Cardiology in the Young

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Subclinical left ventricular structural and functional alterations in children with obesity: is body mass or insulin resistance the main issue?

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Abstract

Objective: Obesity is an independent risk factor for cardiovascular diseases. The study aims to assess the left ventricular structure and functions in children with obesity. *Methods:* This study included 29 patients with metabolic syndrome, 31 patients with obesity without metabolic syndrome, and 30 healthy children of similar age and gender. Demographic, anthropometric, and biochemical findings and left ventricular structure and functions evaluated by conventional pulsed wave Doppler and tissue Doppler echocardiography were compared. *Results:* The left ventricular mass index and relative wall thickness were significantly higher in children with obesity compared to controls. The mean left ventricular mass index of children with metabolic syndrome was also higher than for those without it. Most children with obesity had normal left ventricular geometry; concentric hypertrophy (27.6%) was more common in children with metabolic syndrome, and eccentric hypertrophy (25.7%) was more common in those without. The early to late diastolic mitral annular velocity ratios obtained with conventional pulsed wave Doppler echocardiography and tissue Doppler echocardiography (E/A and Em/Am, respectively) were lower in children with obesity than controls. In addition, the ratio obtained by tissue Doppler echocardiography was lower in children with metabolic syndrome than without. The homeostatic model assessment of insulin resistance, systolic blood pressure, and body mass index has been identified as independent factors for left ventricular structures and functions. *Conclusion:* Obesity causes subclinical left ventricular hypertrophy and diastolic dysfunction. Additional metabolic syndrome-related risks lead to further deterioration of cardiac morphology and functions.

The prevalence of obesity is increasing in our country as well as all over the world.[1,2] *Obesity has become an endemic due to changing eating habits and decreasing physical activity in modern life. Metabolic syndrome, characterized by elevated blood pressure, dyslipidemia, and insulin resistance or impaired glucose tolerance, is now more commonly observed in both adults and children as the prevalence of obesity increases.*[3]

Obesity produces a variety of hemodynamic and metabolic alterations that may cause changes in cardiovascular morphology and functions in adults.[4,5] The risk is higher in the presence of metabolic syndrome due to additional components. Children are ideal candidates for detecting obesity-related myocardial changes because they do not have the traditional cardiovascular risk factors observed in adults.[2,6,7] In recent years, left ventricular mass index and cardiac functions have been studied intensively in children with obesity. However, there are a limited number of studies investigating the contribution of metabolic syndrome-related components to changes in cardiac structure and function in childhood.[6–9]

The objective of this study was to examine the structural and functional characteristics of the left ventricular in children with obesity, with and without metabolic syndrome. Additionally, we aimed to determine whether body mass or insulin resistance were the main causes of these changes.

Materials and methods

Study design

In this cross-sectional study, 60 children with obesity aged 6–18 years were included in our paediatric endocrinology outpatient clinic between March 2020 and February 2022. Thirty age- and sex-matched healthy children served as a control group.

This study was approved by the Ethics Committee of University Health Sciences Turkey, Kanuni Sultan Suleyman Training, and Research Hospital (decision no: 2019/57, date: 3/22/2019). The present research was carried out under the principles of the Declaration of Helsinki, and all parents of patients gave written informed consent before enrolling. There has yet to be a universal consensus regarding the diagnostic criteria for childhood metabolic syndrome. The most commonly applied criteria recommended for comparative studies are the modified World Health Organization, Cook, and International Diabetes Federation consensus criteria.[10–12] We used criteria recommended by the International Diabetes Federation for the definition of metabolic syndrome. Patients were diagnosed as having metabolic syndrome when their waist circumference was ≥ 90th percentile and when at least two of the following factors were present: (1) raised concentration of triglycerides: ≥ 150 mg/dL or receiving specific treatment for high triglycerides; (2) reduced concentration of high-density lipoprotein cholesterol: < 40 mg/dL or receiving specific treatment for this lipid abnormality; (3) raised blood pressure: systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg or receiving treatment for previously diagnosed hypertension; and (4) raised fasting plasma glucose concentration ≥ 100 mg/dL or known type 2 diabetes mellitus. In our study, children with obesity were divided into two groups based on the presence or absence of metabolic syndrome. Patients with missing data or who had additional chronic diseases, such as cardiac disease, chronic kidney disease, chronic liver disease, hyperthyroidism, or hypothyroidism, were not included in the study. The control subjects were recruited from healthy children admitted to the hospital for minor illnesses. No artificial intelligence-enabled technologies (such as Large Language Models, chatbots, or image generators) were used in the production of our manuscript.

