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ORIGINAL PAPER

Assessment of nutritional status and the occurrence of complications in children with obesity based on its severity

Agnieszka Koziol-Kozakowska[1,2], Ewelina Cichocka-Mroczek[1], Małgorzata Wójcik[2,3]

[1]Department of Pediatrics, Gastroenterology and Nutrition, Institute of Pediatrics, Faculty of Medicine, Jagiellonian University *Collegium Medicum*, Kraków, Poland
[2]University Children's Hospital, Kraków, Poland
[3]Department of Pediatric and Adolescent Endocrinology, Chair of Pediatrics, Institute of Pediatrics, Faculty of Medicine, Jagiellonian University *Collegium Medicum*, Kraków, Poland

ABSTRACT

Introduction: The increase in the number of children affected by obesity raises serious concerns, especially in terms of long-term health consequences. The purpose of this study was to assess the nutritional status and metabolic complications, depending on the degree of obesity.
Material and methods: This retrospective observational study analyzed the medical records of patients from the Interclinical Childhood Obesity Treatment Center at the University Children's Hospital in Kraków at the beginning of the obesity treatment. The study enrolled 129 obese patients, aged 6–18 years. The study group was divided depending on the level of obesity into either a severely obese group (SO) or a moderately obese group (MO). Severe obesity was defined as a body mass index (BMI) > 35 kg/m^2 (children aged 6–14 years) and a BMI > 40 kg/m^2 (older than 14). Based on these criteria, 60 children were SO and 69 were MO.
Results: The mean BMI Z-score in the study group was 3.5 ±0.8. Severe patients had a significantly higher % of body fat (48.3 vs. 33.2, $p < 0.001$). In the study group, 67% of patients were diagnosed with vitamin D_3 deficiency, 7% had vitamin B12 deficiency, 3% had anemia, and 16% had iron deficiency based on their total iron binding capacity (TIBC) level. The subgroups differed significantly in their TIBC and vitamin B12 level. Both moderate and severe obesity showed a positive correlation with vitamin D deficiency and TIBC, with the association being more pronounced in individuals with severe obesity.
Conclusions: Obesity is a form of malnutrition. Poor diet quality causes nutrient deficiencies, which, among other factors, affect the development of metabolic complications. The micronutrient and vitamin deficiency underscores the need for targeted nutritional interventions that prioritize not only the reduction of calorie intake but also the replenishment of essential vitamins and minerals to improve metabolic health and mitigate the adverse effects of obesity.

KEY WORDS:

childhood obesity, metabolic complications, nutritional status, deficiencies in obesity.

INTRODUCTION

According to Cole *et al.*, severe obesity in children can be defined as having a body mass index (BMI) of at least 35 kg/m^2, which can also be expressed as the 99.8th percentile at the age of 18 years [1]. Kelly *et al.* have defined severe obesity as a BMI equal to or above the 99th percentile, a BMI ≥ 120% of the 95th percentile, and an absolute BMI ≥ 40 kg/m^2 [2].

ADDRESS FOR CORRESPONDENCE:

Agnieszka Koziol-Kozakowska, PhD, Department of Pediatrics, Gastroenterology and Nutrition, Institute of Pediatrics, Jagiellonian University *Collegium Medicum*, Kraków, Poland,
e-mail: agnieszka.koziol-kozakowska@uj.edu.pl

The increase in the number of children affected by this disease raises serious concerns, especially in terms of long-term health consequences. It is estimated that severe obesity affects 1–5% of children and adolescents in Europe [3]. Childhood obesity is associated with complications that can persist throughout life, increasing the risk of chronic diseases such as cardiovascular disease and type 2 diabetes as well as psychological problems such as depression, low self-esteem, and eating disorders [4].

In obesity, the body typically receives an excess of fats and carbohydrates, often at the expense of important nutrients such as vitamins, minerals, and proteins. This imbalance can lead to deficiencies in essential micronutrients, despite an overall high calorie intake. This type of nutrient imbalance, even in the presence of excess food, is a form of malnutrition [5–9]. It is estimated that more than 50% of patients with obesity are nutritionally deficient. Consumption of low-nutrient foods, rich in sugars, poses a risk of malnutrition, despite a high-calorie diet. Micronutrient deficiency can lead to changes in body composition and dysfunction – including affecting the patient's intellectual and emotional state. In addition, it exacerbates comorbidities, due to the need to distribute micronutrients to key organs. Among the micronutrient deficiencies found in an obese patient's diet, the most common are deficiencies of vitamins A, C, D, E, and minerals such as calcium and magnesium [10].

