Obesity in Children and Adolescents, Prevalence and its Consequences on the Respiratory, Circulatory and Musculoskeletal Systems

Maria Zofia Lisiecka*

Department of Allergology, National Medical Institute of the Ministry of the Interior and Administration, Warsaw, 02-507, Poland

Abstract: *Background:* This study aimed to summarize and analyze data from 2020 to the first half of 2025 on obesity in children and adolescents in Poland, focusing on its prevalence, pathogenesis, and consequences for the respiratory, cardiovascular, and musculoskeletal systems.

Methods: The work synthesizes results from 52 studies conducted in Poland and abroad, applying epidemiological, clinical, functional, and molecular approaches.

Findings: The findings confirm a rising prevalence of childhood obesity in Poland, with gender and regional disparities: overweight prevalence reaches 32-36%, obesity- 12-14%, with higher rates in rural areas and among boys. Pathogenetically, key roles are played by neuroendocrine dysregulation of appetite, insulin resistance, and socio-economic and genetic influences. Respiratory effects include reduced lung capacity, impaired ventilation, high risk of obstructive sleep apnea (13-59%), and aggravated asthma with heightened inflammation and reduced treatment efficacy. Cardiovascular issues affect about 6% of adolescents with hypertension, alongside early endothelial dysfunction, dyslipidemia, and myocardial hypertrophy linked to insulin resistance and systemic inflammation. Musculoskeletal consequences include joint overload, postural defects, flat feet, impairedmotor coordination, and decreased quality of life, with 30-60% of obese children showing such dysfunctions.

Conclusions: These results highlight the urgency of early detection and multidisciplinary management of pediatric obesity, integrating national and sociocultural considerations in Poland.

Keywords: Metabolic dysfunction, Inflammatory markers, Physical inactivity, Endothelial dysfunction, Motor coordination, Sleep apnea.

INTRODUCTION

Obesity in children and adolescents is now considered one of the most pressing public health problems worldwide, and Poland is no exception. Over the period 2015 to the first half of 2025, the prevalence of overweight and obesity among young people increased in many European countries, including Poland, which threatens the health of future generations and creates a significant burden on the healthcare system [1]. Identifying the factors contributing to this increase, as well as the consequences of obesity for children's health, are key tasks of modern medical science. Of particular concern are complications affecting the respiratory, cardiovascular and musculoskeletal systems, as they can serve as precursors to chronic diseases in adulthood [2].

A review of the literature shows that scientists worldwide, including those in Poland, have studied childhood obesity. The growing trends in obesity among Polish children are part of a global epidemic, but also have their own specific features related to regional characteristics of lifestyle, nutrition and socio-economic status [3]. A that obese children most commonly exhibit functional postural abnormalities flat feet, hyperlordosis, thoracic kyphosis, and scoliotic curves due to a key driver of obesity - a trend clearly reflected in epidemiological data from 2020 to the first half of 2025 [4, 5]. However, there is a relative lack of studies that comprehensively assess the impact of obesity on various body systems in the Polish population, particularly the respiratory and musculoskeletal systems, creating gaps in knowledge and practical recommendations.

One crucial area is the study of the pathogenetic mechanisms underlying obesity in children and adolescents. The presence of insulin resistance, hormonal imbalance, and the influence of social and genetic factors, as described in detail by Singh *et al.* [6], is considered a cornerstone in understanding the multifactorial pathogenesis of childhood obesity. These authors highlight how endocrine dysregulation interacts with inherited predispositions and socio-economic background, forming a self-perpetuating cycle of weight gain. Despite the robustness of such theoretical

*Address correspondence to this author at the Department of Allergology, National Medical Institute of the Ministry of the Interior and Administration, Warsaw, 02-507, Poland; E-mail: mariazofialisiecka@gmail.com

frameworks, the lack of region-specific data for Poland leaves important questions unanswered — in particular, how local dietary patterns, physical activity levels, and health inequalities amplify or mitigate these mechanisms.

In the respiratory domain, Mazzotta and Barkai [7] present compelling evidence linking obesity to a heightened risk of bronchial asthma, obstructive sleep apnea, and hypoventilation syndromes in children. Their findings underline the role of excess adiposity in airway inflammation and reduced pulmonary compliance. Yet, while these trends are well-documented globally, the exact prevalence and severity of such complications in Polish children remain insufficiently characterized, especially in relation to urban-rural disparities. Mainieri *et al.* [8] provide a thorough account of cardiovascular sequelae, noting the frequent occurrence of elevated arterial pressure, dyslipidemia, and early myocardial remodeling among obese adolescents. They argue for proactive screening to detect subclinical dysfunction before irreversible changes occur. However, their work, like that of Singh *et al.,* primarily draws on non-Polish cohorts, limiting its direct applicability without local adaptation of diagnostic thresholds and intervention strategies. Attention is also drawn to the negative impact of obesity on the musculoskeletal system - increased load on the joints, impaired posture, and delayed motor development, which significantly reduces the quality of life of children and requires comprehensive rehabilitation [9].

