

Assessment of Dietary Pattern, Nutritional Status and Insulin Resistance Among a Group of Overweight and Obese Adolescents in Egypt

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ABSTRACT

Background: Overweight and obesity among adolescents represent a growing public health concern in Egypt and are strongly associated with insulin resistance, which increases the risk of type 2 diabetes mellitus and other metabolic complications later in life. Unhealthy dietary patterns, including high consumption of fast foods and sugar-sweetened beverages, are increasingly prevalent among Egyptian adolescents. Different dietary approaches were used to improve metabolic outcomes and enhance insulin sensitivity in different populations. However, limited data are available regarding the dietary patterns and the impact of such approaches on insulin resistance among overweight and obese adolescents in Egypt. Therefore, this study aimed to assess the dietary habits and nutritional status among a group of overweight and obese adolescents.

Methods: A hospital-based cross-sectional study was conducted on overweight and obese adolescents aged 10–19 years attending the obesity clinic at the National Nutrition Institute, Egypt. Dietary habits were assessed using a validated questionnaire. Anthropometric measurements were recorded, and insulin resistance was evaluated using the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR).

Results: These findings indicate a nutritional imbalance characterized by adequate macronutrient intake but significant micronutrient deficiencies, particularly in calcium, fiber, and potassium, alongside excessive sodium intake. This pattern reflects a diet high in processed foods and low in fruits, vegetables, and dairy products. The food frequency data indicate a diet characterized by high refined carbohydrate intake, insufficient consumption of micronutrient-dense foods, and suboptimal dietary diversity, which aligns with the observed micronutrient deficiencies and excessive sodium intake.

Conclusion: Nutritional assessment of a group of overweight and obese adolescents revealed unhealthy dietary habits, low physical activity and tendency to insulin resistance. This indicates a high-risk for future non-communicable diseases. These findings emphasized the urgent need for targeted interventions to promote healthier dietary patterns.

Keywords: Nutritional status; Adolescents; Obesity; Insulin resistance; Egypt.

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Introduction:

Adolescence is a transition phase of life between childhood and adulthood, it ages from ten years to nineteen years old (1). During this age, puberty is starting, it is associated with many physiological changes, specifically hormonal and metabolic changes, and one of these is a decrease in insulin sensitivity, that recovers at puberty completion, but if other risk factors exist as obesity, it may last (2).

Overweight or obesity is abnormal or excessive body fats that can affect health. Most of the overweight and obese cases in young age is due to malnutrition (3). Obesity is considered one of the most important nutritional diseases worldwide (4).

According to World Health Organization (WHO) estimates, obesity and overweight are in increase among Egyptian adolescents (4). In Egypt previous studies indicated that obesity is an important public health

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problem among school children, the prevalence of obesity among Egyptian adolescents was 14.7% in boys and 15.08% in girls, respectively (2), recent data from the Egypt Family Health Survey 2021 indicates that among children aged 5 to 19 years, the prevalence of overweight is 16% in females and 13% in males, while obesity affects 7% of both females and males.

The insulin hormone is the main hormone that regulates glucose homeostasis, its action is glucose stimulation in muscle tissue and adipose tissue for insulin usage and uptake. Adipose tissue has a role in the insulin action regulation in addition to lipids storage. Adipocytes secrete adipokines. In overweight or obese cases adipokines become of abnormal secretion levels, affects the action of insulin and lets the target tissues and other body organs become less sensitive to insulin, then results in insulin resistance (5). The insulin level can be triggered by the dietary approach. There are many tools to measure the insulin level, the frequently used tool example is the Homeostatic Model Assessment (HOMA) index (6).

Widespread of fast food consumption and wrong unhealthy diet choices was noticed among Egyptian adolescents that may lead to develop non communicable diseases as obesity, insulin resistance and diabetes (7).

