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Childhood obesity in South Asian population

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ABSTRACT

Introduction: Obesity is worldwide health concern, with its prevalence rising steeply specially in low and middle-income countries in the past decade. World Obesity Federation estimates that one in five women and one in seven men - will be obese by 2030.Obesity numbers are expected to double during same year in South and South Asian countries, with obesity in children over age of five estimated to be at forty-five million.

Methods: Relevant articles, full text and abstract pertaining to childhood obesity, pediatric obesity, technology in childhood obesity and specifically articles on obesity in children in South Asian countries were obtained from search engines like PUBMED, Google Scholar and Cochrane data base. The full text relevant articles and abstracts and the cross references after verification suitable to the topic were used to draft this review.

Results: The double burden of undernutrition and obesity poses a unique public health challenge in Southeast Asia. In recent decades, South and Southeast Asia have experienced a period of rapid nutrition and lifestyle transition, leading to a proportional rise in the burden of obesity and Type 2 diabetes. The traditional diets of whole grains and vegetables in this region are being replaced by highly processed fast food due to rapid urbanization and westernisation in this region.There is growing and unrelenting burden of health risks in adulthood like diabetes, heart disease, hypertension, dyslipidaemia and mental health issues due to childhood obesity. Therapy mainly focuses on lifestyle changes underpinned by underlying behaviour changes, addressing emotional stress and sleep issues, pharmacotherapy and metabolic surgery in certain situations. Personalisation of therapy remains corner stone of therapeutics in childhood obesity.

Conclusion: This comprehensive review aims at addressing the risk factors, complications, treatment and highlights effective preventive strategies for childhood obesity in South Asia.

1. Introduction

Obesity is a now a global phenomenon with almost one billion people estimated to have obesity world-wide by year 2030 as per World Obesity Federation [1]. Obesity is caused by excess body fat and is chronic progressive and relapsing disease. Obesity is a complex multifactorial disease that often is promoted by reduced physical activity and increased consumption of calorie dense diet [2].

The bio socioecological model is proposed to explain the increase in obesity numbers [2].

The regions particularly affected are low and middle-income countries. South and Southeast countries are estimated to double their obesity numbers by 2030 [3]. The obesity in children is cause of concern in these regions which were traditionally thought to be facing the issue of under-nutrition. 45 million children of age above five will have obesity in these countries by 2030 [4,5]. The reasons for this surge in obesity numbers in children is this region is due to change from traditional diets of whole grains, fruits, cereals and pulses to energy dense packed foods, processed and polished grains, and decrease time of playing and engaging in physical activity [4]. The rising obesity in children will translate into increase in adult obesity and metabolic disorders in adults which can threaten the health structure and economies of South and South Asian countries (SA) [5,6]. The other factors like screen time increase, non-availability of play grounds, rigorous school curriculum are also responsible.

The treatment and management of childhood obesity is aimed to restoring the maladapted behaviour of unhealthy lifestyle by counselling and education [6]. Pharmacotherapy is now available for select ages and metabolic surgery can be considered in select cases where primary treatments have failed and obesity poses threat to longevity and quality of life [7]. The mainstay of the child hood obesity prevention is education with sensitisation of both parents and children with schools playing a major role alongside. Policies which can foster conducive environment for accessibility to healthy and nutritious food and

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engaging children in activities which can promote physical and mental growth is the need of the hour. Strategy shift is needed now to control this burgeoning problem of obesity in children and technology and artificial intelligence use can come to rescue in this endeavour [8].

2. Definition and epidemiology

2.1. Definition

Obesity is defined as excessive fat mass having a negative impact on health [9]. It is a chronic progressive and relapsing disease with multifactorial aetiologies and results from gene-environment-behaviour interaction [1].

2.2. Measurement of obesity in South Asian children

For children and adolescents aged 2–20 years, body mass index(BMI) percentiles based on age and sex are typically used for assessment. Generally, a BMI between the 85th and 95th percentile is considered overweight, while a BMI at or above the 95th percentile indicates obesity. Another method uses standard deviations (SDs) above the World Health Organization (WHO) Growth Reference median; for ages 5–19 years, a BMI-for-age greater than 1 SD is classified as overweight, and greater than 2 SDs is classified as obesity [9].

These assessments rely on standard growth data from specific countries but can be influenced by ethnic diversity within the population. BMI tends to underestimate body fat in South Asian children due to their lower lean body mass compared to Europeans [10].Thus, country-specific growth charts are preferred when available. International Obesity Task Force charts, when country specific charts are not available, are used, which include data partially derived from Asian populations [11].

Abdominal or central obesity is linked to a higher cardio-metabolic risk in children and adolescents. Waist circumference can be adjusted for age and sex using regional and international growth references [12,13]. A waist-to-height ratio greater than 0.5 is commonly used to indicate abdominal adiposity in clinical and research contexts, without the need for a comparison reference [14].

Other measurements besides BMI, such as waist circumference, upper arm circumference, waist-to-height ratio, and skin-fold thickness, can also be considered. However, there is no universal tool that correlates these anthropometric measurements with biophysical measurements or the risk of metabolic disease in children.

3. Prevalence

In 2019, the World Obesity Federation projected that by 2025, there would be 206 million children and adolescents aged 5–19 years living with obesity, and this number would rise to 254 million by 2030. Among the 42 countries estimated to have over 1 million children with obesity in 2030, the highest numbers are expected in China, followed by India, the USA, Indonesia, and Brazil. Notably, only seven of these 42 countries are high-income nations [1,3,9].

Children of SA ethnicity shows a higher likelihood of overweight and obesity and a more precipitous increase in its severity when compared to Caucasian children. Prevalence of obesity amongst children in native SA countries varies between 2 and 9% [15]. The recent study published by Bansal D et al. [16] looking at trend estimates for prevalence of obesity in South Asian population from the year 1994–2023 showed that the prevalence estimates for obesity (OB), overweight (OW), and the combined categories (OB + OW) were 6.6 %, 12.4 %, and 19.3 % respectively. The findings regarding obesity prevalence among South Asian children align with a meta-analysis by Biswas et al. [17], which reported a pooled obesity prevalence of 6 % in this population. Additionally, a 2014 national epidemiological survey of Bangladeshi children aged 6–15 years found that 3.5 % were obese, 9.5 % were overweight, and 17.6 % were underweight [18]. In Bangladesh, the prevalence of OW was higher at 13.6 %, compared to 7.1 % in Bhutan. Similarly, obesity rates were also higher among Bangladeshi children. However, recent epidemiological data on OW and OB prevalence in Bangladesh remain sparse. Bangladesh, a densely populated emerging nation in South Asia, has undergone significant epidemiological and demographic shifts over the past few decades [17].

4. Risk factors

Obesity in the children is seen due to complex interaction between the biological self, and the environment and influenced by behaviours they adapt through their life journey. The bio-socioecological framework explains this complex interaction. The interplay of energy homeostasis, genetic and epigenetic factors, appetite and satiety regulation determine the body composition of an individual, coupled with bio-behaviours like sleep, medications, stress etc [2,19].

Table 1 summarises the risk factors of childhood obesity.

4.1. Nutrition and diet

Nutrition and diet are significant risk factors for childhood obesity. High consumption of sugar-containing soft drinks and fast food increases the risk due to their high energy content, leading to a positive energy balance [20]. The quality of the diet is also crucial, as evidenced by the Healthy Eating Index (HEI) study, which correlated diet quality with obesity in adolescents [21]. Earlier studies suggested skipping breakfast was linked to increased adiposity, however recent studies show that there is no clear relationship between skipping breakfast and obesity [22,23]. The availability of energy-dense and ultra-processed foods, designed to stimulate the brain's reward response, contributes to the challenge of excessive calorie intake. Large portion sizes, especially when eating out, exacerbate this issue [24]. Consuming vegetables at least twice daily can help protect against overweight and obesity [25]. In infants' excessive protein content in formula milk has been recognized as a negative factor, and doubling the risk of becoming obese compared to infants with low-protein formula. Higher protein intake in infancy and early childhood is associated with higher BMI in childhood [26,27].

4.2. Socioeconomic factors

Socioeconomic factors, such as low socio economic status (SES), low parental education, non-parental caregivers, infrequent fruit consumption, short sleep duration, and parental obesity, also influence childhood obesity [28]. Adverse childhood experiences, lack of nutrition assistance programs, and inadequate areas for active transportation and exercise increase the risk of obesity [29]. Food Insecurity (FI) creates a paradox where children may experience both malnutrition and obesity due to unhealthy eating patterns and stress. The concept of Food Insecurity and Obesity seems contradictory but studies have shown that FI is linked to

Table 1
Risk factors for childhood obesity [20–41].