Another important aspect is the impact of the COVID-19 pandemic, which has dramatically changed the lifestyles of children and adolescents in Poland, contributing to an increase in obesity prevalence due to restrictions on physical activity and changes in eating habits, as evidenced by recent national reports [10-12]. This factor creates an additional challenge for the healthcare system and stimulates the search for new approaches to prevention and treatment.

Despite the significant amount of scientific data, several vital gaps remain. In particular, the complex impact of obesity on multisystem complications in the Polish pediatric population has not been sufficiently studied, and there are no systematic national protocols for comprehensive obesity management that would integrate medical, social and educational components. The absence of such systemic approaches complicates the coordination of prevention, early diagnosis and therapy measures, as well as makes it challenging to assess the effectiveness of interventions.

Therefore, in the context of existing scientific knowledge and socio-economic challenges for Poland, it is essential to conduct a deep analysis of the prevalence of obesity among children and adolescents, its impact on the central systems of the body, as well as the prospects for the development of multidisciplinary approaches in clinical practice and public health. This article aimed to review data on the prevalence, mechanisms, and health consequences of childhood obesity in Poland, focusing on national specifics and current challenges. In accordance with the goal, the following tasks were formulated: to analyze the prevalence of childhood obesity in Poland, taking into account national characteristics, to investigate the main mechanisms of its development, to assess the impact on the respiratory, cardiovascular and musculoskeletal systems, as well as to identify current challenges and directions for further research.

MATERIALS AND METHODS

To prepare a literature review on the prevalence of childhood and adolescent obesity in Poland, trends over recent decades, and related pathogenetic and clinical aspects, a systematic search for scientific publications was conducted in leading electronic databases. The primary sources were PubMed, Scopus, and Web of Science, as well as specialized databases of the World Health Organization (WHO), in particular the repository of the Health Behaviour in School-aged Children (HBSC) study and the Childhood Obesity Surveillance Initiative (COSI) project.

The search was performed between January and March 2025 and covered publications from January 1, 2020, to June 30, 2025. Queries were conducted in English and Polish, using combinations of keywords and phrases such as “childhood obesity Poland”, “pediatric obesity prevalence Poland”, “HBSC Poland obesity”, “COSI Poland data”, “obesity respiratory complications children Poland”, “cardiovascular consequences pediatric obesity Poland”, and “musculoskeletal impact obesity children Poland”. Similar queries were adapted for Scopus and Web of Science with filters by publication date (2020-2025), language (English, Polish), and study type (review articles, epidemiological studies, clinical studies).

For pathogenetic aspects, additional queries were used: “pathogenesis childhood obesity”, “leptin resistance pediatric obesity”, “insulin resistance obesity children”, and “genetic factors obesity children Poland”. This approach ensured the inclusion of studies

addressing neuroendocrine regulation, metabolic disturbances, and gene-environment interactions relevant to the Polish population.

To explore health consequences, targeted searches were carried out: “respiratory complications obesity children Poland”, “obstructive sleep apnea pediatric obesity Poland”, “cardiovascular risk obesity children Poland”, “endothelial dysfunction childhood obesity”, “musculoskeletal disorders obesity children Poland”, and “postural defects obesity children”. These queries yielded clinical studies, systematic reviews, and meta-analyses addressing respiratory, cardiovascular, and musculoskeletal outcomes.

The search initially retrieved 184 publications. After title and abstract screening, 112 articles were excluded due to irrelevance, duplication, low methodological quality, or insufficiently detailed Polish data. Full-text analysis was performed for 72 papers; 51 met all inclusion criteria and were included in the final review. A methodological quality appraisal of the included studies was performed using predefined criteria to enhance the reliability of the evidence. Each full-text article was assessed for sample size adequacy, clarity of study design, statistical validity, and relevance to the Polish pediatric population. Studies with low methodological quality or insufficient reporting (e.g., unclear outcome measures or high risk of bias) were excluded to ensure the robustness of the review. Publications were included if they contained original epidemiological or clinical data on Polish children and adolescents, or if they provided comparative international data with Poland represented. Studies with small sample sizes (<50 participants), adult-only populations, or indirect relation to pediatric obesity were excluded.

The analysis was thematic, grouping the evidence into epidemiology, pathogenesis, respiratory effects, cardiovascular consequences, and musculoskeletal impact. Data from WHO projects (HBSC, COSI) and official Polish reports were used for prevalence trends, enabling cross-national comparisons.

Special attention was paid to studies conducted during and after the COVID-19 pandemic (2020-2023), reflecting the influence of lifestyle changes, reduced physical activity, increased screen time, and dietary shifts. This was critical for understanding the acceleration of obesity trends in the target population during the first half of the 2020s.

The systematic approach ensured comprehensive coverage of relevant literature, with transparent selection and exclusion criteria, and a focus on high-quality, peer-reviewed evidence supplemented by validated official statistical sources.