Anthropometric measurements

We measured the weight, height, and waist circumference of children with obesity and controls. Height was measured to the nearest millimetre by a wall-mounted stadiometer, and weight was measured to the nearest 100 g by a SECA digital scale with minimal clothes and without shoes. Body mass index was calculated by dividing the body weight in kilograms by the height in meters. The standard deviation scores of body mass index were calculated for all patients. On the body mass index reference curve, which was prepared for Turkish children and adjusted for age and gender, those with body mass index values above the 95th percentile were defined as "obese."[13] Waist circumference was measured at the level of the umbilicus with the child standing and breathing normally. Waist measurements were evaluated using the percentile curves for the waist circumference of healthy Turkish children.[14]

Blood pressure measurements

Blood pressure was measured three times at 2-minute intervals on the right arm in a seated patient after at least five minutes of rest by the auscultation method (ERKA®, Germany) with an appropriate cuff size according to the age and constitution of the child. The last two BPs were averaged for analysis. Systolic blood pressure and diastolic blood pressure measurements of all patients were evaluated according to the American Academy of Pediatrics 2017 hypertension guideline, and based on these data, we calculated the blood pressure standard deviation scores.[15] Systolic blood pressure and/or diastolic blood pressure values of ≥ 95th percentiles were defined as hypertension. For the definition of hypertension in patients with metabolic syndrome, the values in the IDF diagnostic criteria adapted for children were taken as references.[12]

Biochemical measurements

Fasting glucose, insulin levels, and lipid profiles (total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and triglycerides) were measured in blood samples taken in the morning after overnight fasting. Blood glucose levels were measured by the glucose oxidase method, and serum lipid profiles were measured using routine enzymatic methods. Insulin measurements were made using the immunofluorometric method (Modular E170 analyser, Roche Diagnostics, Mannheim, Germany).

Homeostasis model assessment of insulin resistance was calculated with the formula: fasting plasma glucose (mg/dL) x fasting plasma insulin (μU/mL)/405. Homeostasis model assessment of insulin resistance levels > 2.5 for prepubertal and > 4 for pubertal (Tanner ≥ 2) participants were defined as insulin resistance. Glucose, lipid profile, and insulin levels were measured in all children following a 12-hour fast.

Echocardiographic measurements

Echocardiography examinations were performed according to American Society of Echocardiography guidelines and using General Electric ViVid 7 Pro (California, USA) equipped with tissue Doppler imaging technology.[16] Participants were examined by the same experienced paediatric cardiologist blinded to clinical and laboratory outcomes. All subjects underwent a complete two-dimensional, M-mode, conventional pulsed wave Doppler echocardiography and tissue Doppler echocardiography. All echocardiographic data were evaluated using the average values of three consecutive cardiac cycles. Measurements of the left ventricular end-diastolic diameter and left ventricular end-systolic diameter were acquired in the parasternal long-axis view obtained perpendicular to the left ventricular long axis and measured at the level of the mitral valve leaflet tips. Interventricular septal end-diastolic diameter and left ventricular posterior wall end-diastolic diameter were measured in the basal ventricular segment of the respective myocardial wall at the end of diastole.