Lifestyle interventions and changing the dietary habits are the cornerstone of the treatment of nutritional overweight and obesity (8), where they can be used separately or combined.(9)

Obese adolescents are seeking to improve their body image and getting better body weight as during this period of life they are getting more awareness development and may suffer bullying from people in their surrounding environment from their peers or families. This could trigger psychological issues such as anxiety or depression or poor self-esteem and eating disorders (10).

Improving the dietary habits, following a healthy diet and changing lifestyle are considered the first line of treatment of obesity (11,12). Few studies in Egypt reviewed the effect of healthy lifestyle or the effect of dietary approaches on insulin resistance in overweight and obese adolescents.

Our study aims to assess the dietary habits and nutritional status on insulin resistance among a group of overweight and obese adolescents (10-19 years) attending obesity clinic at National Nutrition Institute in Egypt.

Methods

This cross-sectional study was conducted at the obesity clinics of National Nutritional Institute (NNI), which is affiliated to the General Organization of Hospitals and Teaching institutes (GOHTI), in Cairo governorate. The protocol was reviewed and approved by the ethical committee at faculty of medicine, Cairo

University. And also, the protocol was reviewed and approved by the ethical committee at General Organization for Teaching Hospitals and Institutes (GOTHI). Every participant provided guardian informed consent and adolescent assent.

The study inclusion criteria included the participants who are adolescents, aged between 10–19 years, obese (BMI \geq 95 percentile) or overweight The exclusion criteria included participants who stated that they could not continue with the study to the end, had an endocrinal disease, were using metformin, having renal problems or hypertensive.

Participants were subjected to interviewed questionnaire: including personal history data of; name, age, sex, and past history of family and personal illnesses, exercise level and dietary. Anthropometric measurements (weight, height, body mass index) were assessed for all participants by a well-trained nurse. The BMI for adults calculation divides body weight in kilograms by their height in meters squared, for age from 12-19 years old, the Z score body mass index was used for males and females. The following categories of weight status were determined according to WHO Z score body mass index (1,13).

Dietary assessment:

Methods used for measuring food consumption were classified into two major methods. The first method, known as quantitative daily consumption method "twenty four-hour recall" method. The second method is qualitative methods which include the dietary pattern and food frequency questionnaire.

a- 24 hours recall method

In this method every participant was asked to recall the exact foods intake during the previous 24 hours period. Quantities of foods consumed were estimated in household measures and were converted to grams according to **FAO/ WHO (14) & WHO (15)**.

The obtained dietary information included detailed description of all food consumed including cooking method and the amount of each ingredient in the recipe was recorded. The conversion of household measures to grams was achieved through the use of prepared list of weight of commonly used household measures in Egypt developed by NNI (16). The compiled food composition tables of the NNI (16) were used to determine energy and nutrient intake of each participant.

b- Dietary pattern "food frequency questionnaire"

This method about usual food and consumption pattern for the participant daily, weekly, monthly and seasonally. The food groups were classified into main food groups to know the pattern of food consumption

Laboratory investigations:

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Fasting insulin and fasting blood glucose were measured with 8 hours fasting. Assessment of the insulin resistance state was done by the homeostatic model assessment (HOMA-IR) test.

This test describes the glucose-insulin homeostasis by means of a set of simple, mathematically-derived nonlinear equations. The product of FPG \times FPI is an index of hepatic insulin resistance and according to the measuring unit the result will be multiplied by specific figure according to the measuring unit. The optimal insulin sensitivity if HOMA-IR is less than 1, Levels above 1.9 signal early insulin resistance, while levels above 2.9 signal significant insulin resistance (17).

Statistical analysis:

Pre-coded data were statistically analyzed using the statistical package of the social science software version 21 (SPSS). Comparison between qualitative variables was done using Chi-square test, while for quantitative variables which are normally distributed, P value equal or less than 0.05 is considered statistically significant.