RESULTS AND DISCUSSION

Prevalence of Childhood and Adolescent Obesity in Poland: Trends in Recent Decades

Over the past decades, the problem of obesity among children and adolescents in Poland has shown a significant increase, becoming one of the key challenges for the public health system. Data from national and international epidemiological studies indicate a stable trend towards an increase in the prevalence of overweight and obesity among the younger population of Poland, which correlates with the general European dynamics. One of the most authoritative sources for studying the health status and prevalence of overweight among children is the Health Behaviour in School-aged Children (HBSC) study, conducted under the auspices of the WHO. Poland has been an active participant in this project since the 1990s. The results of the latest wave of surveys in 2017/2018 showed that approximately 15% of adolescents aged 11-15 in Poland are overweight. Gender differences have been identified: the proportion of overweight boys is about 18%, while among girls this figure is about 12% [13].

The European Childhood Obesity Surveillance Initiative (COSI), implemented under the auspices of the WHO, regularly conducts standardized anthropometric measurements of children aged 6-9 years. In the context of Poland, data from the fifth round (2021) showed that approximately 35.6% of 8-year-olds were overweight, of which 13.6% were obese- 14% of boys and 12% of girls. In the sixth round (2022-2023), the prevalence of overweight in the 7-9-year-old group was about 32.3%, and obesity was 12%, with higher rates among boys [14].

Recent studies indicate a persistent trend towards a higher prevalence of overweight and obesity among children in rural areas, which contrasts with traditional European trends. For example, according to the Finnish Institute for Health and Welfare [15], the proportion of primary school children with overweight in rural areas is 36%, while in urban areas it is only 26%; the prevalence of obesity among boys in rural areas is 14% vs 7% in urban areas. In a Polish study by

Długoński *et al.* [16], obesity rates among school-age girls in rural areas (8.62%) are almost twice those in urban areas (4.17%). These data highlight the need to account for local characteristics and target interventions in the fight against obesity in adolescence.

Particular attention should be paid to the age- and gender-specific prevalence of obesity. COSI data show that with age, the risk of obesity gradually increases, especially in boys. At the age of 6, obesity is detected in approximately 5-6% of children, but by the age of 9, this figure increases to over 10% among boys. The trend is also present in girls, but less pronounced. Such sexual dimorphism persists in adolescence, which is confirmed by the results of HBSC: boys are more likely to be overweight, but girls are prone to a distorted perception of their own weight and a higher risk of eating disorders [17].

A comparison of the situation in Poland with that of other European Union countries, according to the WHO European Childhood Obesity Surveillance Initiative, shows that Poland is in the middle range of obesity prevalence among children [1]. Thus, in Malta, the obesity rate among school-age children reached approximately 19%. In comparison, in Poland this figure fluctuated between 10% and 12%, which is significantly lower than in Hungary, Malta, and Greece, but higher than in the Netherlands, the Czech Republic and Sweden (Table **1**) [18].

The data presented in Table **1** demonstrate notable variations in childhood obesity prevalence and adolescent physical activity levels across selected EU countries during 2020-2022. Malta exhibits the highest obesity rates among children aged 7-9 years (19%) and adolescents aged 10-19 years (10.1%), while Poland shows moderate obesity prevalence (15% and 6.1%, respectively). Other countries, such as Hungary and Greece, also report relatively high obesity percentages, whereas Czechia and the Netherlands display lower rates, especially in adolescents. Regarding physical activity, Poland is the only country with available gender-specific data, revealing a significant disparity between boys and girls. Boys in Poland engage more frequently in at least 60 minutes of daily physical activity (23%) compared to girls (14%). Socio-cultural factors, including traditional gender roles, differences in participation in organized sports, and varying levels of encouragement for physical activity among boys and girls, may influence this difference. Additionally, societal expectations and safety concerns may limit girls' outdoor activities, contributing to lower physical activity levels. Understanding and addressing these gender disparities is essential for developing targeted interventions to promote physical activity equitably among all adolescents.

At the same time, only about 20% of Polish adolescents achieve the recommended level of physical activity (≥60 min/day), which is lower than in the northern EU countries. This suggests that insufficient physical activity may be an essential factor in the potential further increase in obesity prevalence among Polish youth [21].

In the context of dynamics, the COVID-19 pandemic has significantly affected children's behavioral and eating habits in Poland. According to a study by Zachurzok *et al*.[22], among 177 children with endocrine disorders, a significant increase in BMI z-score was observed during quarantine restrictions in the period June-September 2020 compared with pre-lockdown indicators (January-March 2020). At the same time, physical activity levels decreased (from 41.2% to 31.1% of children who exercised ≥60 min daily), and the proportion of children who spent more

Table 1: The Comparison of Childhood Obesity and Adolescent Physical Activity Among Selected EU Countries (2020-2022 Data)

Country	Obesity 7-9 years (%)	Obesity 10-19 years (%)	Poland physical activity ≥60 min/day (%)
Malta	19	10.1	39 (boys), 10 (girls)
Poland	15	6.1	23 (boys), 14 (girls)
Hungary	12-13	13.7	-
Greece	18	9.7	-
Netherlands	-	4.5	-
Czechia	9	4.5	-
Sweden	13	9.4	-

Source: compiled by the author based on [19, 20].

than 5 h in front of a screen increased to 46.9%. Similarly, Krupa-Kotara *et al.* [23] in a sample of 294 adolescents aged 6-14 years recorded a decrease in the frequency of five specific meals with vegetables/fruits and an increase in screen time to more than 4 h per day.