Insufficient intake of nutrients translates into deficiencies of these substances in the body, which results in various complications. Studies have shown that one in five children aged 1–11 are vitamin D deficient – regardless of the obesity problem. School-aged children 6–11 years old are more likely to be deficient (73%), while younger children are slightly less likely (63%). The function of the said vitamin is to regulate gene expression, promote bone health through increased calcium absorption, and improve wound healing. In addition, it has anti-inflammatory properties and increases insulin secretion by the pancreas. Patients with obesity show lower levels of CYP27B and CYPJ2 enzymes, which are involved in vitamin D activation. Deficiency of the described vitamin leads to an increased risk of infections, autoimmune diseases, or cancer as well as the occurrence of chronic diseases. In addition, low serum vitamin D levels and adipokine imbalances can contribute to the development of insulin resistance (IR) and, subsequently, diabetes. Another consequence of this deficiency is the deterioration of pancreatic β-cell function and a decrease in serum insulin secretion. In children, as in adults, vitamin D protects the pancreas from cytokine-induced β-cell apoptosis in type 2 diabetes [10].

The high prevalence of iron deficiencies in obese patients, regardless of age and gender, suggests a link between obesity and iron metabolism. These deficiencies in obese individuals may result from increased levels of hepcidin, a peptide hormone responsible for regulating iron homeostasis in the human body, and chronic low-grade inflammation. However, the mechanisms responsible for this link are still incompletely understood [7]. As many as 20.1% of children aged 0–4 years in industrialized countries were found to have iron deficiency anemia. The same is true for 39% of children who reside in non-industrialized countries. Regardless of anemia, iron deficiency affects 2.3 billion people worldwide, including 50% of younger children and adolescent girls. The consequences of a deficiency of this element have a significant impact on the development and physiological functions of the body [8]. In addition, it has been observed that an increase in BMI leads to an increase in total iron binding capacity (TIBC), a parameter indicating iron-binding capacity [9].

An additional important and often deficient component in obese patients is vitamin B_{12} (cobalamin) – which supports DNA synthesis, neurological function, red blood cell (RBC) maturation, and cellular metabolism, among other things [10]. Available studies show that higher serum levels of vitamin B_{12} are correlated with a reduced risk of obesity, and the deficiency of this vitamin frequently co-occurs with obesity. This situation may be caused by a diet deficient in vitamin B_{12}, or an increased requirement among obese pediatric patients due to their faster growth and larger body surface area compared to their non-obese peers [11].

Studies suggest that obese children may have higher levels of hemoglobin – whose primary function is to transport oxygen – attaching it in the lungs and releasing it in the tissues. Increased erythropoiesis, due to reduced oxygen diffusion as a result of chronic hypoxia accompanying excess body fat, leads to a compensatory increase in red blood cell production. Another hypothesis links high hemoglobin values to a compensatory mechanism for reduced oxygen availability caused by obstructive sleep apnea – common in obese pediatric patients [12]. Reduced hemoglobin levels in obesity, on the other hand, may result from lower serum iron levels and elevated levels of hepcidin, a hormone that inhibits iron absorption [13].

The primary aim of the study was to evaluate the prevalence of vitamin and mineral deficiencies in patients based on the severity of obesity and to assess their metabolic complications.

MATERIAL AND METHODS

This retrospective, observational study analyzed the medical records of patients from the Interclinical Childhood Obesity Treatment Center at the University Children's Hospital in Kraków. The results of blood tests and anthropometric measurements refer to tests performed at the time of patient evaluation for inclusion in the obesity treatment program and were performed during the first hospitalization in the pediatric endocrinology department.