Risk Factor Category	Specific Factors	Description
Nutrition and Diet	High-calorie foods, Sugary drinks	Increased energy intake leading to obesity
Socioeconomic Factors	Low SES[a], Low parental education	Links to higher obesity rates in children
Maternal Factors	Higher pre-pregnancy BMI[b], short breastfeeding duration	Influences childhood weight from birth
Physical Activity	Sedentary lifestyle, limited outdoor play	Direct correlation with obesity rates in children
Sleep Duration	Inadequate sleep, Poor sleep quality	Associated with appetite regulation issues

[a] SES: Socio Economic Status.
[b] BMI: Body Mass Index.

non communicable diseases such as Obesity, Diabetes etc. FI is prevalent in half of all children in Southern Asia and one in five children in Eastern Asia and the Pacific (which includes South-eastern Asia). They suffer from triple malnutrition - stunting, wasting and overweight. However, more data needs to be generated to pin down FI to obesity [30].

4.3. Comorbidities and healthcare facilities related factors

Children with comorbidities like autism spectrum disorders, sleep issues, and affective problems are more likely to have unhealthy weight [31]. The absence of strategies to prevent weight stigma and a shortage of trained healthcare professionals for managing eating disorders are significant risk factors. Despite the recognized clinical consequences of obesity, it is often not prioritized in health insurance plans, making treatment less affordable and accessible [32].

4.4. Maternal-related factors

Higher pre-pregnancy BMI is directly linked to childhood obesity [25]. Parental BMI significantly affects children's body weight, with fetal growth during pregnancy contributing to lean body mass development later in life [21]. Small-for-gestational-age children tend to accumulate fat mass, especially in the abdominal area, due to the obesogenic environment they are raised in Refs. [33,34]. This environment can lead to a lifestyle that promotes obesity. Abdominal obesity is associated with metabolic syndrome, including dyslipidemia, hypertension, and abnormal glucose and insulin regulation. Parental BMI above normal is strongly correlated with an increased risk of metabolic syndrome in children [35,36]. Higher birth weight is also associated with an increased risk of overweight and obesity in early school age, suggesting a linear relationship between birth weight and BMI in later life. Promoting a healthy lifestyle during pregnancy can prevent excessive fetal weight and reduce the risk of childhood obesity [21]. There is evidence, particularly in high-income country settings, that shorter breastfeeding duration causes higher weight gain during infancy [37]. Environmental and dietary factors can affect the epigenetic factors and thus it can become the gene regulator for life course. Reviews have shown the relationship between epigenetic factors and obesity. Epigenetics mediates how environmental factors (like diet, physical activity, and socioeconomic status) interact with genetic predispositions for obesity. For example, children with a genetic tendency toward obesity might experience enhanced or suppressed expression of those genes based on their lifestyle and environment [38].

4.5. Physical activity

Physical activity frequency is another crucial factor. Lack of physical activity and a sedentary lifestyle contribute to a positive energy balance, which is a significant cause of obesity. Increased physical activity can lower obesity risk by 10 % for each hour per day of moderate to vigorous exercise. Conversely, high media viewing and screen time are associated with lower physical activity levels and higher obesity rates [39].

4.6. Sleep duration and quality

Sleep duration and quality are significant risk factors for childhood obesity. A meta-analysis by Han et al. found that short sleep durations, particularly in children under 10, are linked to increased obesity risk [40]. Short sleep duration is also associated with poor dietary intake, such as reduced fruit consumption [41].

5. Consequences of childhood obesity

Many medical conditions which were previously affecting the obese adults are seen in childhood obesity. Many organ systems are impacted by childhood obesity with multitudes of disease process.

Fig. 1 summarises the various systems which can be affected by obesity.

5.1. Cardiovascular disease

Childhood obesity adversely impacts the cardiovascular system similarly to adult cases. Common cardiovascular risks associated with childhood obesity include hyperinsulinemia or insulin resistance, dyslipidemia, hypertension, ventricular defects, and abnormalities in endothelial function. Children with obesity also, are about three times more likely to develop hypertension compared to their non-obese peers [42,43].

5.2. Respiratory disease

Obstructive sleep apnea (OSA) in children can lead to failure to thrive, behavioural issues, reduced intellectual performance, and an elevated risk of cardiovascular problems, insulin resistance, and weight gain. OSA in children earlier was mainly attributed to adeno-tonsillar hypertrophy, but the prevalence of childhood obesity has changed this understanding [44]. Risk of asthma also increases, though the mechanism is not well defined. Nonetheless, obesity is more prevalent among children with asthma, and research has shown a connection between high body mass index (BMI) and asthma in both adults and children [45].

5.3. Endocrine disease

The surge in childhood obesity rates has paralleled an increase in type 2 diabetes mellitus (T2DM) among young people. Early onset of T2DM accelerates beta cell deterioration, predisposing youths to early development of metabolic conditions similar to those in adults. The link between diabetes, impaired glucose tolerance, and obesity is believed to be mediated by oxidized low-density lipoprotein antibodies [46]. Central precocious puberty (CPP) occurs when puberty starts before age 8 in girls and age 9 in boys, due to early release of gonadotrophin-releasing hormone [47]. Obesity is a major factor, with a Chinese study showing

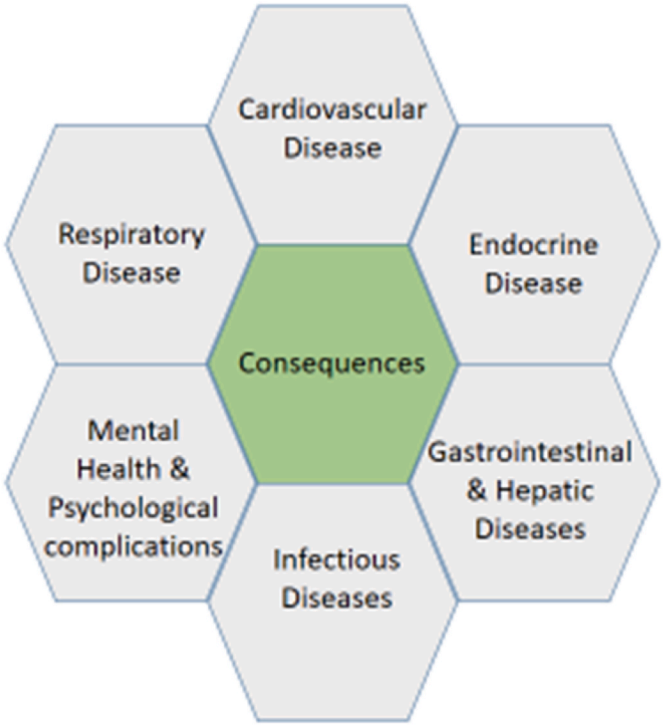

Fig. 1. Organ systems impacted by childhood obesity [42–57].

that overweight and children with obesity, especially girls, have higher odds of developing CPP [48]. The risk increases if the weight issue persists for over a year in girls and two years in boys.

For girls with precocious adrenarche (PA) born at an appropriate gestational age (AGA), initial evaluations show favourable lipid profiles but increased BMI and waist circumference correlate with a higher atherogenic index [49].

Obesity is also linked to polycystic ovary syndrome (PCOS) through insulin resistance and hyperinsulinemia, which raise androgen production and decrease sex hormone-binding globulin (SHBG), enhancing androgen bioavailability. This highlights the connection between obesity during puberty and the increased prevalence and severity of adolescent PCOS [50].

5.4. Mental health and psychosocial complications

Individuals with obesity often face public stigma and body shaming with women experiencing more discrimination. In children, obesity can lead to significant psychosocial issues, as it is perceived as a major handicap [51]. A Swedish study found that children with obesity have higher odds of developing anxiety and depression compared to their non-obese peers, with girls being at a greater risk than boys [52]. Additionally, overweight and children with obesity are more prone to bullying and academic failure, impacting them well into adulthood.

5.5. Gastrointestinal and hepatic diseases

Childhood obesity significantly increases the risk of metabolic dysfuntion-associated steatotic liver disease (MASLD), which presents differently in children than in adults, showing higher rates of fibrosis and cirrhosis. A Chinese study confirmed the high incidence of MASLD in children with obesity, identifying obesity as a key trigger, though MASLD can also occur in those with normal BMI [53,54]. Obesity is also linked to a higher risk of gastroesophageal reflux disease in children and adolescents and correlates with increased hospitalizations for pediatric cholelithiasis [55].

5.6. Infectious diseases

Individuals with obesity are more susceptible to infections, such as Helicobacter pylori, compared to those with normal weight [56]. Obesity is associated with impaired immune responses and reduced function of several immune cells due to disrupted lymphoid tissue integrity and altered adipocytokine secretion, including leptin and adiponectin [57].

