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ORIGINAL ARTICLE

Blood pressure parameters affecting ventricular repolarization in obese children

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Abstract

Background Ventricular repolarization (VR) increases the risk of sudden cardiac death due to ventricular arrhythmia. We aimed to evaluate the blood pressure (BP) parameters affecting VR in obese children.

Methods Obese (BMI ≥ 95p) and healthy children ≥ 120 cm between January 2017 and June 2019 were included. Demographic and laboratory data, peripheral and central BPs evaluated by a device capable of ambulatory blood pressure monitoring (ABPM), and pulse wave analysis were assessed. Electrocardiographic ventricular repolarization indices, left ventricular mass index (LVMI), and relative wall thickness (RWT) were calculated.

Results A total of 52 obese and 41 control patients were included. Uric acid, triglyceride, total cholesterol, LDL, and ALT values, systolic and diastolic office BPs, 24-h, daytime and nighttime systolic and mean arterial BPs, daytime diastolic BP SDS levels, daytime and nighttime systolic loads, daytime diastolic load, 24-h, daytime and nighttime central systolic and diastolic BPs, and pulse wave velocity values were significantly higher, whereas 24-h, daytime and nighttime AIx@75 were similar between the groups. fT4 levels of obese cases were significantly lower. QTcd and Tp-ed were higher in obese patients. Although RWT was higher in obese cases, LVMI values and cardiac geometry classifications were similar. The independent factors affecting VR in obese cases were younger age and higher diastolic load at night ($B = -2.83$, $p = 0.010$; $B = 0.257$, $p = 0.007$, respectively).

Conclusion Obese patients have higher peripheral and central BP, arterial stiffness, and higher VR indices that develop before an increase in LVMI. It would be useful to prevent obesity from an early age and follow up nighttime diastolic load to control VR associated sudden cardiac death in obese children.

Keywords Obesity · Children · Ventricular repolarization dispersion · Arterial stiffness · Pulse wave velocity · Augmentation index · Blood pressure

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Background

Obesity is an important health problem leading to cardiovascular problems including hypertension, left ventricular hypertrophy, vascular stiffness, and increased ventricular repolarization (VR) representing cardiac arrhythmia risk, even in childhood [1–3]. As blood pressure (BP) measurement is a part of a routine physical examination, hypertension and associated left ventricular hypertrophy (LVH) are more frequently observed as well-known consequences of obesity. However, obesity associated arterial stiffness (AS) and VR studies are scarce and are encountered only during academic pursuits.

AS reflects the viscoelastic property of the vessel wall and it is usually assessed by pulse wave analysis (PWA) [4]. PWA is the evaluation of the pressure created by the pulse wave starting from the aortic arch during its progression to the periphery, the compliance it creates on the vessel walls, and wave reflections [4]. Central BPs, pulse wave velocity (PWV), and augmentation index normalized for a rate of 75 beats per minute (AIx@75) are the main parameters evaluated in PWA.

Ventricular repolarization dispersion (VRD), which is increased with obesity and metabolic syndrome, intensifies the risk of sudden cardiac death due to ventricular arrhythmia [5–9]. Recently, VRD has begun to be evaluated with more effective markers such as QTc dispersion (QTcd), JTc dispersion (JTcd), and those like Tp-e and Tp-e/QT, which represent transmural dispersion of repolarization (TDR) (defined under electrocardiographic section) [5, 6, 9, 10]. Left ventricular mass, QTc and QTcd, and thus arrhythmia and sudden death risk were higher in overweight and obese children even in the absence of hypertension [3, 9]. However, studies on the variability of regional or transmural ventricular repolarization in children are still limited and the results are inconsistent [6, 10]. In this study, we aimed to evaluate the cardiovascular risk factors determined by PWA affecting VRD in obese children.