Although Poland ranks in the middle among EU countries in terms of childhood obesity prevalence, an analytical comparison with European averages reveals essential differences. The rates in Poland among children aged 7-9 (15%) and adolescents aged 10-19 (6.1%) are lower than in the group of EU countries with high prevalence, which includes Malta, Greece, and Hungary (≈18-19% among younger children and 9-14% among adolescents), but remain higher than the rates recorded in countries such as the Netherlands, the Czech Republic, and Sweden, where the obesity rate among adolescents often remains below 5%. Thus, Poland shows a moderate epidemiological profile, but its regional differences and gender trends differ from the EU average. In Poland, obesity is systematically more prevalent in rural areas and among boys. This trend is only partially reflected in broader European databases, where prevalence in cities is typically higher. In addition, the proportion of Polish adolescents who achieve the recommended level of physical activity (≥60 min/day) remains significantly lower than in Northern European countries, which may explain the risk of progressive convergence with EU regions with higher prevalence in the coming years. Ingeneral, Polandis experiencing a transitional epidemiological situation — it is neither among the countries with the highest obesity rates nor among those with protective demographic and lifestyle profiles, which highlights the need to take measures adapted to national conditions rather than relying on general strategies at the EU level.

Mechanisms of Pathogenesis of Obesity in Children and Adolescents

The pathogenesis of obesity in children and adolescents is a complex, multifactorial process involving interactions among neuroendocrine, metabolic, behavioral, genetic and social factors [24-26]. Understanding these mechanisms is key to developing effective preventive and therapeutic strategies, especially given the increasing prevalence of obesity among young people in Poland. One of the central mechanisms in the development of obesity is dysregulation of energy homeostasis at the hypothalamic level, where the main neuronal centers of appetite control are located. Usually, a complex interaction among hormones—such as leptin, ghrelin, insulin, and neuropeptide Y—maintains the balance between food intake and energy expenditure. Obese children have leptin resistance, which means a decrease in sensitivity to leptin—a hormone that signals satiety. As a result, appetite control is reduced, leading to hypercaloric eating and subsequent adipose tissue accumulation [27]. Insulin resistance is also a key pathogenetic factor, especially in children with abdominal obesity. It is accompanied by hyperinsulinemia, which further stimulates lipogenesis in the liver and adipocytes, creating a vicious cycle that contributes to the progression of metabolic syndrome in childhood [28].

The data on physical activity levels in the referenced studies, including Górna *et al.* [29], were primarily collected via self-reported questionnaires and standardized surveys administered to school-aged children and adolescents. These surveys assessed the frequency, duration, and intensity of physical activity, as well as sedentary behaviors, including sitting time. Objective measures using activity trackers or accelerometers were limited or not systematically applied in the Polish context during the study period. Therefore, the findings largely reflect subjective reporting, which may be influenced by recall bias or social desirability. Despite these limitations, the data highlight a concerning trend: only 25-33% of Polish children meet the WHO recommendation of at least 60 minutes of moderate to vigorous physical activity per day, and a significant proportion of adolescents exhibit very low exercise frequency and high sedentary time.

Socioeconomic conditions play a critical role in the risk of childhood obesity [30]. World Health Organization [1] data show that adolescents from lower-income families have a significantly higher prevalence of overweight (27%) than their peers from wealthier families (18%). They also have worse eating habits: only 32% consume fruits and vegetables daily (vs. 46%), and they consume sugary drinks more often (18% vs. 15%) [31] in a study of territorial inequalities in deprivation. Nguyen *et al.* [32] showed that in areas with a high social deprivation index, the probability of obesity among schoolchildren aged 5-7 years is more than twice that in regions with low deprivation (PR=2.02; 95% CI=1.46-2.78). At the same time, the mother's educational level turned out to be one of the key factors: children of mothers without higher education had approximately 60% higher risk of obesity than children of mothers with higher education. In the

Polish population of children, a significant relationship was established between the genetic factor and body mass index. In particular, carriers of the A-allele rs9939609 of the FTO gene had a significantly higher BMI - AA homozygotes had more than twice the risk of obesity (OR=2.11; 95% CI: 1.50-2.99, $p=2.23\times10^{-}$□) compared to TT or AT carriers. A strong influence of family history was also found: children with one or both obese parents had a significantly higher risk of overweight and abdominal obesity, which confirms the data of the study by Matłosz *et al.* [33].

All of the above factors do not act in isolation, but form a complex network of interdependencies that determines a child's individual susceptibility to obesity. Such a multidimensional approach to understanding pathogenesis is necessary for building effective intersectoral prevention strategies that take into account not only medical aspects, but also social, cultural and educational determinants. This is especially true in Poland, where structural differences across regions, the academic level of the population, and access to healthy-lifestyle infrastructure remain deeply uneven. Therefore, further study of neuroendocrine mechanisms, the relationship between genetic and environmental factors, and the improvement of public health policies that account for the national context are essential directions for reducing the burden of childhood obesity in Poland.