The study enrolled 129 obese patients, aged 6–18 years. The inclusion criteria were as follows: severe obesity was

TABLE 1. Comparison of anthropometric measurements according to the degree of obesity

Parameters	Total (X ±SD)	Severe obesity (X ±SD)	Moderate obesity (X ±SD)	*p*-value
Age (years)	12.50 ±2.71	12.42 ±2.95	12.66 ±2.48	0.56
Hight [cm]	162.01 ±14.66	162.15 ±15.30	161.45 ±14.00	0.34
Weight [kg]	88.34 ±25.71	99.25 ±25.18	75.01 ±19.14	< 0.001
BMI	33.11 ±5.85	37.13 ±4.48	28.22 ±2.84	< 0.001
BMI Z-score	3.51 ±0.82	3.82 ±0.6 4	2.80 ±0.11	< 0.001
Fat mass (%)	42.60 ±7.44	48.32 ±8.23	33.23 ±5.11	< 0.001
Free fat mass [kg]	68.20 ±12.21	63.45 ±8.11	72.70 ±5.32	< 0.001

BMI – body mass index, X ±SD – mean ± standard deviation

defined as a BMI > 35 kg/m^2 (children aged 6–14 years) and a BMI > 40 kg/m^2 (older than 14). Based on these criteria, 60 children were severely obese (SO) and 69 were moderately obese (MO). Written informed consent of the patient's parent/guardian, and the patient if above the age of 13 years, was obtained to participate in the study. The exclusion criterion was the patient's vitamin and mineral supplementation.

The study included data on anthropometric measurements (height, weight, bioelectrical impedance analysis – BIA), blood pressure (BP) measurements, and laboratory tests, performed routinely during patient admission.

Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using a stadiometer and a balanced scale (SECA, Germany). Body composition was assessed with BIA using a multifrequency BIA (Tanita BC 418 S MA, Tokyo, Japan). The measurements were performed according to the manufacturer's guidelines, at least 2 hours after ingestion of a light breakfast and urination. The office BP was assessed with certified, calibrated oscillometer devices. The cuff size was appropriate to the arm size while a participant was in a sitting position following a 15-minute rest period before the examination. Results were interpreted according to European Society of Hypertension reference values [14].

Glucose, triglyceride (TG), high-density lipoprotein (HDL) cholesterol, alanine aminotransferase, aspartate aminotransferase, and uric acid levels were analyzed as well as biochemical parameters of nutritional status such as hemoglobin, ferritin, vitamins (B_{12}, D_3), and TIBC. The diagnostic criteria for impaired fasting glucose were a fasting blood glucose level of 100–125 mg/dl (5.6–6.9 mmol/l), and impaired glucose tolerance (IGT) was defined as a 2-hour plasma glucose level of 140–199 mg/dl (7.8–11.0 mmol/l) [15]. A concentration of vitamin B_{12} ≤ 200 ng/ml was considered vitamin B_{12} deficiency [16], a concentration of vitamin D_3 < 20 ng/ml was considered vitamin D_3 deficiency [17], and a concentration of TIBC ≥ 80 μmol/l was considered an abnormal indicator of iron deficiency [18]. The following were considered low hemoglobin concentrations, indicative of anemia: children aged 2–9 years ≤ 11.5 g/dl, boys aged 10–17 years ≤ 12.5 g/dl, and girls aged 10–17 years ≤ 12.0 g/dl [19]. For ferritin, a reference range of 7–150 μg/l was used [20].

Data analysis was carried out using IBM SPSS Statistics 29 and the PS IMAGO PRO 10.0 package. Spearman's rank correlation coefficient was used to assess the relationship between level of obesity and selected nutritional status parameters. The study was conducted according to the guidelines of the Declaration of Helsinki "Ethical Principles for Medical Research in Humans" (9 July 2018). The study was approved by the local ethics committee (IRB) – the Bioethics Committee of the Jagiellonian University (KE 118.0043.1.2024).

RESULTS

The analysis included 129 patients (65 female) with obesity at the mean age of 12.5 ±2.7 SD (range 6–18) years at time of the study (Table 1). The mean BMI *Z*-score in the study group was 3.51 ±0.8. Severe patients had significantly higher BMI *Z*-scores (3.82 vs. 2.80, $p < 0.001$), and higher fat mass percentage (48.3 vs. 33.2, $p < 0.001$). In contrast, children with moderate obesity had higher levels of fat-free body mass (Table 1).