To assess dietary adequacy, the median daily intake of energy, macronutrients, and micronutrients was compared with Recommended Dietary Intake (RDI) values derived from internationally recognized guidelines.

The percentage of RDI (%RDI) for each nutrient was calculated using the formula:

$$\%RDI = (\text{Observed intake} / \text{Recommended intake}) \times 100 =$$

Nutrient adequacy was classified as follows:

- < 70% of RDI: Inadequate intake
- 70–120% of RDI: Adequate intake
- > 120% of RDI: Excess intake

Results:

The characteristics of study participants:

A total of 200 adolescents were included. The mean age of participants was 13.2 ± 2.0 years. There were no significant differences between groups in sex distribution ($p = 0.125$). However, a significantly higher proportion of participants reported a family history of obesity (89%, $p < 0.001$). Similarly, family history of hypertension and diabetes was more prevalent among chronic diseases (47.5% and 26%, respectively).

Regarding lifestyle characteristics, approximately 31% of participants were physically active. Among those, walking was the most commonly reported form of physical activity (50%), followed by football (16%).(Table (1)) Furthermore, the majority of participants (85%) reported regular breakfast consumption.(Table (2))

Nutritional assessment:

Anthropometric measurement and HOMA IR:

The study participants had a mean weight of 76.7 ± 19.5 kg and a mean height of 152.2 ± 9.6 cm. The mean body mass index (BMI) was 32.7 ± 5.7 kg/m², indicating that, on average, the study population falls within the obese category.

Regarding metabolic parameters, the mean HOMA-IR value was 2.6 ± 0.8 , suggesting insulin resistance among participants. (Table (3))

Dietary Intake (24-Hour Recall)

Dietary Intake in Relation to Recommended Dietary Intake (RDI)

The dietary intake of participants, assessed using 24-hour recall (Table (4)), was compared with the Recommended Dietary Intake (RDI) values. (Table (5))

Overall, the median daily energy intake (1810.74 kcal) was slightly below the recommended levels for adolescents, indicating a borderline inadequate caloric intake among the study population.

Protein intake (median: 73.48 g/day) was found to be within or slightly above the recommended range, suggesting adequate protein consumption. In contrast, carbohydrate intake (median: 232.34 g/day) was generally within acceptable limits, while fat intake (median: 62.88 g/day) tended toward the upper recommended range, indicating a relatively high-fat dietary pattern.

Median fiber intake (10.84 g/day) was markedly below the recommended levels, reflecting inadequate consumption of fiber-rich foods.

However, regarding micronutrients, several deficiencies were observed. Median calcium intake (446.79 mg/day) and magnesium intake (135.60 mg/day) were lower than RDI values, suggesting poor intake of dairy products and green vegetables.

Potassium intake (1471.76 mg/day) was also considerably below recommended levels, whereas sodium intake (3188.66 mg/day) exceeded the RDI, indicating excessive salt consumption.

Iron (9.06 mg/day) and zinc (5.74 mg/day) intakes were borderline inadequate, particularly concerning for adolescents due to increased physiological requirements.

Vitamin intake analysis revealed that vitamin A intake (1266.91 μ g/day) was generally adequate, while vitamin C (43.20 mg/day) and folate (215.70 μ g/day) were below recommended levels for a considerable proportion of participants.

Food Frequency Consumption Patterns

Analysis of food frequency data helps to explain the observed nutrient imbalances.(Table (6))

Additionally, high fast food and sweets consumption, with the near absence of olive oil consumption, suggests poor adherence to a healthy dietary pattern. Participants demonstrated a high

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consumption of refined carbohydrate sources, particularly bread (median: 154.3 g) and moderate intake of rice and pasta, which may contribute to adequate caloric intake but relatively low fiber content.

Protein sources were predominantly derived from chicken (median: 35.7 g) and meat, while fish consumption was relatively low, suggesting limited intake of omega-3 fatty acids.

The intake of legumes and nuts was notably low, which may partially explain the inadequate intake of fiber, magnesium, and other micronutrients.