5.7. Increment in healthcare services and costs

Obesity impacts most organ systems with increase in demand for health care services and cost from child health perspective. The most services consumed are psychological and musculoskeletal [58]. Data suggests that obesity leads to increase in length of stay in the hospital [59]. The lifetime costs of childhood obesity are proportional to BMI. Girls incur higher healthcare costs and income penalties, while boys have higher costs related to lost workdays. Obesity-related medical expenditures exert a significant financial strain on healthcare systems [60].

There are disparities between the health consequences of childhood obesity in South Asian and low income countries as compared to West and high income countries, The study by Obita G et al. concluded that the median prevalence of childhood obesity-related hypertension was 35.6 vs. 12.7 % among middle- and low-income countries compared with high-income countries; 37.7 vs. 32.9 % among boys compared with girls; and 38.6, 25.3, and 20.1 % in Asia, South America, and Europe, respectively [61]. For metabolic syndrome, the median prevalence was 26.9 vs. 5.5 % among middle- and low-income countries compared with high-income countries; 55.2 vs. 12.0 % among boys compared with girls; and 40.3, 25.8, and 7.7 % in South America, Asia, and Europe, respectively. The prevalence of childhood obesity-related non-alcoholic fatty liver disease was 47.5 vs. 23 % among middle- and low-income countries compared with high-income countries; and 52.1, 39.7, and 23.0 % in Asia, South America, and Europe, respectively. The median prevalence of dyslipidemia was 43.5 vs. 63 % among middle- and low-income countries compared with high-income countries; 55.2 vs. 12.0 % among boys compared to girls; and 73.7 and 49.2 % in Australia and Europe, respectively.

6. Assessment of childhood obesity

Assessing obesity in children involves a combination of physical measurements, laboratory tests, and clinical evaluation.

6.1. Anthropometric measurements

A) Body Mass Index (BMI): The primary tool for screening obesity. BMI is calculated as weight (kg) divided by height (mˆ2). BMI-for-age percentiles are used for children [2,4].
B) Waist Circumference: Measures central adiposity. Waist circumference percentiles are compared to standardized charts [11].
C) Skinfold Thickness: Uses callipers to measure subcutaneous fat at specific sites (triceps, subscapular) [2,4].

6.2. Biochemical Markers [2,4,62–64]

a) Lipid Profile: Measures total cholesterol, high density cholesterol (HDL-C), low density cholesterol (LDL-C), and triglycerides. Elevated levels can indicate dyslipidemia associated with obesity.
b) Blood Glucose and Insulin Levels: Fasting glucose, glycosylated hemoglobin (HbA1c), and fasting insulin levels help assess risk for type 2 diabetes and insulin resistance.
c) Liver Function Tests: Elevated liver enzymes ALT, AST can indicate metabolic dysfunction-associated steatotic liver disease(MASLD), a common obesity-related condition. Fibrosis-4 (FIB-4) index can estimate the amount of liver fibrosis. FIB-4 is based on routine blood tests (age, AST, ALT, and platelets) and widely accessible.
d) Enhanced Liver Fibrosis (ELF) test measures three serum biomarkers associated with the liver's fibrotic process:
   a. Hyaluronic acid (HA)
   b. Tissue inhibitor of metalloproteinase-1 (TIMP-1)
   c. Procollagen III N-terminal peptide (PIIINP)

These markers reflect liver matrix remodeling and fibrosis. The ELF score is derived from a mathematical algorithm applied to these biomarkers, providing a numerical value that correlates with the degree of liver fibrosis. ELF measures specific fibrosis-related markers and may provide a more direct indication of fibrotic activity but requires specialized testing. ELF might provide more accuracy, especially for early or mild fibrosis detection.

e) Thyroid Function Tests: Thyroid-stimulating hormone (TSH) and free T4 levels to rule out hypothyroidism as a cause of weight gain.
f) Inflammatory Markers: C-reactive protein (CRP) and adipokines (leptin, adiponectin) to assess chronic inflammation and metabolic syndrome.
g) Imaging Studies [62–64]:
   a. Ultrasound: To evaluate hepatic steatosis in suspected cases of MASLD.
   b. Dual-energy X-ray Absorptiometry (DEXA): Measures body composition, including fat mass and lean mass.
   c. MRI-pdff (Magnetic Resonance Imaging – Proton Density fat fraction) is a non-invasive and highly sensitive test which detects the presence and degree of steatosis.

d. MRS (Magnetic Resonance Spectroscopy) is another MRI-based method which assesses liver fat content and provides detailed information about the type and quantity of fat.
e. Transient Elastography (FibroScan) is a non-invasive provides an estimate of liver fat content.

6.3. EOSS-P staging

The Edmonton Obesity Staging System for Paediatrics (EOSS-P) is a comprehensive framework designed to classify the severity of obesity-related health risks in children and adolescents. It considers physical, metabolic, and psychological health impacts [65].

EOSS-P Stages:

Stage 0: No apparent risk factors or physical symptoms.

Normal clinical and laboratory results.

No apparent impairment in well-being.

Stage 1: Presence of mild obesity-related risk factors or mild symptoms.

Slightly elevated blood pressure, mild dyslipidemia, or slightly elevated fasting glucose.

Mild psychological distress (e.g., self-esteem issues).

Stage 2: Presence of moderate obesity-related risk factors or symptoms.

Hypertension, dyslipidaemia, or impaired fasting glucose.

Moderate psychological distress (e.g., anxiety, depression).

Some functional impairment (e.g., difficulty in physical activities).

Stage 3: Significant obesity-related comorbidities or severe symptoms.

Type 2 diabetes, sleep apnoea, severe hypertension.

Severe psychological distress impacting daily function.

Significant functional impairment (e.g., inability to engage in physical activity).

Stage 4: Severe disability or end-stage conditions related to obesity.

Severe organ damage (e.g., end-stage liver disease, cardiovascular disease).

Severe, disabling psychological conditions.

Profound functional impairment.

7. Prevention of child hood obesity

Prevention of child hood obesity involves emphasis on ameliorating the obesogenic environment through change in diet, reducing sedentary behaviour and screen time, increasing physical activity and improving sleep.

7.1. Dietary intervention

7.1.1. Before and after child birth

Preventative strategies for childhood obesity should start with managing maternal health, including diabetes control, healthy weight gain, proper nutrition, and physical activity during pregnancy.

Maternal factors play a significant role in shaping a child's risk of developing adiposity and obesity. Research indicates that higher maternal BMI is associated with increased adiposity in children, even when they are born at a normal weight [66]. Gestational diabetes and maternal hyperglycemia can disrupt fetal glucose regulation, heightening the risk of adiposity in the offspring. Diet during pregnancy also matters; a high-fat, high-protein diet correlates with greater adiposity risks, whereas a diet rich in vegetables, fruits, and fiber is linked to lower instances of neonatal macrosomia [66]. Postnatal extended breastfeeding has been shown to offer greater protection against adiposity and metabolic syndrome. A meta-analysis of nine studies involving 69,000 infants revealed a significant reduction in obesity risk among breastfed babies [67]. The protective effects of breastfeeding are likely due to both behavioural and hormonal mechanisms. Breastfed infants tend to develop better satiety regulation compared to those who are formula-fed. Furthermore, formula-fed infants often experience more rapid and unregulated weight gain, which can contribute to excessive weight gain later in life. Overall, breastfeeding offers optimal nutrition, safeguarding against both under-nutrition and adiposity [68].

7.1.2. Early childhood and adolescence

Introducing complementary feeding too early, especially before 4 months, has been linked to a six-fold increase in obesity risk by age three in formula-fed infants, though breastfed babies don't face the same risk [69]. The timing and quality of complementary foods are crucial. It's essential to promote the introduction of varied, healthy foods, including fruits, vegetables, and appropriate proteins, while avoiding energy-dense, nutrient-poor options and sugary drinks. Establishing healthy eating habits through repeated exposure to nutritious foods during early childhood is vital [70].

