk of obesity. Research indicates that adolescents with adverse experiences exhibit a neuroendocrine-mediated programming of obesity risk, manifested behaviorally through a heightened propensity for selecting high-calorie food options in dietary patterns [10]. Additionally, certain endocrine disorders (e.g., hypothyroidism) and medications (e.g., glucocorticoids) may also contribute to abnormal weight gain. It is noteworthy that prevalent modern lifestyle issues such as sleep deprivation and chronic stress can further disrupt energy metabolism regulation mechanisms, thereby exacerbating the onset and progression of obesity. These multi-layered risk factors underscore the necessity of implementing comprehensive prevention and control strategies for obesity intervention, commencing from early life stages.

5. Fundamental Structure and Characteristics of the Mediterranean Diet

The traditional MD is predominantly plant-based, comprising an abundance of vegetables, fruits, minimally refined grains, legumes, root vegetables (e.g., potatoes), nuts, and seeds. It emphasizes the use of locally sourced, seasonal ingredients with minimal processing [11]. Virgin and extra virgin olive oils serve as the primary sources of dietary fat in the Mediterranean eating pattern. In MD, the core value of olive oil lies in its abundant bioactive compounds, including α-tocopherol, carotenoids, oleuropein, phytosterols, and oleocanthal with ibuprofen-like activity [12]. These components are instrumental in enhancing metabolic health and mitigating obesity-associated chronic low-grade inflammation for individuals at risk of adolescent obesity. Olive oil contains 70-80% oleic acid by composition. Moderate consumption of olive oil can elevate high-density lipoprotein cholesterol levels, thereby mitigate the oxidation of low-density lipoprotein and reduce visceral adipose tissue accumulation. Meanwhile, the phytosterols and tocopherols present in olive oil also exhibit distinctive physiological functions. Phytosterols competitively inhibit cholesterol absorption and reduce serum total cholesterol levels by 5-10%, while tocopherols protect cellular membranes from lipid peroxidation damage, maintain mitochondrial function, and promote lipolysis. In addition, olive oil modulates glycemic homeostasis by delaying gastric emptying and inhibiting α-glucosidase activity, thereby attenuating postprandial blood glucose spikes. Within the Mediterranean dietary pattern, dairy consumption primarily consists of moderate amounts of cheese and yogurt. Egg consumption is typically limited to 0-4 units per week, with moderate intake recommended for fish and poultry, while red meat should be consumed sparingly. Desserts predominantly feature fresh fruits, with sugar-based and honey-infused confections consumed only on an occasional basis. Moderate consumption of wine (particularly red wine) constitutes a defining characteristic of this dietary pattern. Comprehensively, the MD emphasizes a high proportion of plant-based foods combined with olive oil, with its specific implementation demonstrating diversified variations based on geographical regions and ingredient availability. This traditional Mediterranean diet structure is abundant in antioxidant vitamins (e.g., β-carotene, vitamin C and E), folate, flavonoids, and selenium [12]. Whole grains and olive oil contain diverse phytochemicals with anti-inflammatory and antioxidant properties. Wheat bran is rich in plant protectants such as ferulic acid, demonstrating anticancer potential. The germ of whole grains contains spermidine, which extends lifespan, enhances antioxidant capacity, and mitigates age-related inflammation.

6. Application and Efficacy of the Mediterranean Diet in Adolescent Obesity

6.1. Reduction of Waist Circumference and Visceral Adiposity

The MD regimen employs extra virgin olive oil as a substitute for conventional cooking oils such as peanut oil, while implementing dietary modifications including restricted red meat consumption and increased intake of high-quality protein sources like deep-sea fish and legumes to facilitate reduction in adolescent body circumference. The multicenter MED4Youth trial conducted in 2023 yielded robust evidence-based findings. This study enrolled 240 obese adolescents and demonstrated that after a 4-month targeted intervention, the experimental group (which adopted olive oil consumption, restricted red meat intake, and increased protein uptake) achieved a significant 4.2 cm reduction in waist circumference from baseline, markedly superior to the 1.8 cm reduction observed in the control group ($p<0.05$). Furthermore, a 12.5% decrease in visceral adipose tissue area was documented in the intervention cohort [13]. At the mechanistic level, this ameliorative effect is closely associated with the biological functions of specific nutrients. Specifically, the polyphenols abundant in extra virgin olive oil can directly suppress the differentiation of preadipocytes into mature adipocytes and reduce abnormal proliferation of adipocyte populations by modulating key transcription factors such as PPARγ. Meanwhile, ω-3 fatty acids (particularly EPA and DHA) derived from deep-sea fish mitigate localized chronic inflammatory states and enhance the metabolic activity of adipocytes through downregulating the expression of pro-inflammatory cytokines including tumor

necrosis factor-α (TNF-α) in adipose tissue [14]. The synergistic interaction between the two factors collectively facilitates favorable alterations in body composition.

6.2. BMI Reduction

The MD exhibits distinctive characteristics in carbohydrate selection and snack design, advocating for the substitution of refined carbohydrates such as white rice and white bread with whole grain staples like brown rice and oats. Additionally, it promotes a "fruit + nuts" snacking pattern (comprising two daily servings of fruit paired with 30g of nuts). A large-scale school intervention program conducted in Greece in 2024, encompassing 6,000 students aged 12-15, demonstrated the efficacy of this dietary pattern through one year of implementation. The study revealed that adolescents in the intervention group (characterized by whole-grain carbohydrate intake in their diet and exclusive consumption of fruits and nuts as snacks) exhibited a reduced annual BMI increase of 0.38 kg/m², whereas the control group (consuming refined carbohydrates and snacks containing other processed foods) demonstrated a 1.0 kg/m² increase ($p<0.01$). Concurrently, snack consumption decreased by 47% from baseline levels, indicating effective dietary behavior modulation [15]. From a physiological perspective, the dietary fiber abundant in whole grains prolongs gastric emptying time, sustaining postprandial satiety by delaying glucose absorption rate and thereby reducing additional caloric intake. Meanwhile, the magnesium-rich composition of nuts activates the AMPK signaling pathway, enhancing insulin receptor sensitivity and improving cellular energy metabolism efficiency [16]. The two modalities synergize through the dual mechanisms of "intake reduction" and "metabolic optimization," collectively suppressing abnormal weight gain.