Dairy consumption, including milk, cheese, and yogurt, was suboptimal, consistent with the markedly low calcium intake observed in the nutrient analysis.

Fruit and vegetable intake showed variability; although median fruit consumption was moderate, fresh and cooked vegetable intake remained insufficient, contributing to deficiencies in fiber, and Micronutrients. **Table (1): Distribution of study participants**

Variable		No	%	P value
Sex	Male	83	41.5	0.125
	Female	117	58.5	
Presence of obesity among family members	Yes	178	89.0	0.000*
	No	22	11.0	
Family members who are suffering from obesity	Father	103	57.9	
	Mother	89	50.0	
	One of the brothers	7	3.9	
	Grandfather	43	24.2	
	Grandmother	40	22.5	
	Another person	11	6.2	
Presence of other diseases among family members	Hypertension	95	47.5	0.012*
	Heart diseases	19	9.5	0.073
	Diabetic	52	26.0	0.008*
	Tumors	7	3.5	0.222
	Another diseases	4	2.0	0.061
Family member suffering from other diseases	Father	95	48.2	
	Mother	49	24.9	
	One of the brothers	6	3.0	
	Grandfather	56	28.4	
	Grandmother	48	24.4	
	Another person	9	4.6	
	Diseases among participants	White coat Hypertension	10	5.0

Variable		No	%	P value
	Heart diseases	1	0.5	0.500
	Pseudo diabetic	3	1.5	0.500
	Tumors	-	-	-
	Another diseases	10	5.0	0.166
Participants taking regular medications	Yes	8	4.0	0.140
	No	192	96.0	
Medications type	Cortisone	2	25.0	0.446
	Insulin	2	25.0	
	Estrogen	-	-	
	Appetite stimulants	1	12.5	
	Antidepressants	-	-	
	GIT problems	3	37.5	
Onset of obesity	Since birth to 2 years	27	13.50	0.408
	Above 2 years	173	86.50	
Practice sport regularly	Yes	62	31.0	0.000
	No	138	69.0	
Sport type	Walking	31	50.0	
	Walking with effort	4	6.5	
	Running	5	8.1	
	Cycling	2	3.2	
	Swimming	7	11.3	
	Tennis	3	4.8	
	Football	10	16.1	

Table (2): Distribution of participants according to breakfast intake

Variable		No	%	P value
Breakfast intake	Yes	170	85.0	0.000*
	No	30	15.0	

*Significant differences ($p \leq 0.05$)

Table (3): Anthropometric measurement and Homa IR of the study participants:

	Mean	SD
Weight	76.7	19.5
Height	152.2	9.6
BMI	32.7	5.7
HOMA IR	2.6	0.8

Table (4): Assessment of the participants regarding 24 hours recall intake

	50th (Median)	25th	75th
Calories	1810.74	1430.55	2216.72

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Protein	73.48	55.78	94.70
Carbohydrates	232.34	178.51	292.54
Fat	62.88	46.42	83.42
Fiber	10.84	5.40	17.20
Calcium	446.79	297.77	598.80
Magnesium	135.60	90.20	193.85
Phosphorus	607.40	409.80	810.42
Potassium	1471.76	1038.78	2031.42
Sodium	3188.66	2385.90	4361.96
Iron	9.06	6.25	12.11
Zinc	5.74	3.90	8.95
Copper	0.71	0.46	1.075
Vitamin A	1266.91	689.98	2282.31
Vitamin B1	0.69	0.41	1.20
Vitamin B2	0.78	0.53	1.19
Vitamin C	43.20	19.54	111.32
Folate	215.70	116.68	339.38

*Significant differences ($p \leq 0.05$)

Table (5): Percentage of Recommended Dietary Intake (% RDI)