In the SO group, children had significantly higher systolic (127.0 vs. 117.0, $p < 0.001$) and diastolic BP (80.0 vs. 78.0, $p = 0.003$) as well as higher mean HDL cholesterol levels (1.2 vs. 1.0 mg/dl, $p < 0.001$) compared to the MO group (Table 2).

The present study revealed that the most common disorder in adolescents with severe obesity was high BP (diagnosed in 78.2% of participants). Low HDL affected 34.7% of the participants in the SO group and 28.6% in the MO group; $p = 0.709$. Impaired glucose tolerance affected 22.0% in the SO group and 2.1% in the MO group; $p < 0.001$. At the same time, the problem of hypertriglyceridemia affected 30.7% of the SO patients and 10.6% of the MO patients; $p = 0.049$, and the problem of hyperuricemia affected 24.8% in the SO group and 21.4% in the MO group; $p = 0.918$ (Figure 1).

QUALITATIVE NUTRITIONAL STATUS

In the entire group of children with obesity, 67% were diagnosed with vitamin D_3 deficiency, 7% with vitamin B_{12} deficiency, 3% had anemia, and 16% had iron deficiency based on TIBC levels (Figure 2). In the study group, mean

TABLE 2. Comparison of metabolic parameters according to the degree of obesity

Parameters	Total	Severe obesity (X ±SD)	Moderate obesity (X ±SD)	*p*-value
Fasting glucose [mmol/l]	4.9 ±0.5	4.8 ±0.2	4.8 ±0.4	0.742
Glucose 120'OGTT	5.0 ±3.2	5.1 ±3.3	4.9 ±3.0	0.501
HOMA-IR	4.8 ±3.3	7.0 ±3.6	3.0 ±1.3	< 0.001
Systolic BP [mm Hg]	136 ±13.1	127 ±14.0	117 ±12.1	< 0.001
Systolic BP [centile]	77.9 ±22.1	88.7 ±18	66.5 ±22.1	< 0.001
Diastolic BP [mm Hg]	81.0 ±9.5	80.0 ±8.7	78 ±11.1	0.003
Diastolic BP [centile]	87.1 ±7.3	89.6 ±18.5	84.0 ±15.3	0.05
HDL [mmol/l]	1.1 ±0.2	1.0 ±0.2	1.2 ±0.1	< 0.001
TG [mg/dl]	1.6 ±0.9	1.5 ±0.7	1.8 ±1.1	0.035
Uric acid [μmol/l]	354.2 ±87.1	369.2 ±90.1	346.8 ±78.2	0.172
ALT [μU/ml]	39.1 ±8.1	39 ±7.2	30 ±5.2	0.105
AST [μU/ml]	32.5 ±3.2	33.6 ±2.3	29.9 ±3.1	0.562

ALT – alanine aminotransferase, AST – aspartate aminotransferase, BP – blood pressure, HDL – high-density lipoprotein, HOMA-IR – homeostasis model assessment of insulin resistance, OGTT – oral glucose tolerance test, TG – triglycerides, X ±SD – mean ± standard deviation