The left ventricular mass was calculated using the formula of Devereux et al.[17] by the following equation: Left ventricular mass = 0.81[1.04([interventricular septal end-diastolic diameter + left ventricular end-diastolic diameter + left ventricular posterior wall end-diastolic diameter]^3−[left ventricular end-diastolic diameter]^3)] + 0.6. The left ventricular mass index was calculated as left ventricular mass/height in meters.[2,7] Correcting left ventricular mass for height[2,7] minimizes the effect of gender, race, age, and obesity.[17] Left ventricular relative wall thickness was calculated as (interventricular septal end-diastolic diameter + left ventricular posterior wall end-diastolic diameter)/left ventricular end-diastolic diameter. The 95th percentile value for relative wall thickness for normal children and adolescents (relative wall thickness > 0.41) was used as a cut-off value to categorise the left ventricular structure (geometry). Left ventricular geometric patterns were defined based on whether relative wall thickness and/or left ventricular mass are normal versus increased: normal geometry (left ventricular mass and relative wall thickness are normal), concentric remodelling (increased relative wall thickness but normal left ventricular mass), concentric hypertrophy (left ventricular mass and relative wall thickness are increased), and eccentric hypertrophy (increased left ventricular mass with normal relative wall thickness). Left ventricular systolic

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function was assessed by calculating ejection fraction and fractional shortening.

Ejection fraction = (end-diastolic volume - end-systolic volume) / (end-diastolic volume) × 100.

Fractional shortening = (end-diastolic diameter - end-systolic diameter) / (end-diastolic diameter) × 100.

Left ventricular diastolic functions were evaluated using conventional pulsed wave Doppler echocardiography and tissue Doppler echocardiography. The peak early (E) and late (A) diastolic mitral annular velocities were obtained using conventional pulsed wave Doppler echocardiography tracings of the mitral valve from an apical four-chamber view, and the E/A ratio was calculated. Similarly, the early (Em) and late (Am) diastolic mitral annular peak velocities were measured by tissue Doppler echocardiography from the same view on the septal side of the mitral annulus. All the measurements were repeated three times, and the average was calculated.

Statistical analysis

SPSS version 26.0 (SPSS, Chicago, IL, USA) was used for data analysis. Continuous variables with skewed distributions were described with medians and ranges, and categorical variables with proportions or percentages. Student's t, Mann-Whitney U, and chi-squared tests were used for comparison between patients and controls and between patient subgroups according to the data distribution pattern and/or sample size. The strength of associations between normally distributed continuous variables was measured using Pearson's correlation coefficient or Spearman's correlation coefficient when the variables had a skewed distribution. Stepwise linear regression analysis was performed to assess the independent predictors of left ventricular mass index, relative wall thickness, and the early to late diastolic mitral annular velocity ratio obtained with tissue Doppler echocardiography (Em/Am). In all tests, $p < 0.05$ was considered significant.

Results

The demographic characteristics, laboratory findings, and echocardiographic results for 60 children with obesity and 30 healthy controls are presented in Table 1. Among the 60 children with obesity, 29 were found to have metabolic syndrome, while 31 were obese without metabolic syndrome. The mean age and gender of the three groups were similar. Body mass index, body mass index standard deviation scores, waist circumference, diastolic blood pressure, and diastolic blood pressure standard deviation scores were similar in groups with and without metabolic syndrome, but significantly higher than the values of the control group. Systolic blood pressure, systolic blood pressure standard deviation scores, insulin, and homeostatic model assessment of insulin resistance were significantly different between the three groups, while glucose, total cholesterol, and low-density lipoprotein cholesterol levels were similar. Triglyceride levels and triglyceride/high-density lipoprotein cholesterol ratio were significantly higher and high-density lipoprotein cholesterol was lower in the group with metabolic syndrome compared to the other two groups.

Table 1 contains the study groups' values for left ventricular mass index, relative wall thickness, and systolic and diastolic function. The left ventricular mass index was significantly different between the three groups and was highest in the group with metabolic syndrome. Relative wall thickness was significantly higher in children with obesity (both with and without metabolic syndrome) than in the control group. The majority of children had normal left ventricular geometry in patients with and without metabolic syndrome (respectively, 44.8% and 61.3%). The most common left ventricular concentric geometry pattern was concentric left ventricular hypertrophy (27.6%) in the group with metabolic syndrome and eccentric left ventricular hypertrophy (25.7%) in the group without metabolic syndrome. Ejection fraction and fractional shortening were similar and within normal values in all study groups. The early to late diastolic mitral annular velocity ratio (E/A) obtained by conventional pulsed wave Doppler echocardiography was lower in patients with and without metabolic syndrome than the controls. The early to late diastolic mitral annular velocity ratio (Em/Am) obtained by the tissue Doppler echocardiography method was significantly different between the three groups, and it was lowest in the group with metabolic syndrome.