Methods

This study was conducted on obese (BMI ≥ 95p) cases and healthy volunteers aged 8–18 years who applied to our outpatient clinics between January 2017 and June 2019 and agreed to participate in the study. All children were included in the study, provided that their height was not less than 120 cm as ABPM charts were organized only for children with a height of ≥ 120 cm. Patients with a known kidney and/or cardiac disease, type 1 diabetes or latex allergy, those receiving anti-hypertensive treatment, and those with missing ABPM, electrocardiographic, or echocardiographic data were excluded from the study. Informed consent was obtained from both children and their legal guardians. Ethical approval was obtained from İzmir Katip Çelebi University Ethical Committee (13.10.2016/137).

Study design

At the first visit of the study, case selection was made and demographic data, medical history, and physical examination findings were filled in the case report form for each case. Blood and urine samples were obtained and office BP and 12-channel electrocardiography (ECG) measurements were performed. A device capable of ambulatory blood pressure monitoring (ABPM) and PWA was connected to all children for 24 h. On the second day of the study, the devices were removed and the echocardiographic evaluations were performed.

Evaluation of physical examination parameters

Body mass index (BMI) was calculated according to the following formula: $BMI = Weight$ (kg) / $Height$ (meter)^2, and standard deviation scores (SDSs) were calculated according to the Child Metrics program [11].

Waist to hip ratio was calculated as the ratio of the abdominal circumference measured at the umbilical level to the hip circumference measured from the line passing through the right and left spina iliaca anterior superior.

Evaluation of office and ambulatory blood pressure measurements and pulse wave analysis

Office blood pressure measurements Aneroid sphygmomanometers and cuffs with a width/height ratio of ½ and covering at least 40% of the middle arm circumference of the width and at least 80% of the middle arm circumference of the length were used for the BP measurements. Each child was rested in a sitting position for 5 min before the measurement. After BP measurements, SDS values were calculated according to the Child Metrics program [11].

ABPM and PWA studies (oscillometric measurements) Mobil-O-Graph PWA monitor system (I.E.M. GmbH, Stolberg, Germany), a device that can measure peripheral and central BP and PWA for 24 h, was used [12, 13]. Measurements were obtained from the non-dominant arm, using the appropriate size cuff. The subjects were asked to continue their daily activities, to have the arm in a comfortable position during the measurement, and to note the sleep–wake times properly. Blood pressure measurements of the subjects were made automatically at intervals of 15 min while awake and 30 min while asleep. The percentage of

measurements above the 95th percentile, according to the reference values for age, height, and selected day section published by Wuhl et al., was defined as "blood pressure load" [14]. Daytime and nighttime SBP and DBP loads, mean SBP dip, and DBP dip values were recorded.

The SDSs of BP measurements were established by using the LMS method, in which skewness (L), median (M), and the coefficient of variation (S) were used to transform the data to normality. We automatically calculated SDS values of 24-h, daytime and nighttime SBP, DBP, and MAP via the Child Metrics program according to the published reference LMS tables for healthy children established by Wühl et al. [11, 14].

In PWA, brachial (peripheral) systolic and diastolic BP, central SBP, DBP, and PP, and waveforms were obtained and converted into a mathematical model of arterial impedance and aortic hemodynamics with the help of a published algorithm (ARC Solver algorithm). PWV radiating from the brachial artery and aortic AIx@75 from aortic waveforms were calculated using PWA and wave separation analysis [15]. PWV is measured by dividing the length (L) traveled by pulse wave by the time (t) taken to travel this distance [$PWV = \Delta L / \Delta t$], and expressed as meters/second [16]. PWV is high in chronic diseases such as obesity, kidney failure, diabetes mellitus, or insulin resistance [17, 18]. The pulse wave travels forward through the artery forming the anterograde wave. The wave is reflected in a retrograde fashion affected by the resistance from branch points, smaller arteries, and peripheral vascular beds. The difference between the amplitudes of the antegrade (P1) and retrograde (P2) waves is defined as the augmentation pressure. Augmentation index is calculated by dividing augmentation pressure divided by pulse pressure [$Aix = (P2 - P1) / (sBP - dBP)$] and expressed as % [2, 16]. As it is increased, the amplitude of the forward wave increases as well as AIx. Additionally, the AIx value rises as the total peripheral resistance increases. The AIx is reported as a normalized index for a rate of 75 beats per minute to consider the heart rate differences (AIx@75) [2].