Nutrient	Median Intake	RDI *	%RDI	Interpretation
Energy (kcal)	1810.7	2200	82%	Below adequate
Protein (g)	73.5	52	141%	Excess
Carbohydrates (g)	232.3	275	84%	Slightly low
Fat (g)	62.9	70	90%	Adequate
Fiber (g)	10.8	25	43%	Inadequate
Calcium (mg)	446.8	1300	34%	Severely inadequate
Magnesium (mg)	135.6	240	56%	Inadequate
Phosphorus (mg)	607.4	1250	49%	Inadequate
Potassium (mg)	1471.8	3000	49%	Inadequate
Sodium (mg)	3188.7	1500	213%	Excess
Iron (mg)	9.1	11	83%	Borderline
Zinc (mg)	5.7	8	72%	Slightly low
Vitamin A (μg)	1266.9	900	141%	Adequate/High

Vitamin C (mg)	43.2	75	58%	Inadequate
Folate (μg)	215.7	400	54%	Inadequate

Table (6): Assessment of participants regarding food frequency groups amount in bread, rice, pasta, legumes, sweets, butter, olive oil, meat, chicken, fish and eggs

	50th (Median)	25th	75th
Bread	154.3	90.0	180.0
Rice	34.3	28.6	51.4
Pasta	28.6	17.1	34.3
Legumes	17.1	8.6	30.0
Sweets	2.9	0.7-	8.6
Butter	0.0	0.0-	1.4
Olive oil	0.0	0.0	0.7
Meat	7.1	1.8	14.3
Chicken	35.7	17.9	71.4
Fish	8.9	4.3	17.9
Eggs	14.3	7.1	21.4

*Significant differences ($p \leq 0.05$)

Table (6) Continued: Assessment of participants regarding food frequency groups amount in milk, cheese, yogurt, fresh and cooked vegetables, fruits, fast food, nuts, corn and ice-cream

	50th (Median)	25th	75th
Milk	28.6	16.1	57.1
Cheese	12.9	7.1	21.4
Yogurt	11.3	3.8	15.0
Fresh vegetables	28.6	14.3	64.3
Cooked vegetables	21.4	14.3	42.9
Fruits	42.9	11.4	57.1
Fast foods	4.4	0.0	14.3
Nuts	1.8	0.3	4.3
Corn	8.6	0.0	21.4
Ice Cream	0.2	0.0	10.6

*Significant differences ($p \leq 0.05$)

Discussion:

The present study findings reveal important patterns in the distribution of family history and lifestyle characteristics among participants with chronic diseases. While sex distribution showed no significant differences between groups ($p = 0.125$), the remarkably high prevalence of family history of obesity (89%, $p < 0.001$), along with reporting family history of hypertension (47.5%) and diabetes (26%), underscores the critical role of familial factors in chronic disease susceptibility. Moreover, the relatively low physical

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activity participation (31%) and high prevalence of regular breakfast consumption (85%) require careful attention as regards chronic disease prevention.

There was a significant difference in family history of obesity, particularly fathers and grandparents. This may suggest a genetic or environmental predisposition toward obesity. About family histories of hypertension and diabetes were also more prevalent, these results are similar to results observed in Reilly et al., (18) study which suggested that personalized dietary recommendations based on family health history could enhance the effectiveness of later interventions. This may reflect the well-established link between family history and metabolic disorders.

Also another research by Hebebrand et al., (19) highlighted how familial predisposition can affect outcomes in dietary interventions, it agreed with our results especially in adolescents. These baseline differences may have influenced the participants' metabolic responses to the diets.

There were no significant differences noted in the prevalence of diabetes or other comorbidities, suggesting a relatively balanced metabolic profile aside from hypertension.

A notable difference was observed in the prevalence of hypertension among participants. A study by Kavey et al., (20), observed a higher rate of elevated blood pressure in adolescents is often linked to obesity and poor dietary habits. This may have contributed to differences in metabolic risk.