A univariate analysis was conducted on all clinical and laboratory results to determine cardiometabolic risk factors for left ventricular structure and function in groups with and without metabolic syndrome (Table 2). The left ventricular mass index was positively correlated with systolic blood pressure, systolic blood pressure standard deviation scores, insulin, homeostatic model assessment of insulin resistance, triglyceride/high-density lipoprotein cholesterol ratio, and relative wall thickness. Relative wall thickness demonstrated positive correlations with diastolic blood pressure, diastolic blood pressure standard deviation scores, insulin, homeostatic model assessment of insulin resistance, cholesterol, triglyceride/high-density lipoprotein cholesterol ratio, and left ventricular mass index. Furthermore, the early to late diastolic mitral annular velocity ratio (Em/Am) obtained by the tissue Doppler echocardiography was found to be positively correlated with systolic blood pressure standard deviation scores, diastolic blood pressure, and diastolic blood pressure standard deviation scores, and negatively correlated with body mass index, body mass index standard deviation scores, and high-density lipoprotein cholesterol.

Stepwise linear regression analysis identified homeostatic model assessment of insulin resistance and systolic blood pressure standard deviation scores as independently associated with left ventricular mass index ($\beta = 0.542$, $p < 0.001$ and $\beta = 0.270$, $p = 0.011$, respectively), whereas homeostatic model assessment of insulin resistance independently predicted relative wall thickness ($\beta = 0.315$, $p = 0.014$). Additionally, Em/Am was independently associated with body mass index standard deviation scores and systolic blood pressure standard deviation scores ($\beta = -0.381$, $p = 0.009$ and $\beta = 0.361$, $p = 0.003$, respectively).

Discussion

The current study revealed that childhood obesity led to notable alterations in myocardial geometry and function when compared to healthy children of the same age without obesity. Both children with and without metabolic syndrome exhibited higher left ventricular mass index and relative wall thickness than the controls and left ventricular diastolic function was impaired. Furthermore, homeostatic model assessment of insulin resistance and systolic blood pressure were identified as independent predictors of structural changes in the left ventricle, including increased left ventricular mass index and relative wall thickness, while body mass index and systolic blood pressure were independent predictors of the left ventricular diastolic dysfunction.

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Table 1. Comparison of demographic characteristics, laboratory findings, and echocardiographic results