Electrocardiographic evaluation (ventricular repolarization studies)

Recordings at a speed of 25 mm/s and an amplitude of 1 mV/cm were performed in all cases while in the supine position by a standard 12-channel ECG device (Cardiofax GEM, Model 9022 K; Nihon Kohden Tokyo, Japan). ECG measurements were transferred to the computer environment by the device automatically for accurate measurements and all measurements of QT interval, QT dispersion (QTd), corrected QT dispersion (QTcd), Tp-e interval, Tp-e/QT, and Tp-e/QTc ratios were calculated by an expert researcher (ES) manually who was blinded to the patient data as mentioned in our previous study [19].

QT dispersion The time from the beginning of the QRS complex to the end of the T wave was calculated in the presence of a T wave. If there was no T wave, no calculation was made. If the T wave had two peaks and the second peak was less than 50% of the first, the point where the first peak reaches the isoelectric line was taken as the end of the T wave. Corrected Q-T interval (QTc) according to Bazett's formula [$QTc = QT / \sqrt{RR}$ (ms)] was calculated for each patient [20]. An ECG recording was considered analyzable if the QT interval could be measured in more than 8 leads. QTd and QTcd were recorded as the difference between the minimum and maximum QT intervals in at least 8 leads [5].

Tp-e interval was calculated as the difference between the highest point of the highest amplitude T wave (Tp) and the end of the T wave (Te). Te was taken as the point where the descending branch of the T wave intersects with the isoelectric line. If a lead contained inverted T waves, the measurement was taken as the distance from the lowest point of the T wave to Te. U waves were not considered [5].

Echocardiographic evaluation was performed by the same cardiologist (TD) each time with the echocardiography device and the appropriate transducer after resting for each patient. During the evaluation, heart muscle and valve movements were monitored and anatomical structures that may have caused flow disturbances were determined. Ejection fraction and fractional shortening were evaluated for each patient.

Left ventricular mass index (LVMI) For this calculation, interventricular septum thickness (IVST), left ventricular posterior wall thickness (LVPWT), and left ventricular end-diastolic diameter (LVEDD) were measured. Left ventricular mass (LVM) was calculated according to the Devereux formula as follows: $LVM = 0.8\ [1.04\ ([LVEDD + LVPWT + IVST]^3 - [LVEDD]^3)] + 0.6$ and corrected for height $(m)^{2.7}$ to reach the LVMI value [21, 22]. The value found was evaluated according to the LVMI percentile according to the age and gender specified by Khoury et al., and values above the 95th percentile were accepted as left ventricular hypertrophy [22, 23].

Relative wall thickness (RWT) was calculated according to the formula $RWT = 2 \times LVPWT / LVEDD$.

Cardiac geometry was classified according to LVMI and RWT as [23, 24]:

- Normal: LVMI ≤ 95th percentile and RWT ≤ 0.42
- Concentric LV remodeling: LVMI ≤ 95th percentile and RWT > 0.42
- Concentric LV hypertrophy: LVMI > 95th percentile and RWT > 0.42
- Eccentric left ventricular hypertrophy: LVMI > 95th percentile and RWT ≤ 0.42

Statistical analysis

The SPSS 24.0 (SPSS Inc., Chicago, IL, USA) package program was used for statistical analysis. Shapiro–Wilk test was used to evaluate the normal distribution of continuous variables between groups. Normally distributed continuous variables were presented as mean ± standard deviation and compared by Student's *t* test, whereas parameters not distributed normally were presented as median (25Q-75Q) and compared by Mann–Whitney *U* test. Chi-square test was used to compare categorical variables between groups, which were expressed as frequency. Depending on the distribution type of the variables, Pearson or Spearman correlation analysis was performed. Multivariate regression analysis was performed to evaluate the independent factors affecting ventricular repolarization. A p-value < 0.05 was considered statistically significant for all statistical evaluations.

Results

There were 52 obese and 41 control group patients included in the study. Age and gender were similar between the groups. As expected, body weight, height, and BMI SDS values were significantly higher in obese subjects. While eGFR values were similar, uric acid, triglyceride, total cholesterol, LDL, and ALT values were higher, and fT4 was lower in obese subjects (Table 1).