During school years and adolescence, dietary habits remain a critical factor in obesity prevention. Children and adolescents are highly influenced by peer pressure, media, and the availability of unhealthy foods. Diets rich in fruits, vegetables, and low in fat and refined carbohydrates are essential to reducing obesity risk [71]. It is recommended that children consume at least 5 servings of whole fruits and vegetables daily while avoiding intake of calorie dense nutrient poor foods including sugar sweetened beverages, most 'fast foods' or those with added table sugar, high fructose corn syrup, high fat or high sodium processed foods and snacks [71,72]. Fat consumption should be restricted to 25–35 % of total energy intake [73].Clear guidance and support should be provided to caregivers to avoid specific categories of foods (e.g., sugar sweetened milks, fruit juices and energy-dense, nutrient-poor foods) to prevent excess weight gain. Active efforts should be made at the level of schools for limiting availability of unhealthy foods and drinks and promoting consumption of low energy density healthy foods and safe drinking water. Frequent 'eating out' and 'fast food' should be discouraged. The portion of food served during a meal should also be regulated as children served with larger portions are reported to have poor regulation of energy intake. Recent evidence also supports beneficial role of family meals in improving healthy eating behaviours. Therefore, parental counselling for appropriate child feeding practices should be encouraged. Frequent snacking and 'grazing' should be discouraged. Parents should avoid using unhealthy foods stuffs for rewards during childhood [73].

7.2. Physical activity promotion

Low physical activity among children is a significant factor in the global obesity epidemic. Obesity, in turn, can further reduce physical activity, creating a vicious cycle. Regular exercise is essential, not only for reducing body fat but also for improving cardio-respiratory fitness and bone health [74]. The World Health Organization (WHO) recommends that children and adolescents aged 5–17 years should engage in at least 60 min of moderate to vigorous physical activity daily, which can be spread throughout the day through various activities, including sports, play, and chores. Incorporating 30 min of exercise into the school schedule is also advised [75]. Both structured and unstructured activities should be enjoyable and sustainable, with parental involvement to set a positive example [76].

7.3. Reducing screen time

Excessive television viewing and screen time contribute significantly to the risk of obesity in children [77]. These activities encourage a sedentary lifestyle, increase snacking, and reduce the time available for physical activity. Furthermore, exposure to commercials promoting unhealthy foods can negatively influence dietary habits. Studies show that each additional hour of screen time is associated with a 13 % increase in obesity risk [78]. To mitigate this, non-academic screen time should be limited to 1–2 h per day, and digital platforms should be

leveraged to promote healthy eating and active lifestyles.

7.4. Maintaining sleep hygiene

Poor sleep quality and insufficient sleep duration are linked to an increased risk of obesity in children. Sleep disturbances can disrupt the neuro-hormonal regulation of the biological clock, leading to changes in appetite and energy balance [79]. Adequate sleep, with a minimum of 8.5–10.5 h for adolescents, is essential for preventing obesity. Ensuring a quiet, electronic-free environment for sleep is also crucial [80].

A '3–2-1' approach can be emphasized upon parents for obesity prevention where a child should consume 3 major meals, have less than 2 h of screen time and engage in at least 1 h of physical activity daily.

8. Role of technology and artificial intelligence in prevention of childhood obesity

8.1. Digital health technology

Digital health technologies such as mobile health (mHealth) apps and telehealth services, are increasingly important in obesity prevention [8].These tools enable continuous tracking of diet, exercise, and other health behaviours, offering real-time feedback through reminders and motivational messages [81]. Some systems engage children in an interactive manner, providing personalized advice on nutrition and physical activity. This approach not only helps children make healthier choices but also allows parents and healthcare providers to monitor progress, fostering a collaborative environment that boosts accountability and promotes a healthier lifestyle [82].

8.2. Artificial intelligence (AI)

AI is transforming obesity prevention by analysing large datasets to uncover hidden patterns. Machine learning models can predict obesity risk by evaluating various factors like diet and activity levels, providing personalized recommendations for weight management. These tools are also key in early detection, with some capable of identifying obesity risks in children as young as two years old. Real-time monitoring through AI applications helps children and caregivers track progress and adjust behaviours, making obesity prevention more proactive and personalized [83].

8.3. Social robots

Emerging technologies like social robots are being explored as tools to encourage healthier behaviours in children. These robots engage kids in a way that is both enjoyable and educational, helping to promote physical activity and better eating habits [84]. With their human-like features, these robots become relatable to children, enhancing their role as effective agents of behavioural change.

9. Obesity prevention levels

Preventing childhood obesity involves intervening at various levels with which child interaction can be identified. Obesity prevention interventions can be deployed at home, school or community levels for effective results and forms the basis of obesity prevention framework.

Refer Table 2 for Levels of obesity prevention.

9.1. Home based interventions

The family environment plays a crucial role in shaping a child's behaviour, giving parents a unique opportunity to promote healthy eating and physical activity from an early age. Home-based interventions aimed at fostering these healthy behaviours should begin as early as the toddler years. While research highlights the importance of parental involvement in successful family interventions to prevent and treat obesity, there is still limited data on which specific parenting approach (coercive, facilitatory, or monitoring) is most effective [85].

Table 2
Overview of community and school-based interventions [85–94].

Intervention Type	Program Name	Target Demographic	Key Components	Outcomes
School-Based	Healthy Eating Initiative	School Children	Nutrition education, Active breaks	Improved BMI[a], better eating habits
Community-Based	Active Living Campaign	Families	Free exercise classes, Community sports events	Increased physical activity engagement
Policy Level	Healthy Foods in Schools	Schools	Guidelines for healthier food options	Decreased availability of junk food

[a] BMI: Body Mass Index.

Poor family functioning is linked to higher obesity risk. Effective interventions involve family counselling for diet and physical activity changes, and sometimes general parenting skills. Studies show that involving both parents and children yields better results than parent-only interventions, which are, however, more cost-effective [86].

Overall, intense and longer interventions tend to be more effective. Family-based programs that support positive behaviours have shown promising long-term effects on children's BMI and healthy lifestyle habits [87].

9.2. School based interventions

School-based interventions have proven effective in both preventing and treating childhood obesity [88]. These programs can be standardized and implemented on a large scale, focusing on healthy eating, physical activity, and lifestyle education. Studies show that mandatory aerobic exercise, as part of these interventions, is more effective than voluntary programs. School-based interventions have also been linked to improved academic performance and cognitive functions [88]. Meta-analyses confirm significant benefits on BMI and blood pressure, especially when parents are involved [89].

9.3. Community based interventions

Community and political interventions are also vital for achieving sustainable benefits. Societal support through school wellness policies, recreation programs, and shifts in food advertising is necessary, along with a broader commitment to preventive strategies across sectors such as education, agriculture, and urban planning [90]. A combined approach involving multiple settings, including schools, communities, and healthcare, is considered most promising. Combining clinical care with community initiatives seems promising. For instance, a study by Hoffman et al. showed that an integrated approach improved physical activity and quality of life for at-risk children more effectively than clinical care alone [91].

Globally, the WHO's 2004 strategy aimed at reducing non-communicable diseases by promoting healthier diets and physical activity has laid the groundwork for tackling obesity. This strategy emphasizes the need for governments to engage in comprehensive interventions, from policy changes to grassroots health promotion [92].

9.4. Global initiatives

WHO established a commission focused on ending childhood obesity, which released a report in 2016 [93]. Key recommendations include promoting healthy food intake, physical activity, and providing support for prenatal care and early childhood health. The Commission

also calls for stricter regulations on advertising unhealthy foods and beverages, improved access to healthy foods, and the promotion of healthy eating and lifestyle behaviours at home and in schools.

Aligned with ASEAN's sustainable development goals, several countries in the region have launched initiatives to improve nutrition, encourage healthier eating habits, and boost physical activity. For instance, Singapore has rolled out the Healthy Meals in Schools Program and the National Steps Challenge, while Malaysia has implemented nutrition labeling and introduced taxes on sugar-sweetened beverages [94]. All ASEAN member states have also put in place measures to promote breastfeeding. In a broader context, China has recently proposed a comprehensive national strategy for obesity prevention and control. Although there are geopolitical differences across Asia, these efforts could offer valuable lessons that might be adapted for South and Southeast Asia. Considering the magnitude of the obesity problem, bold and extensive programs are essential at both national and regional levels to prevent obesity and mitigate its medical, financial, and personal impacts [94].

10. Treatment of childhood obesity

Treatment if childhood obesity involves a multidisciplinary approach involving paediatricians, dietitians, psychologists, and other healthcare professionals is often necessary to provide comprehensive care for children and adolescents with obesity. The majority of emphasis is on lifestyle and behaviour change supported by pharmacotherapy and metabolic surgery if necessary.

10.1. Lifestyle interventions [95]

Lifestyle interventions are crucial for preventing and treating childhood obesity by focusing on dietary changes, physical activity, and health education. Research supports these interventions as effective in promoting sustainable weight loss and better health outcomes.

Age-appropriate and culturally sensitive lifestyle modifications are the first-line treatment for childhood obesity, aimed at reducing fat mass and improving cardiovascular fitness. These include dietary changes, increased physical activity, and behavioural modifications. Lifestyle interventions are effective in reducing BMI and lowering the risk of type 2 diabetes later in life, particularly when parents are involved, though the effects may be short-lived without continued support.