	MS group (n = 29)	Non-MS group (n = 31)	Control (n = 30)	p
Demographic-laboratory findings				
Age (y)	13.3 ± 2.6	13.3 ± 3.1	12.4 ± 2.4	0.994
Male, n (%)	15 (51.7)	16 (51.6)	16 (53.3)	0.993
BMI (kg/m^2)	29.4 ± 5.8	29.9 ± 4.4	19.4 ± 2.1**	**<0.001**
BMI-SDS	2.24 ± 0.90	2.52 ± 0.64	0.02 ± 0.58**	**<0.001**
WC (cm)	98.2 ± 14.0	98.3 ± 13.0	76.6 ± 8.8**	**<0.001**
Systolic BP (mmHg)	131.7 ± 14.5	124.9 ± 12.0	109.5 ± 7.1	**0.034***
Systolic BP-SDS	1.85 ± 0.71	1.42 ± 0.89	0.41 ± 0.38	**0.037***
Diastolic BP (mmHg)	86.1 ± 11.0	81.7 ± 9.11	67.8 ± 5.41**	**<0.001**
Diastolic BP-SDS	1.82 ± 0.72	1.59 ± 0.68	0.49 ± 0.41**	**<0.001**
Glucose (mg/dL)	83.8 ± 7.1	82.9 ± 4.4	83.8 ± 6.1	0.996
Insulin (lU/mL)	24.9 ± 9.9	12.3 ± 3.99	7.65 ± 2.3	**<0.001***
HOMA-IR	5.22 ± 2.25	2.50 ± 0.79	1.59 ± 0.50	**<0.001***
Cholesterol (mg/dL)	147.3 ± 26.3	148.4 ± 22.1	145.5 ± 21.0	0.923
LDL (mg/dL)	81.0 ± 20.2	80.0 ± 20.4	75.3 ± 19.8	0.695
HDL (mg/dL)	39.3 ± 6.9**	49.4 ± 10.0	49.0 ± 9.7	**<0.001**
Triglycerides (mg/dL)	135.1 ± 77.4**	100.8 ± 42.3	97.0 ± 23.0	**0.013**
TG/HDL ratio	3.71 ± 2.82**	2.19 ± 1.13	2.12 ± 0.96	**0.007**
Echocardiographic findings				
LVMI, g/m$^{2.7}$	35.7 ± 8.0	30.5 ± 6.7	24.8 ± 6.5	**<0.001***
RWT, %	38.7 ± 6.2	37.9 ± 5.4	32.6 ± 4.4**	**0.001**
EF (%)	73.2 ± 7.9	73.4 ± 6.7	73.0 ± 5.4	0.921
FS (%)	43.8 ± 8.8	42.7 ± 6.1	44.3 ± 8.9	0.830
E (m/s)	1.00 ± 0.20	0.93 ± 0.17	0.99 ± 0.17	0.864
A (m/s)	0.63 ± 0.20	0.63 ± 0.17	0.52 ± 0.09**	**0.003**
E/A	1.64 ± 0.33	1.57 ± 0.46	1.92 ± 0.32**	**0.001**
Em (m/s)	0.18 ± 0.04	0.18 ± 0.04	0.18 ± 0.03	0.818
Am (m/s)	0.13 ± 0.05	0.14 ± 0.03	0.10 ± 0.02**	**<0.001**
Em/Am	1.32 ± 0.23	1.50 ± 0.36	1.80 ± 0.23	**<0.001***
E/Em	5.65 ± 1.13	5.34 ± 1.27	5.76 ± 1.28	0.723
Left ventricular geometry				
Normal geometry, n (%)	13 (44.8)	19 (61.3)		
Eccentric LVH, n (%)	4 (13.8)	8 (25.7)		
Concentric LVH, n (%)	8 (27.6)	2 (6.5)		
Concentric remodelling, n (%)	4 (13.8)	2 (6.5)		

A = peak late diastolic mitral annular velocity by conventional pulsed wave Doppler echocardiography; Am = peak late diastolic mitral annular velocity by tissue Doppler echocardiography; BMI = body mass index; BP = blood pressure; E = peak early diastolic mitral annular velocity by conventional pulsed wave Doppler echocardiography; EF = ejection fraction; Em = peak early diastolic mitral annular velocity by tissue Doppler echocardiography; FS = fractional shortening; HDL = high-density lipoprotein; HOMA-IR = homeostatic model assessment for insulin resistance; LDL = low-density lipoprotein; LVH = left ventricular hypertrophy; LVMI = left ventricular mass index; MS = metabolic syndrome; RWT = relative wall thickness; MS = metabolic syndrome; SDS = standard deviation scores; TG = triglycerides; WC = waist circumference.
*The results of all groups were statistically different from each other.
**The results were significantly different from the other two groups.