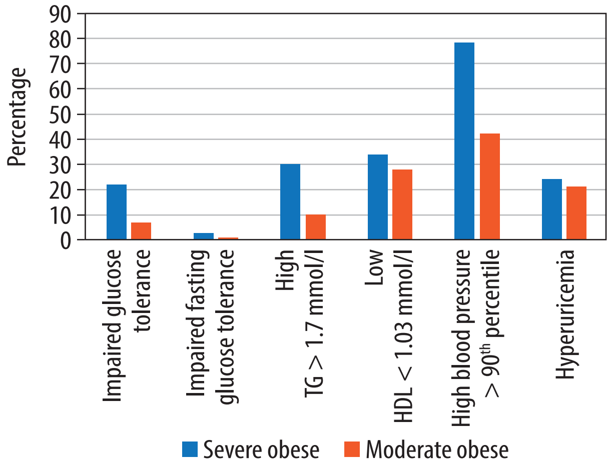

FIGURE 1. Prevalence of metabolic complications by the level of obesity

HDL – high-density lipoprotein, TG – triglycerides

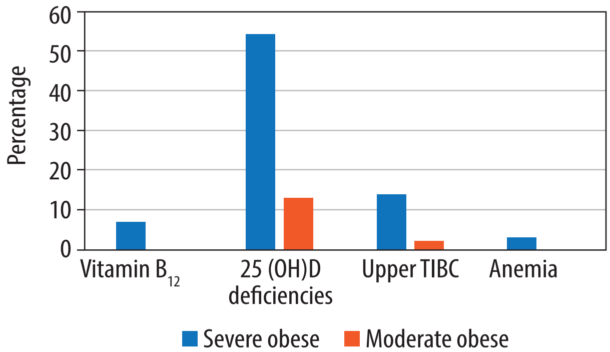

FIGURE 2. Percentage of children with vitamin and mineral deficiencies according to the degree of obesity

TIBC – total iron binding capacity

ferritin and hemoglobin levels were within normal ranges. There were no differences between groups in these variables except for TIBC and vitamin B_{12} (Table 3). Both severe and moderate obesity were positively correlated with vitamin D deficiency, as well as TIBC, with the relationship being stronger for severe obesity ($p < 0.01$) (Table 4).

DISCUSSION

The results of the conducted study provide important information on the relationship between the degree of obesity nutritional status and the incidence of metabolic complications in children. The present study revealed that high BP, high TG, and IGT occur more frequently in children with severe obesity. These findings are in line with previous studies that show a stronger correlation between higher levels of obesity and the risk of such conditions. It was observed that obesity is a major risk factor for the development of IR and chronic inflammation, which can lead to metabolic complications such as type 2 diabetes and fatty liver [4, 21]. According to Valaiyapathi *et al.*, obesity is the most important risk factor for IR and type 2 diabetes in children. The authors pointed out that weight gain and BMI have a direct impact on the development of IR and worsening metabolic problems. They also pointed out that puberty is associated with transient IR caused by an increase in hormones such as growth hormone and IGF-1. Children who are obese during puberty have a higher risk of progressive deterioration in glycemic control. It was also emphasized that the genetic burden such as diabetes in parents and environmental factors such as poor diet and physical inactivity have a synergistic effect on the development of diabetes and, in terms of therapeutic approaches, interventions such as insulin use were found to be effective in the short term but did not address the underlying problem of insulin resistance. As a result, it was recognized that there is a need to develop more effective therapeutic strategies, including early treatment of obesity and lifestyle interventions such as changing diet and increasing physical activity, which are crucial but difficult to implement in the pediatric group [22]. In a study from the Netherlands, the most common complication of obesity in children and adolescents was arterial hypertension [23]. The incidence of high BP among children

TABLE 3. Qualitative nutritional status – results depending on the level of obesity

Parameters	Total (X ±SD)	Severe obesity (X ±SD)	Moderate obesity (X ±SD)	*p*-value
Vitamin B_{12} [pg/ml]	342.9 ±111.5	325.9 ±116.5	336.3 ±129.6	0.021
25(OH)D [ng/ml]	21.0 ±8.1	20.0 ±9.1	22.5 ±9.2	0.167
TIBC [μmol/l]	77.3 ±10.0	80.1 ±6.0	66.4 ±6.6	< 0.001
Hemoglobin [g/dl]	14.0 ±1.0	13.8 ±1.1	14.0 ±1.2	0.510
Ferritin [ug/l]	35.4 ±1.4	37.4 ±1.1	36.6 ±27.6	0.814

TIBC – total iron binding capacity, X ±SD – mean ± standard deviation

worldwide is rising along with the increase in body weight [24–26]. In a study by Szczudlik *et al.*, high BP was diagnosed in almost 90% of SO patients [27].