Consequences of Obesity for the Respiratory System

Obesity in children and adolescents leads to mechanical and inflammatory impairment of the respiratory system, manifested by reduced ventilatory efficiency, particularly decreased forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and expiratory reserve volume. The mechanisms involve increased pressure from abdominal adipose tissue on the diaphragm, reduced chest wall compliance, and disruption of the balance between the respiratory muscles and the load they bear. Continuing previous research, a longitudinal study conducted in 2024 among obese children aged 8-15 (n=66) revealed that an increase in abdominal obesity, as measured by waist circumference and the WC/Ht ratio, significantly correlated with declines in FEV_1/FVC and FEF_{25-75}%/FVC parameters ($p<0.01$). Additionally, a cross-sectional study of children aged 8-16 showed that the obese group had significantly higher FVC values but a reduced FEV_1/FVC ratio, with these changes closely associated with markers of fat mass [34].

Beyond reduced ventilatory capacity, obesity substantially increases the risk of developing obstructive sleep apnea syndrome (OSAS), characterized by recurrent upper airway obstruction, oxygen desaturation, sleep fragmentation, and sympathetic system activation. Polish data indicate that among overweight or obese children and adolescents, the prevalence of OSAS reaches 13-59%, compared to 1-6% in the general pediatric population. An international study conducted between 2019 and 2022 involving 132 obese children identified a high frequency of severe OSAS forms- 48.5%, accompanied by oxygen desaturation in 59.8% and hypoventilation in 20.5% [35]. These findings demonstrate a direct correlation between obesity (BMI, neck, and waist circumference) and OSAS severity ($p<0.001$), confirming the need for early screening and intervention.

Another necessary respiratory consequence of obesity is the increased prevalence and severity of bronchial asthma. Overweight children exhibit elevated levels of proinflammatory cytokines (IL-6, TNF-α, leptin), contributing to chronic airway inflammation characteristic of both atopic and non-atopic asthma. In a comparative study of children with comorbid asthma and obesity, Jiang *et al.* [36] found that this group significantly exceeded the values observed in children with asthma alone or obesity alone: levels of IL-6, TNF-α, and leptin were statistically higher, and there were also elevated PRAM scores, more extended hospital stays, and more difficult disease control. These findings suggest that systemic inflammation, insulin resistance, and obesity-induced endothelial dysfunction may reduce the efficacy of standard pharmacological treatments (inhaled corticosteroids, long-acting β_2-agonists), underscoring the need to refine therapeutic strategies for this patient population.

Childhood obesity significantly reduces tolerance to aerobic exercise, driven by impairments in respiratory mechanics, hypoventilation syndrome, weakened respiratory muscles, and increased overall fatigue. According to a 2021 Polish study (Katowice), children with obesity had higher absolute VO_2 peak values (liters/min) than their normal-weight peers. Still, their mass-specific VO_2 peak (ml/kg/min) was markedly lower (25.44 vs. 36.5 ml/kg/min). Additionally, data from Makni *et al.* [37] showed that children with a BMI above the 97th percentile covered only ~80% of the distance in the 6-minute walk test compared with normative values (approximately 547 m in girls and 575 m in boys). These findings indicate a reduced

functional reserve in children with obesity, creating a vicious cycle: decreased physical activity→weight gain→worsening respiratory function→even less physical activity.

Polish pulmonological observations over the past five years have revealed significant changes in the clinical presentation of respiratory diseases among overweight children. Specifically, in the cities of Wrocław and Poznań, pediatricians have noted more frequent occurrences of nocturnal snoring, daytime sleepiness, and obstructive apnea, often associated with adenoidal/tonsillar hypertrophy and an increased risk of tonsillectomy in children with obesity [38].

Thus, the respiratory consequences of obesity in children and adolescents in Poland are clinically significant, multifactorial, and expanding in scope. They include not only subclinical ventilatory disorders but also the development of severe conditions such as obstructive sleep apnea, exacerbation of bronchial asthma, increased susceptibility to infections, and considerable limitations in physical capacity. Studying these consequences and ensuring their timely diagnosis is critically important for shaping pediatric management algorithms for overweight children within the Polish healthcare system.

Consequences of Obesity for the Cardiovascular System

Childhood and adolescent obesity has a profound systemic impact on the cardiovascular system, creating a foundation for the development of atherosclerosis, hypertension, metabolic syndrome, and structural and functional changes in the heart. One of the most common manifestations is elevated blood pressure in children who are overweight. In a previous study conducted in Central Poland among adolescents aged 15-17 years by Jeong *et al.* [39] (n≈5,200), hypertension was diagnosed in 5.8% of participants, with a higher prevalence in boys (6.8%) compared to girls (4.9%). The causes of hypertension include not only increased circulating blood volume and peripheral vascular resistance but also activation of the sympathoadrenal system, the renin-angiotensin-aldosterone system, and inflammatory processes associated with visceral adipose tissue. Notably, systolic blood pressure often exceeds the 95th percentile, indicating the early presence of pathology already in childhood.