Obesity and obesity-related metabolic syndrome are important risk factors for cardiovascular diseases. It is crucial to investigate the structural and functional changes in children's hearts and understand how they relate to metabolic syndrome parameters. Children are an ideal group for studying myocardial structure and function because they are less exposed to traditional cardiovascular risk factors than adults. While the impact of obesity on adult cardiovascular health is well documented, there is limited data on the effects of metabolic syndrome-related risk factors, in addition to obesity, in children.[7,8,18,19]

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Table 2. Demographic and metabolic factors associated with echocardiographic data in patients with obesity (only significant correlations shown)

	LVMI		RWT		Em/Am	
	r	p	r	p	r	p
BMI					−0.234	0.036
BMI-SDS					−0.306	0.009
Systolic BP	0.301	0.010				
Systolic BP-SDS	0.229	0.039			0.418	0.010
Diastolic BP			0.218	0.047	0.217	0.048
Diastolic BP-SDS			0.222	0.042	0.220	0.046
Insulin	0.403	0.001	0.245	0.030		
HOMA-IR	0.404	0.001	0.266	0.020		
Cholesterol			0.215	0.049		
HDL					−0.228	0.040
TG/HDL	0.234	0.036	0.224	0.043		
LVMI			0.260	0.022		
RWT	0.260	0.022				

Left ventricular hypertrophy is common in adults with obesity and/or metabolic syndrome, and it was previously believed that cardiovascular issues resulting from childhood obesity only manifested in adulthood.[20] Obesity-related metabolic abnormalities have been shown to disrupt left ventricular structure and function at an early age.[7,21] In the present study, left ventricular mass index and relative wall thickness were found to be elevated in children with obesity. Also, compared to children without metabolic syndrome, children with metabolic syndrome had a significantly higher left ventricular mass index.

Obesity can cause an increase in cardiac output and left ventricular wall tension. This may lead to the thickening of the left ventricular wall to compensate for the left ventricular wall tension. The Bogalusa Heart Study reported that obesity was associated with left ventricular dilatation and hypertrophy and that body mass index was the only independent predictor of left ventricular geometry.[22] This study on young adults revealed that those with concentric left ventricular hypertrophy had higher blood pressure than those with eccentric left ventricular hypertrophy. The presence of concentric left ventricular hypertrophy in patients with hypertension, insulin resistance, and diabetes was reported, while eccentric left ventricular hypertrophy was more correlated with body mass index. In support of the above data, we determined concentric left ventricular hypertrophy was more common in children with metabolic syndrome, and eccentric left ventricular hypertrophy was more common in children without metabolic syndrome.

The impact of obesity on left ventricular hypertrophy in adults and children is explained by hemodynamic and metabolic alterations related to obesity. One of the most important factors which is related to obesity and cardiovascular damage is arterial hypertension. The increase in systemic resistance and afterload due to hypertension initially causes left ventricular dilatation and then left ventricular hypertrophy.[23]

Increased fatty infiltration in the epicardium and myocardium can be the sole explanation for cardiac hypertrophy and remodelling in obesity. Fat cells leaking between myocardial fibres cause degeneration of myocardial cells over time, disrupting glucose transport and oxidation. The role of anabolic effects of hyperinsulinemia in left ventricular hypertrophy and remodelling in individuals with obesity has been the focus of recent studies.[23]

Increased left ventricular mass index and relative wall thickness in childhood obesity are associated with body mass index, hyperglycaemia, insulin resistance, and/or hypertension.[6,24] In the present study, systolic blood pressure and homeostatic model assessment of insulin resistance were found to be independent factors in increasing left ventricular mass index in children with and without metabolic syndrome. Furthermore, the homeostatic model assessment of insulin resistance was determined to be the only independent factor responsible for increased relative wall thickness. Our research confirmed that left ventricular structural changes in children with obesity are caused by hypertension and insulin resistance, like in previous paediatric studies.[6,7] The powerful anabolic and trophic effects of insulin on the myocardial muscle tissue have also been demonstrated in cell cultures and animal models. It has been reported that insulin-like growth factor-1 receptors could cause these effects.[25,26]

Despite evidence of left ventricular enlargement and hypertrophy, myocardial contractile function is completely preserved in children with obesity. Our data shows that left ventricular ejection fraction and fractional shortening are within normal ranges, as found in previous studies.[7,27,28] Only a few studies have revealed decreased left ventricular systolic functions in children with obesity.[29,30]