In our study, an important goal was the assessment of qualitative nutritional status. The results showed that children with severe obesity had a higher incidence of vitamin D_3 deficiency, which is well documented in the literature. Vitamin D deficiency in obesity is often associated with fat accumulation [28, 29]. A 2019 systematic review already provided information that there is a very high correlation between the prevalence of obesity and vitamin D deficiency. At the time, the analysis included 24,600 children aged 0–18 and found that the risk of vitamin D deficiency in obese children and adolescents was 41% higher compared to the non-obese group. Excessive time spent in front of a screen and limited sun exposure as well as the solubility of vitamin D in fat, which would limit its bioavailability, were identified at that time as potential contributing factors [30]. Similar conclusions were also provided in a review by Malden *et al.*, which assessed among other things the associations between childhood obesity and the prevalence of selected nutritional deficiencies, particularly vitamin D and iron [31]. The performed meta-analysis showed that the risk of vitamin D deficiency increases by 90% in children with obesity, and mechanisms associated with vitamin D deficiency may include re-storage of the vitamin in adipose tissue, which limits its bioavailability, as well as limited exposure to sunlight and less physical activity in this group of children. Also worth mentioning here is a theme related to iron deficiency in this group of subjects. A significantly higher risk of iron deficiency was observed in children with obesity. The results of the meta-analysis indicate that the risk of iron deficiency increased more than twofold, which according to the authors may be related to both an improper diet and chronic inflammation, which affects iron metabolism and bioavailability. In their discussion, Malden *et al.* emphasized the need for regular monitoring of vitamin D and iron levels in children with obesity, as deficiencies of these components can have serious consequences for the health of children with obesity, including an increased risk of infection, a weakened immune system, and negative effects on bone development and cognitive function [31]. In our study, it was observed that iron deficiency occurs more frequently in children with severe obesity. However, no differences were observed in ferritin levels, which remained normal across the entire group. This suggests that ferritin, as an acute phase protein, is not a reliable marker for diagnosing iron deficiency in obese children. When discussing nutritional deficiencies in children with obesity, it is impossible not to mention vitamin B_{12}. Although our study illustrated that disorders of too low vitamin B_{12} values concerned only 7% of children, other studies provide somewhat more information on this topic. According to the study by Aureli *et al.*, vitamin B_{12} levels were significantly lower in people with obesity and severe obesity compared to those with underweight or normal weight [32]. It was, therefore, concluded that lower vitamin B_{12} levels are associated with higher BMI, more visceral fat tissue, and more severe fatty liver disease, especially in obese and SO people, and that vitamin B_{12} may be a potential marker of metabolic risk and liver damage. However, further interventional studies are needed to confirm the causal relationship and assess the benefits of vitamin B_{12} supplementation in the treatment of metabolic disorders in young patients with obesity [32]. Similar data are provided in the study by Söbü *et al.*, in which lower levels of vitamin B_{12} also appeared in children with obesity [33]. The conclusions of the study indicate that vitamin B_{12} deficiency may be associated with a worsening of metabolism in children with obesity. In particular, obesity, especially abdominal obesity, is associated with higher levels of insulin and insulin resistance, which may have an impact on the reduction of vitamin B_{12} levels. It was also mentioned that because vitamin B_{12} is often deficient in children with obesity, it is important for these children

TABLE 4. Simple linear correlation analysis between level of obesity and specified variables

Parameters	Severe obesity	Moderate obesity
Vitamin B_{12} [pg/ml]	0.098	0.071
25(OH)D [ng/ml]	0.574*	0.442*
TIBC [μmol/l]	0.425*	0.343*
Hemoglobin [g/dl]	0.155	0.132
Ferritin [ug/l]	–0.113	0.022

TIBC – total iron binding capacity
Spearman correlation coefficient (rS)
**Significant at the 0.01 level*

to be regularly monitored for its level [34]. Vitamin B_{12} deficiency may additionally aggravate metabolic problems and increase the risk of developing cardiovascular diseases in the future [35, 36].

CONCLUSIONS

These studies indicate that obesity is associated with an imbalance of micronutrients and vitamins. The findings emphasize the importance of comprehensive nutritional interventions that go beyond calorie reduction, focusing on optimizing dietary composition to restore essential vitamins and minerals and prevent the worsening of existing deficiencies.

DISCLOSURES

1. Institutional review board statement: Not applicable.
2. Assistance with the article: None.
3. Financial support and sponsorship: None.
4. Conflicts of interest: None.

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