In addition to elevated blood pressure, children with obesity increasingly present early signs of endothelial dysfunction, one of the first stages of atherosclerosis development. According to a 2024 systematic review and meta-analysis by Moretti *et al.* [40], overweight children exhibit an increased intima-media thickness (cIMT) by 0.041-0.045 mm compared to children of normal weight. In the study by Augimeri *et al.* [41], decreased vascular elasticity, altered strain, and increased carotid artery diameter were observed-hallmarks of early arterial stiffness in obese children. At the cellular level, experiments using plasma from such children showed reduced insulin-stimulated NO bioavailability and increased expression of endothelial activation markers (VCAM-1, ICAM-1), indicating endoplasmic reticulum stress and the initiation of inflammatory processes.

Obesity is closely associated with the development of dyslipidemia, characterized by elevated triglycerides, reduced HDL, increased LDL, and lipoprotein rearrangement toward a metabolic syndrome phenotype [42, 43]. For example, a 2020 study by Brzeziński *et al.* [44] in Gdańsk, which included 1,948 overweight or obese children, found dyslipidemia in 38-41% of participants. Low HDL was observed in 20-24% of children, and elevated LDL in 14-16%. Furthermore, Zhao *et al.* [45] reported that in 105 obese children, elevated IL-6 and hs-CRP were statistically associated with HOMA-IR, insulin, and triglyceride levels, while IL-6 was linked to low HDL; TNF-α correlated with elevated LDL (all $p<0.05$).

Cardiological observations from Polish centers over the past decade confirm a trend toward earlier cardiovascular risk and subclinical cardiomyopathies in adolescents with obesity. Specifically, the study by Salamaga *et al.* [46], conducted on 1,722 individuals with a BMI ≥ 30 kg/m², demonstrated a high prevalence of ECG signs of left ventricular hypertrophy according to the Sokolow-Lyon criteria, with strong correlations with hypertension and metabolic status.

In the context of European research, particularly the IDEFICS project, Poland displays trends similar to other EU countries regarding the prevalence of childhood obesity and cardiometabolic risks. However, there are significant differences in parental awareness and access to preventive programs. In Poland, the coverage of children by preventive cardiovascular screening programs is lower, limiting opportunities for early detection and intervention. This highlights the

need to improve the healthcare system and implement effective strategies to prevent childhood obesity.

Thus, childhood obesity in Poland is associated with a wide range of adverse changes in the cardiovascular system, both functional and morphological. These include hypertension, endothelial dysfunction, dyslipidemia, hyperinsulinemia, myocardial hypertrophy, and early signs of cardiac dysfunction.

Consequences of Obesity for the Musculoskeletal System

Obesity in children and adolescents has a significant negative impact on the musculoskeletal system, changing its functional architecture, movement mechanics, and biomechanical loading, which causes acute and chronic pathologies. In particular, patellofemoral loading during walking in children with a BMI above the 95th percentile is almost twice that of their peers with normal weight, 1.98 times in absolute terms and 1.81 times when adjusted for joint area [47]. This significantly increases the axial load on the knee joints, leading to a higher prevalence of knee pain: discomfort after physical activity in 67% of obese children compared with 14% in children with normal weight [48]. However, MRI and ultrasound studies show signs of early cartilage degeneration and inflammation of Hoffa's fat pad in approximately 30-38% of cases among obese adolescents (Figure **1**) [49].

Modern literature highlights the link between excess body weight in children and disruptions in the spinal curvatures. According to a study by Jorgić *et al.* [50] conducted among 2,129 schoolchildren (aged 6-9) in Bulgaria, more than 58% had postural defects, and 24% exhibited structural spinal deformities including kyphosis and lordosis. Contemporary researchers such as Calcaterra *et al.* [51] also demonstrate that obese children most commonly exhibit functional postural abnormalities flat feet, hyperlordosis, thoracic kyphosis, and scoliotic curves due to a forward shift of the center of gravity and overload of the muscular support system. Particularly striking is the finding that the prevalence of idiopathic scoliosis among adolescents with obesity reached 12.2%, which is twice the average rate in the general population [52]. This underscores the need for early orthopedic screening and interventions to prevent the progression of postural disorders.

Another common complication of obesity is longitudinal flatfoot, which arises due to weakening of the foot muscles and overload of the ligamentous apparatus [53-55]. Recent studies support this connection. For example, a study in Ethiopia among 1,072 schoolchildren aged 11-18 showed that the presence of flatfoot was 6.3 times higher among obese children compared to those with normal weight [56]. Another study by Feng *et al.* [57], involving 6,471 children aged 6-12, found that overweight children had reduced arch height and larger foot dimensions compared to their normal-weight peers. Furthermore, research by Jandova *et al.* [58] in Poland, involving 142