There were no significant differences in regular medication use, which minimizes potential confounding effects from pharmacologic influences on weight or metabolism, the onset of obesity did not differ significantly, with the majority of participants becoming obese after the age of two years (86.5%). Early-onset obesity is often more resistant to intervention, but the balanced distribution in this study supports the validity of comparative outcomes (21).

Breakfast consumption was significantly high in our study. Timlin & Pereira, (22) research showed that regular breakfast consumption is associated with healthier weight profiles in adolescents, which is consistent to study by Betts et al. (23). It is considered an important item which can give an initial advantage in weight control and adherence to diet.

The current study shows that physical activity was significantly more common. This agreed with a study about regular exercise role that was proved as a known mediator of weight loss and insulin sensitivity (24). The finding that approximately 31% of participants were physically active aligns with the modest activity levels documented in several comparable populations. A Saudi

youth study reported substantial sedentary behavior (39%), consistent with low physical activity prevalence in similar samples (25).

Although it is within the lower range of population means, the observed median energy intake of 1810.74 kcal/day raises questions about adequacy for elevated energy demands. While average energy intakes may seem sufficient at the population level, significant percentages of adolescents do not meet individualized energy requirements, especially during growth spurts and among physically active individuals, according to national and international surveys (26, 27). A study conducted in Slovenia, showed that only 10% of participants in a representative sample of 341 Slovenian teenagers aged 15.3 ± 0.5 years met national energy intake standards, with a median daily energy consumption of 1733 kcal (26). This result matches the current study findings and emphasizes how widespread individual deficiency can be concealed by population-level techniques.

The macronutrient distribution recorded (protein 73.48 g/day, carbs 232.34 g/day, and fat 62.88 g/day) reflects the regularly recorded levels among populations within the same age group, with a tendency toward increased fat consumption but appropriate protein intake. Total carbohydrate consumption typically falls within acceptable ranges, while fat intake tends to be relatively elevated due to increased consumption of energy-dense and ultra-processed foods (28). Such findings show a general tendency toward diets that are low in whole grains, fruits, and vegetables and high in processed foods.

The daily fiber intake of 10.84 g is significantly less than what is advised. Teenagers were at risk for inadequate fiber consumption, according to a study of 180 healthy male adolescents in the US that used three-day food records to measure dietary fiber intakes (29). Inadequate eating of vegetables, legumes, and whole grains, which are also major sources of several missing micronutrients, is probably the cause of the low fiber intake seen in the current profile (30).

Intakes of calcium (446.79 mg/day), magnesium (135.60 mg/day), and potassium (1471.76 mg/day) are substantially below recommended dietary intakes which is a commonly documented pattern among adolescent populations worldwide (31). Potassium intake of 1471.76 mg/day is below the adequate intake (AI) of 2300–3000 mg/day for adolescents. This matches the results of a study conducted by Bailey et al. who reported that a significant proportion of US adolescents had sodium-potassium imbalance, characterized by sodium intake exceeding 3000 mg/day and potassium intake below 1500 mg/day (32). The observed potassium intake falls within this high-risk category, underscoring the need for increased consumption of potassium-rich foods such as

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fruits, vegetables, legumes, and dairy products. On the contrary, the recorded sodium intake of 3188.66 mg/day is much higher than the adolescent acceptable upper intake level (UL) of 2300 mg/day, and it is also consistent the general pattern of excessive salt consumption found in national surveys. According to Bailey et al. study, the median sodium intakes was found to exceed 3000 mg per day, with a percent of about 70% of US teenagers consuming more than the UL(32). This result highlights the widespread impact of processed and restaurant foods on teenage diets. Adolescents who consume too much sodium have higher blood pressure, a higher risk of cardiovascular disease, and poor bone health due to increased calcium excretion in the urine (33). Because the sodium-to-potassium ratio is a better indicator of cardiovascular outcomes than either mineral alone, the concurrent low potassium intake (1471.76 mg/day) increases this risk (32). Published studies reveal that there are gender difference in salt consumption with higher consumption among males (34, 35).