10.1.1. Dietary interventions

A balanced diet rich in fruits and vegetables, along with a restricted calorie intake (not less than 1200 Kcal daily for children aged 6–12 years), is essential. However, weight regain is often observed after discontinuing these diets. The "traffic light" approach categorizes foods into green (no restriction), yellow (moderation), and red (restricted), helping to simplify dietary choices [96].WHO recommends that less than 10 % of daily energy intake should come from free sugars. Combining dietary counselling with behavioural approaches and strong parental involvement enhances long-term success [9].

10.1.2. Physical activity and behavioural modifications

Exercise, combined with reduced caloric intake, helps achieve and maintain weight loss, improving cardiovascular fitness and cognitive function even without significant weight loss. 60 min of daily physical activity is recommended [75,97]. Limiting screen time and adopting healthy lifestyle habits as a family are crucial for lasting results. Structured weight reduction programs with close supervision and positive reinforcement can be effective for children who do not achieve desired weight loss through preventive strategies alone [75,81,98].

10.1.3. Effectiveness and challenges

Comprehensive lifestyle interventions effectively reduces BMI and improve metabolic health. Long-term programs, particularly those lasting over a year, are more successful. However, challenges include maintaining adherence, individual variability in response to interventions, and the need for strong support systems [98].

10.2. Pharmacological agents

Medication is recommended only when intensive lifestyle modifications fail, particularly for adolescents aged 16 and older with severe obesity or related comorbidities. Orlistat is approved for children aged 12–16 years. Liraglutide, the GLP1 agonist, is approved by most regulatory bodies for treatment on adolescent obesity (ages 12–18) [2,99]. It acts on its receptors in the hypothalamus to reduce appetite, slow gastric motility, and act centrally on the hind brain to enhance satiety [99]. Semaglutide has been approved for all adolescents aged 12–17 years of age and it has the same action as Liraglutide which it causes by enhancing insulin secretion [100,101]. These medications are typically reserved for adolescents with a BMI at or above the 95th percentile and are prescribed when the potential benefits outweigh the risks [100,101]. In addition to the currently approved medications, several new anti-obesity drugs are in development or have recently been approved for adult use, these include:

a) **Incretin receptor co-agonists and tri-agonists**: These novel compounds target multiple receptors involved in appetite regulation and glucose homeostasis, potentially offering enhanced weight loss and metabolic benefits [2,102].
b) **Setmelanotide**: A melanocortin-4 receptor (MC4R) agonist approved for treating obesity associated with genetic disorder [102].

Refer Table 3 for treatment options for childhood obesity.

10.3. Bariatric surgery

Bariatric surgery is considered for adolescents with a high BMI (over 40 kg/m^2, or over 35 kg/m^2 with significant comorbidities) who haven't achieved sufficient weight loss through intensive lifestyle changes or medication. Candidates must have reached Tanner stage 4 or 5 of puberty and be close to their adult height [2,4,73]. Before surgery, a psychological evaluation is recommended to assess the level of psychological distress and ensure a stable, supportive home environment for post-operative care.

The types of bariatric surgery available for adolescents include malabsorptive, restrictive, or a combination of both. Vertical sleeve gastrectomy is a restrictive procedure, while Roux-en-Y gastric bypass combines both restrictive and malabsorptive methods [103]. Bariatric surgery is widely regarded as the most effective long-term solution for significant weight loss in adolescents struggling with obesity. On average, it reduces BMI by 25–40 % within 1–9 years after the procedure. Besides helping with weight loss, these surgeries also greatly improve related health issues like cardiometabolic risks, joint pain, and mobility. Notably, conditions such as type 2 diabetes and hypertension often improve more in teens than in adults after surgery. While short-term boosts in quality of life and fewer depression symptoms are common, mental health outcomes can vary [103–105].

The mortality rate five years after surgery is similar between teens and adults, but adolescents tend to undergo more re-surgeries and are more prone to low ferritin levels, which requires careful monitoring [105]. Although earlier guidelines recommended surgery only for older teens who had reached skeletal maturity, newer guidelines allow for younger candidates if they meet the necessary medical criteria [2,4]. Weight regain is a common issues post surgery and needs behaviour change of child with parental support [103,104]. Despite its benefits, bariatric surgery in adolescents remains uncommon due to concerns about the invasiveness and permanence of the procedures, long-term safety, limited access to surgical facilities, insurance coverage issues, and biases in referrals [105].

Table 3
Summary of treatment options for childhood obesity [2,4,9,73,75,81,95–105].

Treatment Type	Indications	Potential Benefits	Age Appropriateness
	NON PHARMACOLOGICAL		
Lifestyle Interventions	First-line treatment for all children and adolescents with obesity.	- Reduces BMI - Lowers risk of type 2 diabetes - Improves cardiovascular fitness - Enhances cognitive function	Age-appropriate and culturally sensitive interventions for all ages
Dietary Interventions	All children with obesity, especially those needing structured dietary changes.	- Promotes weight loss - Improves overall health - Easy to follow with "traffic light" approach	Children aged 6–12 years and older
Physical Activity	Children with obesity requiring improved fitness and reduced screen time.	- Helps achieve and maintain weight loss - Improves cardiovascular and cognitive health	Recommended for all children (at least 60 min of daily activity)
Behavioural Modifications	Children with obesity needing support in adopting healthylifestyle habits.	- Sustains weight loss - Reduces screen time - Encourages family-wide healthy habits	Appropriate for all ages with family involvement
	PHARMACOLOGICAL		
Orlistat	Adolescents aged 12–16 with severe obesity, failing lifestyle changes.	- Reduces fat absorption - Contributes to weight loss	Approved for children aged 12-16
Semaglutide	Adolescents aged 12–17 when other lifestyle interventions fail.	- GLP-1 receptor agonist - Increases insulin secretion Reduces appetite and slows gastric emptying	Recently approved for adolescents with obesity, but long-term effects are still being studied
Liraglutide	Adolescents aged 12–17 when other lifestyleinterventions fail.	- Significant weight loss - Enhance insulin secretion, reduces appetite, and slows gastric emptying	The long-term safety and effectiveness of GLP-1[b]analogues in children are still being studied, and their use requires careful monitoring
Incretin Receptor Co-Agonists and Tri-Agonists	Adolescents with severe obesity, particularly those with type 2diabetes or metabolic syndrome.	- Potential for significant weight loss - Improves glucose homeostasis	Currently under research; not yet approved for pediatric use
Setmelanotide	Adolescents with obesity linked to specific genetic disorders. (e.g., POMC[a] deficiency)	- Effective for genetically driven obesity - Targets melanocortin-4 receptor	Approved for specific genetic disorders in children as young as 6 years old
	SURGICAL		
Bariatric Surgery	Adolescents with a BMI over 40 kg/m^2 or over 35 kg/m^2 with significantcomorbidities, unresponsive to lifestyle and pharmacological treatments.	- Significant and sustained weight loss - Improves comorbid conditions like type 2 diabetes and hypertension	Typically for older adolescents; newer guidelines allow for younger candidates if medicallynecessary

[a] POMC – Pro-opiomelanocortin.
[b] GLP-1 – Glucagon-like Peptide-1.

11. Conclusion

Childhood obesity is rising in south east Asian countries and needs a viable and long term solution to mitigate the burden of the metabolic complications in adulthood due to childhood obesity that is posing a great threat to the already compromised economies. The combined effort of south Asian countries is required to handle the situation in an adept way and it requires volunteering of experts and local bodies who endorse and reverberate with government sentiments. Extensive regional and national programs to tackle the obesity across this geopolitical region is the need of the hour.

Prevention of childhood obesity is a complex task that requires coordinated efforts from all sectors of society. Key strategies include promoting balanced diets, proper sleep, and healthy lifestyles, with interventions focusing on home, school, and community settings. A comprehensive, life-course approach—starting from maternal care and continuing through adolescence—is essential. Legislation and community education are also critical in supporting these efforts. Achieving lasting reductions in obesity will depend on implementing a multifaceted strategy across all these platforms.

Credit author statement

Vimal Pahuja - Conceptualization, Data curation, Formal analysis , Methodology, Validation, Visualization, Writing – original draft. **Sushma Sanghvi** - Writing – review & editing.