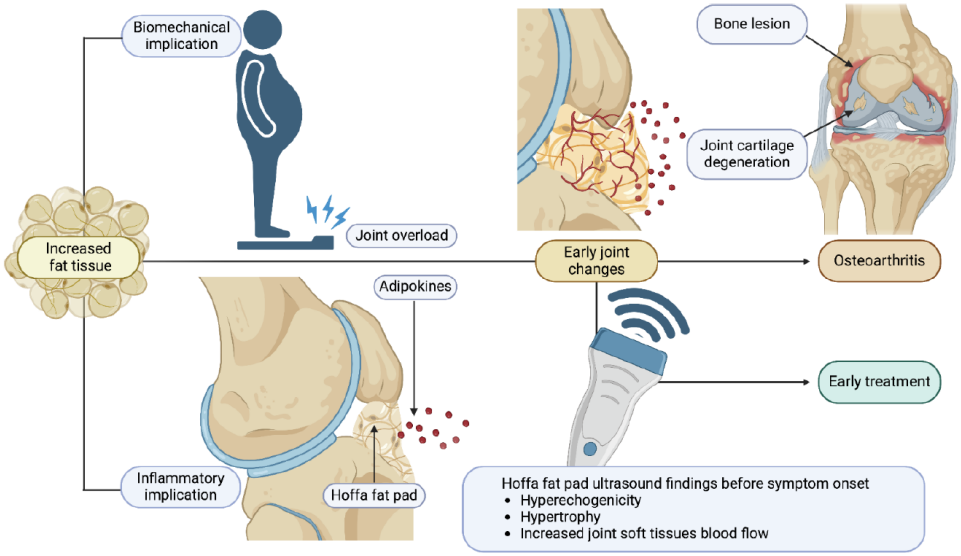

Figure 1: Ultrasound imaging can offer an early glimpse into knee osteoarthritis development, revealing initial joint alterations driven by biomechanical pressure from surrounding fat tissue, which ultimately lead to cartilage deterioration over time.

Source [49].

children with a mean age of 10.3 years, showed that children with flatfoot had a higher body mass index than those with standard foot structure.

Excess body weight in children is also closely associated with impairments in motor coordination [59-60]. A systematic review by Battaglia *et al.* [61] showed that overweight children have lower scores in gross motor coordination and reduced physical activity, supporting the hypothesis of a connection between obesity and motor dysfunction in children. Similar findings were obtained in studies of 9-10-year-old children in China and 6-13-year-old schoolchildren in Italy, where decreased motor coordination was also observed in overweight children. These data emphasize the importance of considering age and gender when planning motor development programs for children with excess weight.

Musculoskeletal dysfunction in obese children significantly affects their quality of life. A study by Aryayev *et al.* [62] in Ukraine showed that children with obesity had a markedly lower quality of life compared to children with normal weight, including reduced physical activity, difficulties in learning, and social interaction challenges. Similar results were reported in a study by van der Heijden *et al.* [63] in the Netherlands, where musculoskeletal dysfunction was found to significantly reduce quality of life in children, particularly in the physical and emotional domains. These findings highlight the need for a comprehensive approach to obesity treatment that includes not only weight reduction but also the restoration of musculoskeletal function to improve children's quality of life [64].

Thus, the consequences of obesity on the musculoskeletal system in childhood in Poland manifest across a broad spectrum: from mechanical joint overload and skeletal deformities to reduced motor activity, psychological distress, and impaired quality of life. Timely diagnosis, an interdisciplinary treatment approach focused on functional rehabilitation, and educational programs for parents are key to preventing long-term orthopedic complications in this vulnerable group of children.

Polish childhood obesity impairs respiratory, cardiovascular, and musculoskeletal capabilities, but rather than repeating statistics, it is essential to understand their broader ramifications [65, 66]. The significant prevalence of sleep apnoea, decreased ventilatory function, hypertension, postural abnormalities, and diminished motor coordination suggests a clinical trajectory that may start in early childhood and continue throughout adulthood. These trends indicate that obesity should be treated as a public health issue that requires a coordinated national response.

Policy-wise, the findings encourage early screening practices in primary healthcare settings, especially for rural and low-income children, where obesity rates are greater. School-based intervention programs, community physical activity initiatives, and nutrition education should be considered essential prevention measures due to studies showing persistent physical inactivity and poor diets.

Metabolic, inflammatory, and mechanical dysfunctions are interconnected, requiring multidisciplinary treatment approaches involving paediatricians, endocrinologists, physiotherapists, psychologists, and nutritionists. Early intervention can enhance functional outcomes, lower adult healthcare costs, and prevent permanent clinical effects. Thus, proactive public health policies should prioritise continuous surveillance, standardised national screening criteria, and individualised rehabilitation programs above reactive therapy. Statistical trends are clinical indicators and signals for policy action and evidence-based decision-making to promote early prevention in Polish healthcare.

The following table summarizes the frequency and scope of these obesity-related health issues in the pediatric population (Table **2**).