The impact of obesity on left ventricular diastolic dysfunction in adults is explained by hemodynamic, neurohormonal, and metabolic alterations related to obesity. However, these pathophysiological mechanisms in children still need to be described. In contrast to the preservation of systolic functions, it was reported that there was left ventricular diastolic dysfunction in children with and without metabolic syndrome. In our study, the early to late diastolic mitral annular velocity ratios obtained with conventional pulsed wave Doppler echocardiography and tissue Doppler echocardiography (E/A and Em/Am, respectively) were lower in both groups with obesity than in the controls. Furthermore, the ratio obtained with tissue Doppler echocardiography (Em/Am) was lower in the group with metabolic syndrome than in the group without. The early to late diastolic mitral annular velocity ratio (E/A) measured by conventional pulsed wave Doppler echocardiography is generally used to evaluate left ventricular diastolic functions in children. However, this ratio is more affected by the patient's fluid volume status than tissue Doppler echocardiography equivalents (Em/Am ratio).[31] Therefore, both echocardiographic methods were used to analyse left ventricular diastolic functions in our study. In many studies, it has been noted that left ventricular diastolic function is impaired in children and/or adolescents with obesity,[7,32] but few authors have found no difference between lean and patients with obesity.[33,34]

The observed diastolic dysfunction in childhood obesity typically involves mild and subclinical impaired relaxation. It is considered impaired due to myocardial adipose tissue increase and vascular changes. In more severe cases of obesity, there is an observed increase in diastolic filling pressure as the body mass index escalates. Left ventricular hypertrophy and blood pressure elevation are also factors leading to left ventricular diastolic dysfunction.[35,36] Previous studies have reported that diastolic dysfunction is associated with the duration of obesity, body mass index, chronic volume overload, hypertension, insulin resistance, and dyslipidemia.[37,38] In our study, body mass index standard deviation scores, and systolic blood pressure standard deviation scores remained independent predictors of Em/Am in linear regression analysis. It has been observed that left ventricular

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diastolic functions are impaired in children with obesity in parallel with increased body mass index and systolic blood pressure. Several factors may lead to left ventricular diastolic dysfunction in these patients. The most important factor is the myocardial collagen/muscle ratio changes due to fat infiltration in myocytes. Also, a causal relationship exists between left ventricular hypertrophy and left ventricular diastolic dysfunction.[39–41]

This single-center case-control study's main strength is evaluating cardiac structure and functions using conventional pulsed wave Doppler and tissue Doppler echocardiography methods together and analysing many risk factors that may affect cardiometabolic risks in children with obesity.

In light of several limitations, it is necessary to discuss the findings of this study. First, our study is an observational, single-centre study with a small sample size. Second, the cross-sectional nature of this study prevented the evaluation of the effect of weight loss on the improvement of left ventricular structure and functions. Third, we could not evaluate the impact of obesity duration on the findings. The patients' weight status history is incomplete due to the lack of regular physician follow-up, which is another limitation. Finally, blood pressure measurements were not possible through ambulatory blood pressure monitoring.

The potential reversibility of obesity-related left ventricular hypertrophy and left ventricular diastolic dysfunction emphasises the importance of early diagnosis and treatment of obesity-induced cardiovascular abnormality in children. The present study shows that left ventricular hypertrophy and left ventricular diastolic dysfunction are present in all children with obesity. It is particularly evident in children with metabolic syndrome. Therefore, routine echocardiographic examinations should be performed for all children with obesity, regardless of their hypertension, insulin resistance, or dyslipidemia. The deterioration of cardiac structure and functions in children with obesity is caused by body mass index, hypertension, and insulin resistance, as shown in our data. Children with metabolic syndrome need to monitor their blood pressure and insulin levels closely in addition to weight control to prevent cardiovascular morbidity.

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Ethical standards. This material is the author's original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' research and analysis wholly and truthfully. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines, regulations, and institutional policies on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and has been approved by the University of Health Sciences, Kanuni Sultan Suleyman Training, and Research Hospital Ethics Committee on 3/22/2019 with the decision number 2019/57.

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