When BP values were compared between groups, both office SBP and DBP measurements were higher in the obese group. When the ABPM data were evaluated, 24-h, daytime and nighttime systolic and mean arterial BP were higher in obese cases. While daytime diastolic BP was higher in obese cases, 24-h and nighttime diastolic BP values were similar between the groups. It was observed that daytime and nighttime systolic load and daytime diastolic load were higher in obese cases. Systolic and diastolic dip values were similar between groups (Table 2). In PWA, 24-h, daytime and nighttime central BP and PWV values were higher in obese cases whereas 24-h, daytime and nighttime AIx@75 values were similar between groups (Table 3).

When the ECG data related to ventricular repolarization of the cases were compared, QTcd and Tp-ed values were slightly but significantly higher in obese patients (Table 4). When echocardiographic data were evaluated, although LVMI values were similar between the groups, RWT was significantly higher in obese children (Table 5). When cardiac geometry categories were evaluated, none was significantly more frequent in obese cases ($p = 0.079$) (Table 5).

Table 1 Comparison of demographic and laboratory findings

	Obese cases ($n = 52$)	Control group ($n = 41$)	p
Age (year)	12.44 ± 2.04	11.58 ± 2.53	0.075
Male gender	54%	40%	0.287
Weight SDS	3.18 ± 1.09	0.24 ± 1.13	**0.001**
Height SDS	0.77 ± 1.34	0.08 ± 1.02	**0.006**
BMI SDS	2.87 ± 0.54	0.17 ± 1.18	**0.001**
Waist/hip ratio	0.95 (0.9–1)	0.88 (0.83–0.93)	**0.029**
Glucose	88.6 ± 8.08	91.28 ± 10.24	0.171
Urea (mg/dl)	22 (19–25)	23 (20–27)	0.260
Serum creatinine (mg/dl)	0.6 (0.6–0.7)	0.6 (0.5–0.7)	**0.023**
eGFR (ml/dk/1.73 m^2)	139.33 (124.14–151.25)	140 (126.5–150.33)	0.772
Uric acid (mg/dl)	5.3 (4.8–6.8)	4.05 (3.2–5)	**0.001**
Na (mmol/l)	140 (139–141)	140 (139–141)	0.810
K (mmol/l)	4.37 (4.2–4.5)	4.38 (4.14–4.66)	0.922
Triglyceride (mg/dl)	112 (85–142.5)	88.5 (59.75–122.5)	**0.018**
Total cholesterol (mg/dl)	169 (141.75–191)	149 (126.25–173)	**0.020**
HDL (mg/dl)	42.5 (36–51)	46 (39.25–52)	0.082
LDL (mg/dl)	101 (86.75–120.75)	80.5 (70–99.5)	**0.002**
fT4	0.8 (0.72–0.92)	0.86 (0.77–0.94)	**0.046**
TSH	2.25 (1.75–2.99)	1.80 (1.13–4.13)	0.149
ALT (IU/l)	27.5 (16–40.5)	13 (11–17)	**0.001**
Microalbumin/creatinine (mg/g)	6.2 (4.4–16.8)	8 (4–18.15)	0.798

*Parametric values with normal distribution are expressed as mean ± SD and compared with Student's *t* test, and those not distributed normally are expressed as median (25Q-75Q) and compared with Mann–Whitney *U* test. Only significant *p* values <0.05 were boldfaced