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References

[1] World Obesity Federation. World obesity atlas 2024. https://data.worldobesity.org/publications/WOF-Obesity-Atlas-v7.pdf; 2024.
[2] Jebeile H, Kelly AS, O'Malley G, Baur LA. Obesity in children and adolescents: epidemiology, causes, assessment, and management. Lancet Diabetes Endocrinol 2022;10(5):1–12. https://doi.org/10.1016/S2213-8587(22)00047-X.
[3] Lobstein T, Brinsden H, Neveux M. World obesity atlas 2022. https://www.worldobesityday.org/assets/downloads/World_Obesity_Atlas_2022_WEB.pdf; 2022.
[4] Tham KW, Abdul Ghani R, Cua SC, Deerochanawong C, Fojas M, Hocking S, Lee J, Nam TQ, Pathan F, Saboo B, Soegondo S, Somasundaram N, Yong AML, Ashkenas J, Webster N. Obesity in South and Southeast Asia—a new consensus on care and management. Obes Rev 2022;23(Suppl. 1):e13520. https://doi.org/10.1111/obr.13520.
[5] Okunogbe A, Nugent R, Spencer G, Powis J, Ralston J, Wilding J. Economic impacts of overweight and obesity: current and future estimates for 161 countries. BMJ Glob Health 2022;7:e009773. https://doi.org/10.1136/bmjgh-2022-009773.
[6] Shaban Mohamed MA, AbouKhatwa MM, Saifullah AA, Hareez Syahmi M, Mosaad M, Elrggal ME, Dehele IS, Elnaem MH. Risk factors, clinical consequences, prevention, and treatment of childhood obesity. Children 2022;9(12):1975. https://doi.org/10.3390/children9121975.
[7] Kühnen P, Biebermann H, Wiegand S. Pharmacotherapy in childhood obesity. Horm Res Paediatr 2022;95(2):177–92. https://doi.org/10.1159/000513192.
[8] Alghalyini B. Applications of artificial intelligence in the management of childhood obesity. J Fam Med Prim Care 2023;12(11):2558–64. https://doi.org/10.4103/jfmpc.jfmpc_469_23.
[9] World Health Organization. Obesity 2022. https://www.who.int/health-topics/obesity.
[10] Inokuchi M, Matsuo N, Takayama JI, Hasegawa T. Population-based waist circumference reference values in Japanese children (0-6 years): comparisons with Dutch, Swedish and Turkish preschool children. J Pediatr Endocrinol Metabol 2020;34(4):349–56.
[11] Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000;320(7244):1240–3. https://doi.org/10.1136/bmj.320.7244.1240.
[12] Xi B, Zong X, Kelishadi R, Litwin M. International waist circumference percentile cutoffs for central obesity in children and adolescents aged 6 to 18 years. J Clin Endocrinol Metabol 2020;105:e1569–83. https://doi.org/10.1210/clinem/dgz237.
[13] Kelishadi R, Mirmoghtadaee P, Najafi H, Keikha M. Systematic review on the association of abdominal obesity in children and adolescents with cardio-metabolic risk factors. J Res Med Sci 2015;20(3):294–307.
[14] Garnett SP, Baur LA, Cowell CT. Waist-to-height ratio: a simple option for determining excess central adiposity in young people. Int J Obes 2008;32(6):1028–30.
[15] Sivasubramanian R, Malhotra S, Fitch AK, Singhal V. Obesity and metabolic care of children of South Asian ethnicity in western society. Children 2021;8(6):447. https://doi.org/10.3390/children8060447.
[16] Bansal D, Vishwakarma S, Devi N, Tripathi AK, Kumar S. Trends estimation of obesity prevalence among South Asian young population: a systematic review and meta-analysis. Sci Rep 2024;14:596. https://doi.org/10.1038/s41598-023-50973-w.
[17] Biswas T, Islam A, Islam MS, Pervin S, Rawal LB. Overweight and obesity among children and adolescents in Bangladesh: a systematic review and meta-analysis. Publ Health 2017;142(1):94–101. https://doi.org/10.1016/j.puhe.2016.10.010.
[18] Bulbul T, Hoque M. Prevalence of childhood obesity and overweight in Bangladesh: findings from a countrywide epidemiological study. BMC Pediatr 2014;14(1):86. https://doi.org/10.1186/1471-2431-14-86.
[19] Sarni ROS, Kochi C, Suano-Souza FI. Childhood obesity: an ecological perspective. J Pediatr 2022;98(Suppl. 1):S38–46. https://doi.org/10.1016/j.jped.2021.10.002.
[20] Alam Mahumud R, Sahle BW, Owusu-Addo E, Chen W, Morton RL, Renzaho AMN. Association of dietary intake, physical activity, and sedentary behaviours with overweight and obesity among 282,213 adolescents in 89 low and middle-income to high-income countries. Int J Obes 2021;45(11):2404–18.
[21] Acar Tek N, Yildiran H, Akbulut G, Bilici S, Koksal E, Gezmen Karadag M, Sanlier N. Evaluation of dietary quality of adolescents using Healthy Eating Index. Nutr Res Prac 2011;5(4):322–8. https://doi.org/10.4162/nrp.2011.5.4.322.
[22] Azadbakht L, Haghighatdoost F, Feizi A, Esmaillzadeh A. Breakfast eating pattern and its association with dietary quality indices and anthropometric measurements in young women in Isfahan. Nutrition 2013;29(3–4):420–5. https://doi.org/10.1016/j.nut.2012.07.013.
[23] Wicherski J. et al. Association between breakfast skipping and body weight – a systematic review and meta-analysis of observational longitudinal studies.
[24] Ledikwe JH, Ello-Martin JA, Rolls BJ. Portion sizes and the obesity epidemic. J Nutr 2005;135(4):905–9. https://doi.org/10.1093/jn/135.4.905.
[25] Nour M, Lutze SA, Grech A, Allman-Farinelli M. The relationship between vegetable intake and weight outcomes: a systematic review of cohort studies. Nutrients 2018;10(11):1626. https://doi.org/10.3390/nu10111626.
[26] Arnesen EK, Thorisdottir B, Lamberg-Allardt C, Bärebring L, Nilsen MM, Terragni L. Vitamin D and dietary intake in young and adult women of immigrant background living in Norway. Nutrients 2022;14(8):1595. https://doi.org/10.3390/nu14081595.
[27] Krebs NF, Jacobson MS. Prevention of pediatric overweight and obesity. Pediatrics 2003;112(2):424–30. https://doi.org/10.1542/peds.112.2.424.
[28] World Health Organization. Body mass index - BMI. https://www.who.int/data/gho/indicator-metadata-registry/imr-details/3020; 2022.
[29] Lissner L, Sohlström A, Sundblom E, Sjöberg A. Trends in overweight and obesity in Swedish schoolchildren 1999-2005: has the epidemic reached a plateau? Obes Rev 2010;11(8):553–9. https://doi.org/10.1111/j.1467-789X.2009.00702.x.
[30] Food and Agriculture Organization of the United Nations & World Health Organization. Asia and the Pacific regional overview of food security and nutrition: addressing the burden of malnutrition for a healthier future. WHO; 2020. https://www.who.int/docs/default-source/wpro—documents/health-topics/nutrition/210118-fao-panorama-report-2020-3.pdf?Status=Master&sfvrsn=1217e849_7.
[31] Lobstein T, Jackson-Leach R. Child overweight and obesity in the USA: prevalence rates according to IOTF definitions. Int J Pediatr Obes 2007;2(1):62–4. https://doi.org/10.1080/17477160601103986.
[32] Puhl RM, Liu S. A national survey of public views about the classification of obesity as a disease. Obesity 2015;23(6):1288–95. https://doi.org/10.1002/oby.21068.
[33] Druet C, Ong KK. Early childhood predictors of adult body composition. Best Pract Res Clin Endocrinol Metabol 2008;22(3):489–502. https://doi.org/10.1016/j.beem.2008.02.002.
[34] Dantas RR, da Silva GAP. The role of the obesogenic environment and parental lifestyles in infant feeding behavior. Revista Paulista de Pediatria 2019;37(3):363. https://doi.org/10.1590/1984-0462/.
[35] Ritchie S, Connell J. The link between abdominal obesity, metabolic syndrome, and cardiovascular disease. Nutr Metabol Cardiovasc Dis 2007;17(4):319–26. https://doi.org/10.1016/j.numecd.2006.07.005.
[36] Yang Z, Li Y, Dong B, Gao D, Wen B, Ma J. Relationship between parental overweight and obesity and childhood metabolic syndrome in their offspring: results from a cross-sectional analysis of parent–offspring trios in China. BMJ Open 2020;10(3):e036332. https://doi.org/10.1136/bmjopen-2019-036332.
[37] Ortega-García JA, Kloosterman N, Alvarez L, Tobarra-Sánchez E, Cárceles-Álvarez A, Pastor-Valero R, López-Hernández FA, Sánchez-Solis M, Claudio L. Full breastfeeding and obesity in children: a prospective study from birth to 6 years. Child Obes 2018;14(5):327–37. https://doi.org/10.1089/chi.2017.0335.
[38] Panera N, Mandato C, Crudele A, Bertrando S, Vajro P, Alisi A. Genetics, epigenetics and transgenerational transmission of obesity in children. Front Endocrinol 2022 Nov 14;13:1006008. https://doi.org/10.3389/fendo.2022.1006008. PMID: 36452324; PMCID: PMC9704419.
[39] Mathialagan A, Nallasamy N, Razali SN. Physical activity and media environment as antecedents of childhood obesity in Malaysia. Asian J Pharmaceut Clin Res 2018;11(9):287–92. https://doi.org/10.22159/ajpcr.2018.v11i9.17095.
[40] Han S-H, Yee J-Y, Pyo J-S. Impact of short sleep duration on the incidence of obesity and overweight among children and adolescents. Medicina 2022;58(8):1037. https://doi.org/10.3390/medicina58081037.
[41] Noorwali E, Potter G, Ford H, Mulla U, Murphy D, Wark P, Frost G, Hardie L, Cade J. Sleep timing and vegetable intakes in UK adults: a cross-sectional study. Proc Nutr Soc 2018;77(OCE4):E132. https://doi.org/10.1017/S0029665118001386.
[42] Kelsey MM, Zaepfel A, Bjornstad P, Nadeau KJ. Age-related consequences of childhood obesity. Gerontology 2014;60(3):222–8.
[43] Sorof J, Daniels S. Obesity hypertension in children: a problem of epidemic proportions. Hypertension 2002;40(4):441–7.
[44] Tauman R, Gozal D. Obesity and obstructive sleep apnea in children. Paediatr Respir Rev 2006;7(4):247–59. https://doi.org/10.1016/j.prrv.2006.07.003.
[45] Sideleva O, Black K, Dixon AE. Effects of obesity and weight loss on airway physiology and inflammation in asthma. Pulm Pharmacol Therapeut 2013;26(4):455–8. https://doi.org/10.1016/j.pupt.2013.02.006.
[46] Babakr AT, Elsheikh O, Almarzoqi A, Assiri A, Abdalla BE, Zaki H, Fatani S, Eldin EEN. Relationship between oxidized low-density lipoprotein antibodies and