The data summarized in Table **2** highlight the broad systemic burden of childhood obesity in Poland, underscoring its multifaceted impact on health. Respiratory complications, ranging from impaired ventilatory function to high rates of obstructive sleep apnea and aggravated asthma, demonstrate how excess adiposity compromises pulmonary performance. Cardiovascular impairments, including hypertension, dyslipidemia, and early structural heart changes, indicate the early onset of metabolic and vascular pathology that predisposes children to lifelong cardiometabolic risk. At the same time, musculoskeletal consequences such as joint overload, cartilage degeneration, postural defects, and flatfoot reflect the mechanical and functional strain imposed on the developing body, ultimately reducing motor coordination and quality of life. Collectively, these findings emphasize that pediatric obesity in Poland is

Table 2: Prevalence and Burden of Health Impairments Associated with Childhood Obesity in Poland

System	Condition/Impairment	Prevalence / Frequency (%)
Respiratory system	Reduced ventilatory function (FEV_1/FVC)	Correlated with abdominal obesity
	Obstructive sleep apnea syndrome (OSAS)	13-59% in overweight/obese children
	Severe OSAS	48.5% of obese children (n=132)
	Bronchial asthma severity	Increased inflammatory markers
	Reduced aerobic capacity (VO_2peak, 6MWT)	~20% lower functional capacity
Cardiovascular system	Hypertension in adolescents	5.8% (boys 6.8%, girls 4.9%)
	Increased carotid intima-media thickness	+0.041-0.045 mm vs. normal weight
	Dyslipidemia (low HDL, high LDL, TG)	38-41% ofoverweightchildren
	Left ventricular hypertrophy (ECG signs)	High prevalence in BMI≥30
Musculoskeletal system	Knee joint overload and pain	67% of obese children vs. 14% normal weight
	Early cartilage degeneration (MRI/US)	30-38% in obese adolescents
	Postural defects and spinal deformities	>58% postural defects, 24% deformities
	Idiopathic scoliosis prevalence	12.2% in obese adolescents
	Longitudinal flatfoot prevalence	6.3 times higher in obese children
	Reduced motor coordination	Lower scores in overweight children
	Reduced quality of life	Significant decrease in physical and emotional domains

Source: compiled by the author.

not limited to excess weight but represents a complex multisystem disorder requiring comprehensive and multidisciplinary intervention strategies.

CONCLUSIONS

The conducted literature review indicates that childhood and adolescent obesity in Poland represents a significant and escalating public health issue with multidimensional consequences for the human body. A steady upward trend in the prevalence of excess body weight has been established, accompanied by pronounced regional, age-related, and gender differences, as well as socio-economic determinants of risk. The COVID-19 pandemic has further exacerbated this issue by contributing to decreased physical activity and altered dietary habits among youth. Analysis of 51 studies revealed that obesity rates among Polish children have reached notable levels, with profound implications for respiratory, cardiovascular, and musculoskeletal health. The following table summarizes the frequency and scope of these obesity-related health issues in the pediatric population.

The pathogenesis of pediatric obesity emphasizes the role of disrupted neuroendocrine appetite regulation, insulin resistance, and the influence of genetic and socio-economic factors. The interaction of these elements creates a complex network that determines individual susceptibility to obesity, underscoring the need for a comprehensive, interdisciplinary approach to both prevention and treatment.

The consequences of obesity affect multiple organ systems. In the respiratory system, there is a notable decline in ventilatory function, an increased risk of obstructive sleep apnea syndrome, and worsening of bronchial asthma, complicating clinical management. Cardiovascular alterations include early signs of hypertension, endothelial dysfunction, dyslipidemia, and morpho-functional cardiac impairments, all of which contribute to long-term cardiometabolic risk.

Musculoskeletal involvement manifests as increased mechanical stress on joints, postural abnormalities, flatfoot, and impaired motor coordination, ultimately reducing quality of life. These complications highlight the importance of early diagnosis and integrated rehabilitation strategies.

This review has certain limitations, including the predominance of cross-sectional studies, a scarcity of longitudinal data, and limited access to comprehensive data from specific regions. Further research is

recommended to expand the scope of studies by incorporating a broader range of social and genetic variables and by implementing long-term monitoring programs.

Future directions should focus on elucidating the molecular mechanisms underlying obesity pathogenesis and on enhancing intersectoral prevention strategies tailored to the national context. Special attention should be given to programs aimed at increasing physical activity levels, improving dietary behaviors, and reducing socio-economic barriers to access high-quality medical care and a healthy lifestyle.

To translate these findings into action, priority should be given to national initiatives for early detection of obesity-related complications, school nutrition and physical activity programs, and behavioral interventions at the family level. The development of community-based education, primary care monitoring systems, and the integration of multidisciplinary support (pediatricians, dietitians, physical therapists, and psychologists) will strengthen preventive measures and promote sustainable lifestyle changes among Polish children and adolescents.

AUTHOR'S CONTRIBUTIONS

MZL conceptualized the research, designed the study, conducted the primary data analysis and interpretation, contributed to the design, data collection, drafting of the manuscript, and its final editing.

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CONFLICT OF INTEREST

The author confirms that there is no conflict of interest.

ETHICS

The study was conducted without human participation. Ethical approval is not required.

AVAILABILITY OF DATA AND MATERIALS

The author confirms that the data supporting the findings of this study are available in the article.

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