Table 2 Comparison of office and 24-h blood pressure measurements

BP measurements	Obese cases ($n=52$)	Control group ($n=41$)	p
Systolic office BP SDS	1.40 ± 0.96	0.84 ± 1.07	**0.009**
Diastolic office BP SDS	1.18 ± 0.86	0.72 ± 0.77	**0.008**
24-h SBP SDS	0.24 ± 1.21	−0.88 ± 0.87	**< 0.001**
24-h DBP SDS	−0.40 ± 1.18	−0.83 ± 1.01	0.064
24-h MAP SDS	0.99 (0.19–1.52)	0.22 (−0.36–0.65)	**< 0.001**
Daytime SBP SDS	−0.13 ± 1.15	−1.18 ± 0.91	**< 0.001**
Daytime DBP SDS	−0.77 ± 1.08	−1.23 ± 0.88	**0.026**
Daytime MAP SDS	0.62 ± 1.26	−0.27 ± 0.78	**< 0.001**
Daytime systolic load (%)	17.5 (7–37.5)	4 (0–9)	**< 0.001**
Daytime diastolic load (%)	13.5 (4–25.75)	7.5 (3.25–13.25)	**0.007**
Nighttime SBP SDS	0.70 (0.22–1.59)	0.07 (−0.43–0.66)	**< 0.001**
Nighttime DBP SDS	0.59 ± 1.23	0.37 ± 1.05	0.343
Nighttime MAP SDS	1.85 ± 1.40	1.08 ± 0.88	**0.002**
Nighttime systolic load (%)	28 (7.5–62)	8 (0–29.5)	**0.001**
Nighttime diastolic load (%)	18.5 (1.5–40.25)	9 (0.25.5)	0.118
Systolic dip (%)	6.29 ± 6.10	5.49 ± 5.21	0.501
Diastolic dip (%)	12.85 ± 9.17	12.41 ± 12.41	0.486

BP, blood pressure; *SDS*, standard deviation score; *SBP*, systolic blood pressure; *DBP*, diastolic blood pressure; *MAP*, mean arterial pressure

*Parametric values with normal distribution are expressed as mean ± SD and compared with Student's *t* test, and those not distributed normally are expressed as median (25Q-75Q) and compared with Mann–Whitney *U* test. Only significant *p* values <0.05 were boldfaced

Table 3 Comparison of pulse wave analysis (PWA) findings

PWA values	Obese cases ($n=52$)	Control group ($n=41$)	p
24-h central SBP	103 (99–109.5)	95 (90.5–98)	**< 0.001**
24-h central DBP	66 (61–71)	63 (57.5–67)	**0.023**
24-h central PP	49 (46.25–53.75)	43 (39.5–46.5)	**< 0.001**
24-h PWV	4.6 (4.43–4.9)	4.3 (4.15–4.5)	**< 0.001**
24-h AIx@75	20.65 ± 6.05	19.05 ± 6.00	0.205
Daytime central SBP	104 (99–109)	96 (90–99)	**< 0.001**
Daytime central DBP	69.5 (64–75)	65 (62.5–70.5)	**0.018**
Daytime central PP	48.5 (45.25–53.75)	42 (38–47.5)	**< 0.001**
Daytime PWV	4.7 (4.5–4.9)	4.4 (4.2–4.5)	**< 0.001**
Daytime AIx@75	20.97 ± 6.51	21.21 ± 6.84	0.860
Nighttime central SBP	102 (98–109.75)	93 (88.5–98.5)	**< 0.001**
Nighttime central DBP	59.5 (55.25–64)	58 (53.5–62)	**< 0.001**
Nighttime central PP	50 (47–53.75)	43 (40–47)	**< 0.001**
Nighttime PWV	4.65 (4.4–4.86)	4.3 (4.1–4.4)	**< 0.001**
Nighttime AIx@75	19.11 ± 8.05	16.08 ± 7.68	0.069

PWA, pulse wave analysis; *SBP*, systolic blood pressure; *DBP*, diastolic blood pressure; *PP*, pulse pressure; *PWV*, pulse wave velocity

*Parametric values with normal distribution are expressed as mean ± SD and compared with Student's *t* test, and those not distributed normally are expressed as median (25Q-75Q) and compared with Mann–Whitney *U* test. Only significant *p* values <0.05 were boldfaced

The correlation of QTcd and Tp-ed with age, body weight SDS, height SDS, BMI SDS, SBP SDS, DBP SDS, waist/hip ratio, eGFR, uric acid, TG, total cholesterol, HDL, LDL, ALT, fT4, TSH, microalbumin/creatinine, LVMI, and RWT with all ABPM and PWA parameters were evaluated in obese cases. QTcd was only significantly correlated with age ($r=-0.327$, $p=0.018$), BMI SDS ($r=0.285$, $p=0.041$), nighttime diastolic load ($r=0.304$, $p=0.028$), and AIx@75 ($r=0.282$, $p=0.045$). When these values were evaluated with regression analysis, younger age and