Vitamin A (1266.91 µg/day) seems sufficient, however folate (215.70 µg/day) and vitamin C (43.20 mg/day) are below recommended amounts. Nair et al. discovered high rates of folate deficiency, especially among females and in populations with limited access to fortified foods, when they examined the prevalence, biochemical correlations, and genetic factors of folate deficiency in North Indian adolescents (36). The significant incidence of folate inadequacy among Indian teenagers was also reported by Kapil et al., with deficient rates surpassing 50% in certain subgroups (37).

On the other hand, the observed vitamin A intake of 1266.91 µg/day is higher than the recommended daily allowance (RDA) of 700–900 µg/day for teenagers and indicates sufficient consumption of foods high in vitamin A, such as eggs, dairy products, fortified cereals, or orange and dark green vegetables. Although significant geographic and dietary pattern diversity was detected, Bailey et al. reported frequent vitamin A deficiency in various US teenage populations (32). In contrast to the numerous other micronutrient deficiencies, the current profile shows an appropriate intake of vitamin A, which may be due to dietary preferences or the consumption of fortified foods.

The daily vitamin C intake of 43.20 mg is less than the recommended daily allowance (RDA) of 65–75 mg for teenagers, or roughly 58–66% of the required level. According to Bailey et al., vitamin C deficiency affected 27–49% of teenagers in national samples, and it was more common in men and those who consumed little fruits and vegetables (32). Low consumption of fruits and vegetables was the main cause of vitamin C deficiency, according to Giguère-Johnson et al.'s analysis of

Senegalese teenage girls' food habits and nutritional intake (38).

The average height (152.2 ± 9.6 cm) and body weight (76.7 ± 19.5 kg) yielded an average body mass index (BMI) of 32.7 ± 5.7 kg/m², clearly placing the cohort in the obese group. Since obesity is known to be a major risk factor for a variety of metabolic and cardiovascular problems, this level of adiposity is clinically relevant. This study's higher BMI is in line with recent clinical and epidemiological findings that show a clear link between excess adiposity and metabolic impairment. Recent research has shown a strong correlation between insulin resistance and associated metabolic diseases and elevated BMI and central obesity indices (39,40).

Regarding metabolic function, participants' mean HOMA-IR score of 2.6 ± 0.8 shows that they have insulin resistance. Although thresholds may differ among populations, recent research indicates that values above roughly 2.0–2.5 are suggestive of insulin resistance (41). Additionally, the co-occurrence of obesity and high HOMA-IR highlights a higher risk of cardiovascular disease and type 2 diabetes. Insulin resistance measures are powerful predictors of poor health outcomes, such as cardiovascular and all-cause death, according to recent longitudinal and clinical research (42). It is also worthy to note that the relatively moderate standard deviation of HOMA-IR (± 0.8) indicates the consistent presence of insulin resistance across the study population. This supports the finding that metabolic impairment is a common characteristic among the cohort rather than a separated occurrence, hence, strengthening the internal consistency of the findings.

Conclusion:

The evidence synthesized by the current study demonstrates that adolescent micronutrient inadequacies are not isolated deficiencies but rather reflect broader defective dietary patterns characterized by insufficient intake of nutrient-dense whole foods. These patterns have significant implications for immediate health outcomes, and the more important are the long-term consequences for chronic disease risk and overall health across the lifespan. From a public health perspective, the current study findings underscore the necessity of early intervention.

Recommendations:

Continued surveillance, research, and evaluation are essential to identify emerging challenges, and ensure that interventions effectively reach and benefit the most vulnerable adolescent populations.

Future research should focus on longitudinal tracking of these participants to determine the progression of their

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metabolic markers and the efficacy of lifestyle or pharmacological interventions in mitigating the risks associated with their current anthropometric profile.

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