obesity in different glycemic situations. Diabetes, Metab Syndrome Obes Targets Ther 2014;7:513–20. https://doi.org/10.2147/DMSO.S63305.
[47] Bradley SH, Lawrence N, Steele C, Mohamed Z. Precocious puberty. BMJ 2020; 368:l6597. https://doi.org/10.1136/bmj.l6597.
[48] Liu G, Guo J, Zhang X, Lu Y, Miao J, Xue H. Obesity is a risk factor for central precocious puberty: a case-control study. BMC Pediatr 2021;21:509. https://doi.org/10.1186/s12887-021-03036-x.
[49] Uçar A, Saka N, Baş F, Hatipoğlu N, Bundak R, Darendeliler F. Reduced atherogenic indices in prepubertal girls with precocious adrenarche born appropriate for gestational age in relation to the conundrum of DHEAS. Endocrine Connections 2013;2(2):1–10. https://doi.org/10.1530/EC-12-0084.
[50] Anderson AD, Solorzano CMB, McCartney CR. Childhood obesity and its impact on the development of adolescent PCOS. Semin Reprod Med 2014;32(3):202–13. https://doi.org/10.1055/s-0034-1371088.
[51] Lindberg L, Hagman E, Danielsson P, Marcus C, Persson M. Anxiety and depression in children and adolescents with obesity: a nationwide study in Sweden. BMC Med 2020;18:30. https://doi.org/10.1186/s12916-020-1502-2.
[52] Brooks SJ, Feldman I, Schiöth HB, Titova OE. Important gender differences in psychosomatic and school-related complaints in relation to adolescent weight status. Sci Rep 2021;11:14147. https://doi.org/10.1038/s41598-021-93512-y.
[53] Lerret SM, Garcia-Rodriguez L, Skelton J, Biank V, Kilway D, Telega G. Predictors of nonalcoholic steatohepatitis in obese children. Gastroenterol Nurs 2011;34(6): 434–7. https://doi.org/10.1097/SGA.0b013e31823787ea.
[54] Peng L, Wu S, Zhou N, Zhu S, Liu Q, Li X. Clinical characteristics and risk factors of nonalcoholic fatty liver disease in children with obesity. BMC Pediatr 2021;21: 122. https://doi.org/10.1186/s12887-021-02564-9.
[55] Koebnick C, Getahun D, Smith N, Porter A, Der-Sarkissian JK, Jacobsen S. Extreme childhood obesity is associated with increased risk for gastroesophageal reflux disease in a large population-based study. Int J Pediatr Obes 2011;6(3): e257–63. https://doi.org/10.3109/17477166.2011.613664.
[56] Nasif WA, Mukhtar MH, Ali ASE-M, Eldein MMN, Almaimani RA, Ashgar SS. Body mass index is associated with Helicobacter pylori infection and increased oxidative DNA damage in an obese population. J Int Med Res 2022;50(5): 3000605221076975. https://doi.org/10.1177/03000605221076975.
[57] Dobner J, Kaser S. Body mass index and the risk of infection—from underweight to obesity. Clin Microbiol Infection 2017;24(1):24–8. https://doi.org/10.1016/j.c.
[58] Ortiz-Pinto MA, Ortiz-Marrón H, Esteban-Vasallo MD, Quadrado-Mercadal A, Casanova-Pardomo D, González-Alcón M, Ordobás-Gavin M, Galán I. Demand for health services and drug prescriptions among overweight or obese preschool children. Arch Dis Child 2019;105(3):292–7. https://doi.org/10.1136/archdischild-2019-316942.
[59] Shanley LA, Lin H, Flores G. Factors associated with length of stay for pediatric asthma hospitalizations. J Asthma 2014;52(5):471–7. https://doi.org/10.3109/02770903.2014.996644.
[60] Carroll CL, Stoltz P, Raykov N, Smith SR, Zucker AR. Childhood overweight increases hospital admission rates for asthma. Pediatrics 2007;120(4):734–40. https://doi.org/10.1542/peds.2006-3361.
[61] Obita G, Alkhatib A. Disparities in the prevalence of childhood obesity-related comorbidities: a systematic review. Front Public Health 2022;10:923744. https://doi.org/10.3389/fpubh.2022.923744.
[62] Mărginean Cristina Oana, Meliț Lorena Elena, Săsăran Maria Oana. Metabolic associated fatty liver disease in children—from atomistic to holistic. Biomedicines 2021;9(12):1866. https://doi.org/10.3390/biomedicines9121866.
[63] Feldstein AE, Patton-Ku D, Boutelle KN. Obesity, nutrition, and liver disease in children. Clin Liver Dis 2014 Feb;18(1):219–31. https://doi.org/10.1016/j.cld.2013.09.003. PMID: 24274876; PMCID: PMC4008146.
[64] Mosca A, Della Volpe L, Alisi A, Veraldi S, Francalanci P, Maggiore G. Non-invasive diagnostic test for advanced fibrosis in adolescents with non-alcoholic fatty liver disease. Front pediatrics 2022;10:885576. https://doi.org/10.3389/fped.2022.885576.
[65] Hadjiyannakis S, Buchholz A, Chanoine JP. The Edmonton Obesity Staging System for Pediatrics: a proposed clinical staging system for paediatric obesity. Paediatr Child Health 2016;21(1):21–6. https://doi.org/10.1093/pch/21.1.21.
[66] Robinson SM, Godfrey KM. Feeding practices in pregnancy and infancy: relationship with the development of overweight and obesity in childhood. Int J Obes 2008;32:S4–10. https://doi.org/10.1038/ijo.2008.212.
[67] Arenz S, Rückerl R, Koletzko B, von Kries R. Breast-feeding and childhood obesity—a systematic review. Int J Obes 2004;28(10):1247–56. https://doi.org/10.1038/sj.ijo.0802758.
[68] World Health Organization. Complementary feeding. Report of the global consultation. Retrieved from, http://www.who.int/nutrition/publications/Complementary_Feeding.pdf; 2001.
[69] Barlow SE. Expert committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: Summary report. Pediatrics 2007;120:S164–92. https://doi.org/10.1542/peds.2007-2329C.
[70] James J, Thomas P, Cavan D, Kerr D. Preventing childhood obesity by reducing consumption of carbonated drinks: cluster randomised controlled trial. BMJ 2004;328(7450):1237. https://doi.org/10.1136/bmj.38077.458438.EE.
[71] Pereira MA, Ludwig DS. Dietary fiber and body-weight regulation: observations and mechanisms. Pediatr Clin 2001;48(4):969–80. https://doi.org/10.1016/S0031-3955(05)70352-7.
[72] Mace K, Shahkhalili Y, Aprikian O, Stan S. Dietary fat and fat types as early determinants of childhood obesity: a reappraisal. Int J Obes 2006;30:S50–7. https://doi.org/10.1038/sj.ijo.0803491.
[73] Styne DM, Arslanian SA, Connor EL, et al. Pediatric obesity: assessment, treatment, and prevention—a European society clinical guideline. J Clin Endocrinol Metabol 2017;102(3):709–57. https://doi.org/10.1210/jc.2016-2573.
[74] Kelley GA, Kelley KS. Effects of exercise in the treatment of overweight and obese children and adolescents: a systematic review of meta-analyses. J Obesity 2013: 783103. https://doi.org/10.1155/2013/783103. 2013.
[75] World Health Organization. Global recommendations on physical activity for health. Retrieved from, http://www.who.int/dietphysicalactivity/factsheet_recommendations/en/index.html; 2011.
[76] McMurray RG, Berry DC, Schwartz TA, et al. Relationships of physical activity and sedentary time in obese parent-child dyads: a cross-sectional study. BMC Publ Health 2016;16(124). https://doi.org/10.1186/s12889-016-2777-1.
[77] Caroli M, Argentieri L, Cardone M, Masi A. Role of television in childhood obesity prevention. Int J Obes 2004;28:S104–8. https://doi.org/10.1038/sj.ijo.0802808.
[78] Zhang G, Wu L, Zhou L, Lu W, Mao C. Television watching and risk of childhood obesity: a meta-analysis. Eur J Publ Health 2016;26(1):13–8. https://doi.org/10.1093/eurpub/ckv213.
[79] Fatima Y, Doi SAR, Mamun AA. Sleep quality and obesity in young subjects: a meta-analysis. Obes Rev 2016;17(11):1154–66. https://doi.org/10.1111/obr.12456.
[80] Mitchell JA, Rodriguez D, Schmitz KA, Audrain-McGovern J. Sleep duration and adolescent obesity. Pediatrics 2013;131(5):e1428–34. https://doi.org/10.1542/peds.2012-2368.
[81] Porri D, Morabito LA, Cavallaro P, et al. Time to act on childhood obesity: the use of technology. Front Pediatr 2024;12:1359484. https://doi.org/10.3389/fped.2024.1359484.
[82] Siu O. Parents' experiences using digital health technologies in paediatric overweight and obesity support: an integrative review. PMC; 2022. Retrieved from, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9819819/.
[83] Riva G, Cattivelli R. Time to act on childhood obesity: the use of technology. Front Pediatrics 2024;12:1359484. https://doi.org/10.3389/fped.2024.1359484.
[84] Hesketh KD, Campbell KJ. Digital health interventions for weight management in children and adolescents: systematic review and meta-analysis. BMC Pediatr 2021;21(1):499. https://doi.org/10.1186/s12887-021-02980-x.
[85] Lindsay AC, Sussner KM, Kim J, Gortmaker S. The role of parents in preventing childhood obesity. Future Child 2006;16(1):169–86. https://doi.org/10.1353/foc.2006.0006.
[86] Van der Kruk JJ, Kortekaas F, Lucas C, Jager-Wittenaar H. Obesity: a systematic review on parental involvement in long-term European childhood weight control interventions with a nutritional focus. Obes Rev 2013;14(8):745–60. https://doi.org/10.1111/obr.12045.
[87] Connelly JB, Duaso MJ, Butler G. A systematic review of controlled trials of interventions to prevent childhood obesity and overweight: a realistic synthesis of the evidence. Publ Health 2007;121(7):510–7. https://doi.org/10.1016/j.puhe.2006.09.043.
[88] Martin A, Saunders DH, Shenkin SD, Sproule J. Lifestyle intervention for improving school achievement in overweight or obese children and adolescents. Cochrane Database Syst Rev 2014;3:CD009728. https://doi.org/10.1002/14651858.CD009728.pub2.
[89] Oosterhoff M, Joore M, Ferreira I. The effects of school-based lifestyle interventions on body mass index and blood pressure: a multivariate multilevel meta-analysis of randomized controlled trials. Obes Rev 2016;17(11):1131–53. https://doi.org/10.1111/obr.12446.
[90] Foltz JL, May AL, Belay B, Nihiser AJ, Dooyema CA, Blanck HM. Population-level intervention strategies and examples for obesity prevention in children. Annu Rev Nutr 2012;32(1):391–415. https://doi.org/10.1146/annurev-nutr-071811-150646.
[91] Hoffman JA, Frerichs L, Story M, Jones J, Gaskin K, et al. An integrated clinic-community partnership for child obesity treatment: a randomized pilot trial. Pediatrics 2018;141(1):e20171444. https://doi.org/10.1542/peds.2017-1444.
[92] World Health Organization. Prioritizing areas for action in the field of population-based prevention of childhood obesity: a set of tools for member states to determine and identify priority areas for action. Retrieved from, http://www.who.int/dietphysicalactivity/childhood/tools/en/; 2012.
[93] World Health Organization. Report of the commission on ending childhood obesity. Retrieved from, http://www.who.int/end-childhood-obesity/en/; 2016.
[94] ASEAN. ASEAN regional action plan on healthy lifestyles 2021–2025. Retrieved from, https://asean.org/storage/2021/10/ASEAN-Regional-Action-Plan-on-Healthy-Lifestyles-2021-2025.pdf; 2021.
[95] Oude Luttikhuis H, Baur L, Jansen H, et al. Interventions for treating obesity in children. Cochrane Database Syst Rev 2009;2009(1):CD001872. https://doi.org/10.1002/14651858.CD001872.pub2.
[96] Spear BA, Barlow SE, Ervin C, et al. Recommendations for treatment of child and adolescent overweight and obesity. Pediatrics 2007;120:S254–88. https://doi.org/10.1542/peds.2007-2329E.
[97] Davis CL, Tomporowski PD, McDowell JE, et al. Exercise improves executive function and achievement and alters brain activation in overweight children: a randomized, controlled trial. Health Psychol 2011;30(1):91–8. https://doi.org/10.1037/a0021766.
[98] Reinehr T. Lifestyle intervention in childhood obesity: changes and challenges. Nat Rev Endocrinol 2013;9(10):607–14. https://doi.org/10.1038/nrendo.2013.149.
[99] Son JE. Genetics, pharmacotherapy, and dietary interventions in childhood obesity. J Pharm Pharmaceut Sci 2024;27. https://doi.org/10.3389/jpps.2024.12861. Article 12861.