Table 4 Comparison of ECG parameters

ECG data	Obese cases ($n=52$)	Control group ($n=41$)	p
QT (ms)	0.04 (0.02–0.04)	0.04 (0.02–0.04)	0.184
QTc (ms)	0.427 (0.418–0.442)	0.421 (0.409–0.438)	0.098
QTcd (ms)	0.05 (0.033–0.06)	0.04 (0.03–0.05)	**0.042**
Tp-e (ms)	0.08 (0.08–0.10)	0.08 (0.08–0.10)	0.602
Tp-ed (ms)	0.02 (0.02–0.04)	0.02 (0.02–0.03)	**0.037**
Tp-e/QT	0.23 (0.219–0.256)	0.236 (0.211–0.28)	0.354
Tp-e/QTc	0.187 (0.181–0.218)	0.193 (0.188–0.235)	0.074
Tp-e/QTcd	2 (1.471–2.625)	2 (1.83–2.66)	0.051

*Data is expressed as median (25Q-75Q). Only significant p values <0.05 were boldfaced

diastolic load were found as the independent factors affecting the QTcd value in obese subjects (Table 6, Figs. 1 and 2). Tp-ed value was not significantly correlated with any of the parameters ($p<0.05$).

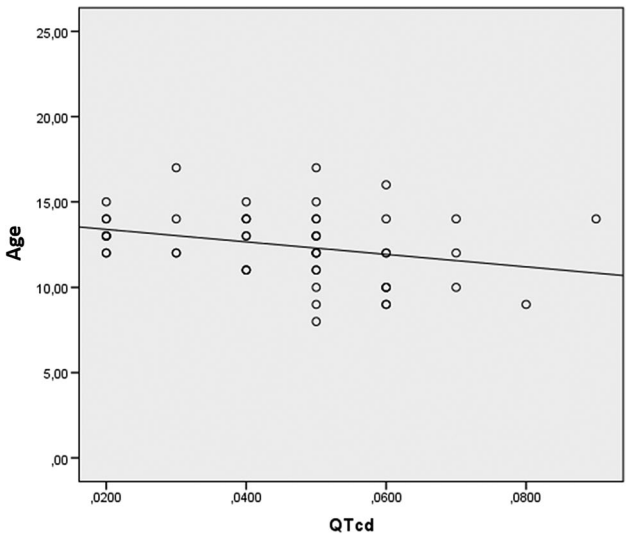


Fig. 1 Correlation of QTcd and age

Discussion

In this study, we have found that uric acid, triglyceride, and ALT levels of the obese children were higher than the control group. In addition, office SBP and DBP values, and especially systolic ABPM values, and 24-h, daytime and nighttime central SBP, DBP, and PWV values obtained from PWA and RWT data were significantly higher, but AIx@75 values were similar in obese patients compared to the control group. Among VR indices, QTcd and Tp-ed values were higher in obese cases compared to the control group. Younger age and nighttime diastolic load were independent risk factors associated with QTcd.

As metabolic disorders are expected to be more frequent in obese cases, higher uric acid, triglyceride, total cholesterol, LDL, ALT levels, and lower fT4 values as well as office BP and ABPM parameters were not surprising in our patients. However, studies on AS and central BP (cBP) in obese children are limited and the results are inconsistent.