6.3. Enhancement of Exercise Performance and Auxiliary Muscle Growth

The synergistic intervention of MD and physical exercise demonstrates significant advantages in enhancing weight loss efficacy among adolescents. The implementation plan explicitly stipulates that in addition to adhering to daily MD, participants must engage in moderate-intensity exercise three times weekly (e.g., brisk walking, swimming, or ball sports, with each session lasting 40-60 minutes). It particularly emphasizes post-exercise nutritional supplementation strategies—specifically adopting a "Mediterranean-style snack" consisting of 100g sugar-free Greek yogurt paired with 80g fresh berries (such as blueberries, strawberries, or raspberries).

A 2025 meta-analysis published in JAMA (Journal of the American Medical Association) provided high-level evidence supporting this approach. The study synthesized data from 34 randomized controlled trials, demonstrating that adolescents in the "Mediterranean Diet + Exercise" combined intervention group achieved an additional 3.5 cm reduction in waist circumference and a significant 2.1 kg increase in muscle mass compared to the MD-only control group within the same intervention period, underscoring the dual benefits of fat loss and muscle gain. This approach better aligns with the physiological requirements for body composition optimization during adolescent growth and development [17]. From a physiological mechanism perspective, the synergistic effects manifest through multi-level mutually reinforcing processes: Moderate-intensity exercise enhances cardiac output and blood circulation, thereby improving the organism's absorption and bioavailability of core MD components (such as polyphenols in extra virgin olive oil), allowing their anti-inflammatory and metabolic regulatory properties to be fully exerted. Post-exercise supplementation with anthocyanin-rich berries specifically activates the AMPK energy-sensing pathway. These bioactive compounds not only accelerate oxidative decomposition of adipocytes post-exercise but also promote glycogen replenishment in muscle tissue, alleviating exercise-induced fatigue while indirectly enhancing adherence to subsequent training sessions and optimizing therapeutic outcomes [18]. Moreover, the high-quality protein provided by yogurt supplies essential amino acids for muscle repair and synthesis, synergizing with exercise stimulation to promote lean body mass growth. This mechanism further elevates basal metabolic rate, thereby establishing a virtuous cycle encompassing "exercise-nutrition-metabolism."

6.4. Facilitating the Transformation of Family Dietary Culture

When parents start using the Mediterranean diet in their cooking—learning to make dishes such as hummus, herb-roasted fish, and quinoa with olive oil—they can significantly change their adolescents' eating habits by cooking together at home. The MELI-POP decade-long follow-up study conducted in 2025 provides longitudinal evidence demonstrating that adherence to a Mediterranean dietary pattern in family meals yields substantial benefits. Tracking analysis of 738 households revealed that the intervention group exhibited a 41% reduction in adolescent obesity prevalence compared to controls, along with a 50% increase in daily vegetable intake and marked improvements in overall dietary behaviors. Physiologically, the fermentable fibers rich in legumes in diets are fermented by gut bacteria into short-chain fatty acids; these compounds influence the release of hormones that control appetite and improve how well nutrients are absorbed. Concurrently, the restructuring of familial dietary culture facilitates the long-term adoption of healthy eating patterns—characterized by increased vegetable/fruit consumption and reduced processed food intake—through behavioral modeling and taste cultivation during shared meals. This transformative process from "environmental modification" to "behavioral internalization" establishes a robust foundation for adolescents' lifelong health [19].

7. Conclusion

Currently, the global prevalence of adolescent obesity has reached alarming levels, while traditional single-exercise interventions demonstrate limited sustainability in efficacy. The MD emphasizes the consumption of abundant fruits, vegetables, whole grains, nuts, and olive oil, moderate intake of fish and poultry, while limiting red meat and processed foods. Its richness in monounsaturated fatty acids, dietary fiber, and antioxidants confers anti-inflammatory properties and metabolic regulation potential. This study investigates the effects of the MD regimen on weight management and metabolic health in adolescent obesity populations. The findings demonstrate that this dietary pattern effectively reduces waist circumference, visceral fat area, and BMI in adolescents, while exhibiting synergistic benefits of fat reduction and muscle gain when combined with physical exercise. From a mechanistic perspective, bioactive compounds such as polyphenols in extra virgin olive oil, dietary fiber from whole grains, and magnesium in nuts collectively regulate adipocyte differentiation, inflammatory responses, and insulin sensitivity. The modification of household dietary environments further reinforces the long-term adherence to healthy eating behaviors. It can be asserted that the MD approach provides a scientifically validated and effective practical pathway for adolescent obesity prevention and control, demonstrating significant potential for widespread implementation.

However, recent research on the application of MD to adolescent obesity management still exhibits notable limitations. From a methodological perspective, the majority of existing studies employ cross-sectional designs, lacking high-quality intervention measures and longitudinal tracking data, thereby limiting the ability to establish causal relationships or assess long-term effects. Furthermore, gender disparities remain largely unaddressed, as evidenced by the absence of tailored interventions accounting for distinct physiological, metabolic, and nutritional requirements between adolescent males and females. Future research should prioritize large-scale longitudinal trials to elucidate causality, incorporate gender-specific analyses to develop personalized recommendations, and implement precision interventions based on individual characteristics to promote adolescent health.

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