[100] Kelly AS, Arslanian S, Hesse D, Iversen AT, Körner A, Schmidt S, Sørrig R, Weghuber D, Jastreboff AM. Reducing BMI below the obesity threshold in adolescents treated with once-weekly subcutaneous semaglutide 2.4 mg. Obesity 2023 Aug;31(8):2139–49. https://doi.org/10.1002/oby.23808. Epub 2023 Jul 9. PMID: 37196421.

[101] Mu Y, Bao X, Eliaschewitz FG, Hansen MR, Kim BT, Koroleva A, Ma RCW, Yang T, Zu N, Liu M, STEP 7 Study Group. Efficacy and safety of once weekly semaglutide 2·4 mg for weight management in a predominantly east Asian population with overweight or obesity (STEP 7): a double-blind, multicentre, randomised controlled trial. Lancet Diabetes Endocrinol 2024 Mar;12(3):184–95. https://doi.org/10.1016/S2213-8587(23)00388-1. Epub 2024 Feb 5. PMID: 38330988.

[102] Mead E, Atkinson G, Richter B, et al. Drug interventions for the treatment of obesity in children and adolescents. Cochrane Database Syst Rev 2016;2016(11): CD012436. https://doi.org/10.1002/14651858.CD012436.pub2.

[103] Inge TH, Zeller MH, Jenkins TM, et al. Perioperative outcomes of adolescents undergoing bariatric surgery: the teen-longitudinal assessment of bariatric surgery (Teen-LABS) study. JAMA Pediatr 2014;168(1):47–53. https://doi.org/10.1001/jamapediatrics.2013.4296.

[104] Inge TH, Xanthakos SA, Zeller MH. Bariatric surgery for pediatric extreme obesity: now or later? Int J Obes 2007;31(1):1–14. https://doi.org/10.1038/sj.ijo.0803734.

[105] Sugerman HJ, Sugerman EL, DeMaria EJ, et al. Bariatric surgery for severely obese adolescents. J Gastrointest Surg 2003;7(1):102–8. https://doi.org/10.1016/s1091-255x(02)00028-8.