Arterial stiffness is determined mainly by PWV and also via AIx@75. The gold standard for PWV is the tonometric method that measures carotid-femoral PWV [25]. However, we used the oscillometric Mobil-O-Graph 24 h PWA Monitor to assess 24-h ABPM and PWA at the same time. This device uses the ARC Solver algorithm that measures the central pulse wave by applying a transfer function to

Table 5 Comparison of echocardiographic parameters

Echocardiographic data	Obese cases ($n=52$)	Control group ($n=41$)	p
LVMI (g/m$^{2.7}$)	35.9 (33–40.6)	34.6 (29–39.7)	0.125
RWT	0.42 ± 0.08	0.38 ± 0.07	**0.024**
Normal cardiac geometry	38.5%	63.4%	0.079
Concentric LV remodeling	19.2%	9.8%	
Concentric LVH	19.2%	7.2%	
Eccentric LVH	17.1%	21.2%	

LVMI, left ventricular mass index; *RWT*, relative wall thickness; *LVH*, left ventricular hypertrophy; *LV*, left ventricle. Only significant p values <0.05 were boldfaced

Table 6 Linear regression analysis of parameters having significant correlation with QTcd in obese cases

Independent variable: QTcd						
Dependent variable	B	Standard error	β	t	p	%95 confidence interval for B
Age	−2.83	1.062	−0.346	−2.667	0.010	−4.969 to −0.696
Nighttime diastolic load	0.257	0.090	0.364	2.844	0.007	0.075–0.439

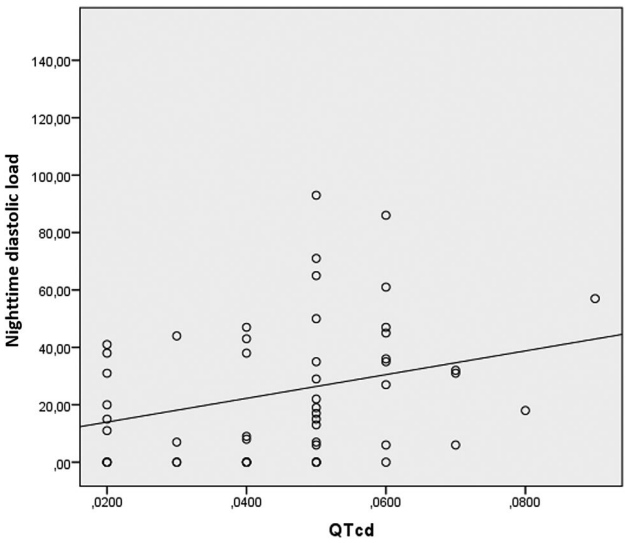


Fig. 2 Correlation of QTcd and nighttime diastolic load

determine PWV and AIx and the results agree with accepted tonometric devices [13]. In children and adolescents, this method shows good accuracy for central BP compared with invasive measurements obtained during cardiac catheterization [26].

As mentioned before, AS may be assessed by the determination of PWV and AIx in PWA [27]. PWV defines the rate of passage of the pulse wave between two determined points in the arterial system and it is a direct measure of AS, whereas AIx is an indirect indicator [28]. It has been observed that AS increases in children and adolescents with high normal BP or in hypertensive patients, but obesity has controversial effects on PWV [29–31]. It has been found that each 1 SD increase in brachial SBP causes an increase of 0.329 m/s in PWV whereas each 1 SD increase in body mass index causes a decrease of 0.129 m/s in PWV [30]. Although adiposity and insulin resistance were found to be associated with thickening of the vascular wall in adults, adiposity was associated with dilation in brachial artery and a decrease in AS obtained by PWV measurement in prepubertal children [30, 31]. Some other researchers found that although obesity resulted in thickening of the carotid vascular wall, it was not related to increased PWV and suggested that obesity may regulate early adaptations in the vascular tree [17]. In a systematic review, it was determined that obesity alone does not have an effect on AS, and AS increases only in the presence of impaired glucose tolerance or metabolic syndrome [32]. On the other hand, obesity and hypertension were both found significantly and independently associated with increased PWV and the highest PWV values were seen in obese hypertensive patients [25, 33, 34]. Finally, two meta-analyses proposed that childhood obesity is associated with greater AS and causes stiffness, especially in large arterial vessels [35, 36]. Another more recent meta-analysis suggested that central PWV increases with elevated BP and BMI in childhood and cardiorespiratory fitness lowers AS [37]. In parallel with the meta-analysis results, we have found that both BP and PWV values were significantly higher in obese cases in the present study. However, 24-h, daytime and nighttime AIx@75 values were similar between the obese and control cases, although both PWV and AIx@75 were determinants of AS. Similar results have been noted in previous studies. For example, 24-h PWV values were higher in obese children, although 24-h AIx@75 values were not different from those of the non-obese cases [31]. That was explained by the fact that the total blood volume increases while the total peripheral resistance decreases, and the heart rate remains the same or increases slightly in non-hypertensive obese cases to maintain BP within normal limits [25, 38, 39]. As a consequence of that adaptation mechanism, augmentation pressure and AIx@75 values do not change in obese cases [38]. This may result in higher PWV despite similar AIx@75 values in obese cases compared to the healthy control peers.

The impact of childhood obesity on central BP is another controversial point. Lately, the importance of central aortic BP measurement has been emphasized. In cases with high peripheral but normal central BP, "pseudo-hypertension" or "spurious hypertension" is mentioned and this situation is not associated with AS. However, an increase in AS is also observed in cases where both peripheral and central BPs are elevated. However, it is thought that in cases where AS increases, the return of the transmitted wave to the central veins will accelerate, which may lead to an increase in the central BP [25]. In our study, we have found that both peripheral and central BP values were significantly higher in obese cases, as well as PWV representing AS.

Obesity may lead to LVH, eccentric left ventricular hypertrophy, or right ventricular hypertrophy [9, 24]. In most studies, LVMI was higher than the control group; however, LVMI of the obese cases was similar to the control group and RWT was significantly higher in obese cases in the present study [9, 24]. We could not demonstrate any concentric or eccentric left ventricular structural abnormality in obese cases; however, although statistically not significant, normal cardiac geometry was more frequent in the control group.

Electrocardiographic indices of ventricular repolarization have been proposed to predict arrhythmogenic risk and sudden cardiac death [5, 9, 24, 40]. Obesity is a well-known risk factor for sudden cardiac death [24], but the number of studies conducted on obese children and adolescents about ventricular repolarization and transmural repolarization distribution is limited. In a recent review on this topic in children, it was concluded that childhood obesity may increase the risk of arrhythmia and sudden cardiac death in adulthood

[24]. In most of the studies, QT, QTc, QTd, and QTcd, which represent regional ventricular repolarization and dispersion of ventricular repolarization, were significantly higher in obese cases compared to those with normal weight [3, 9, 24, 40, 41]. In one of those studies, Tp-e values representing the "transmural dispersion of repolarization (TDR)" were also significantly higher in non-hypertensive obese cases [9]. In the present study, we have demonstrated that not all parameters, but only QTcd as a ventricular repolarization dispersion parameter and Tp-ed, which has not been studied before, as a transmural repolarization distribution parameter were significantly longer, which may lead to malignant ventricular arrhythmias. The two mechanisms proposed for that are the predisposition of the spread of the transmural early after depolarization and blocking of intramural function conduction leading to reentrant polymorphic ventricular tachyarrhythmias [9]. Finally, we have found that younger age and nighttime diastolic load were independent risk factors for prolonged QTcd in obese children and adolescents. To the best of our knowledge, this is the first study to detect the effects of blood pressure and arterial stiffness parameters effective on ventricular and transmural repolarization.

Our study not only has limitations but also has valuable results, to which the prospective design contributed. First, the relatively small number of cases may have caused errors in interpreting the data. Second, we have used the oscillometric method to assess PWA. Although this is not the gold standard method for PWV, it is considered as a reliable method and in addition, oscillometric PWA measurement is more acceptable for the entire analysis. For the first time, the PWA and VR indicating the arrhythmogenic risk of obese children were assessed together in the present study.

In conclusion, obese subjects have a higher risk of peripheral and central BP, arterial stiffness, and risk of sudden cardiac death, and these findings develop before an increase in the LVMI. It may be useful to follow and control obese cases in terms of these abovementioned parameters. It has been observed that the most important factors affecting ventricular repolarization in obese cases are younger age and increased nocturnal diastolic load. It is thought that studies with larger groups with long follow-up periods, including the effects of treatments, will reach more valid results.

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Data Availability Data of this study is available as an SPSS form.

Declarations

Conflict of interest The authors declare no competing interests.

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