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Impact of Adolescent's Obesity in Cardiac Function: An Association of Cardiac Structural and Metabolic Risk Factors with Physical Fitness

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ABSTRACT

Background

Elderly obese results metabolic, cardiac structural and functional derangements. However, such alterations including physical fitness in early age obesity are still controversial.

Objective

To evaluate physical fitness, cardiac structural, functional and metabolic remodeling and their association with obesity markers in adolescents.

Method

This cross-sectional comparative study included 90 adolescents with median age -14(2) years were grouped into Normal weight (NW) and Overweight/Obese (OW/OB) based on the BMI percentile for age and sex. International Diabetes Federation criteria for adolescents selected for lipid profiles, fasting sugar, systolic (SBP) and diastolic blood pressure (DBP). Echocardiographic standard 2-dimensional measurements for cardiac structures, percent ejection fraction (EF%) were performed with standard procedure. Physical fitness index (PFI) was graded using the modified Harvard step test. The data compared with Mann Whitney U test and Spearman's Rank correlation test used to find association among study variables.

Result

Compared to normal weight adolescents, overweight/obese individuals exhibited significantly higher cardiac function parameters, including heart rate, systolic and diastolic blood pressure. Within the realm of cardio-metabolic parameters, it was observed that individuals exhibited diminished levels of high-density lipoproteins and elevated levels of low-density lipoproteins. Notably, these individuals manifested cardiac structural remodeling characterized by augmented left atrial wall and aortal base thickness, and increased left ventricular end-diastolic diameter, concomitant with a markedly decreased percentage of left ventricular ejection fraction. Cardiac structural and functional parameters revealed adverse correlation with obesity markers.

Conclusion

The onset of obesity in early age has been ascertained to exert profound ramifications, encompassing not solely metabolic and biochemical parameters, but also extending to the structural integrity of the cardiovascular system. These outcomes synergistically contribute to a notable attenuation in overall physical fitness.

KEY WORDS

Adolescent's obesity, Body mass index percentile, Cardiac structure, Lipid profile, Physical fitness

INTRODUCTION

Global childhood obesity trends have undergone significant changes in both developed and developing countries. Across 144 surveyed nations, 43 million preschool children (35 million in developing countries) are overweight or obese, with an additional 92 million at risk of overweight.[1] The criteria for obesity in childhood and adolescents has been made as classifying the BMI at the 85^{th} to 95^{th} percentiles for age and sex to identify children or teens (adolescents) who are overweight, and a BMI greater than or equal to the 95^{th} percentile to identify children or teens who are obese.[2]

Excessive obesity affects the heart and metabolism in adults, leading to changes in cardiac structure and function.[3] This is influenced by known risk factors like dyslipidemia, hypertension, glucose intolerance, and inflammation, as well as other unknown mechanisms.[3] Up to 80% Obese children have a high likelihood of remaining obese in adulthood, which can result in future health issues and increased risk of metabolic disorders.[4] Childhood and adolescent obesity are not only present concerns but also potential causes of future health problems.[5]

Several studies have reported the negative association between physical fitness and obesity markers with some controversies.[6-9] The real impact of obesity especially in early ages on physical fitness, cardiac structure and function is still largely unknown. Moreover, such changes in cardiac structure and function, if any, in adolescent obesity and their association with cardiorespiratory physical fitness has remained to be observed. Therefore, this study aims to evaluate physical fitness, cardiac structural, functional and metabolic remodeling and their association with BMI markers in adolescents.

METHODS

This cross-sectional study conducted at the Department of Physiology, Chitwan Medical College, from 01 December 2021 to 01 January 2023, included a total of 90 adolescents of both sexes with age ranging from 10 to 19 years. The study subjects were recruited from the middle schools of mid-region of Nepal. The participants included in this study had their written informed consent both from the participants and parents. The participants were having ≥ 5 th percentile of body mass index (BMI), according to the age- and gender-specific reference values of the 2007 CDC, WHO. The subjects having less than 5^{th} percentile of BMI according to age and sex were excluded from the study. The subjects having any diagnosed systemic disease and under medication were not included in this study.

Obesity and Cardio-metabolic parameters

The subjects were classified as (1) normal weight (NW, 5^{th} – 85^{th} percentile); (2) overweight (OW, 85^{th} – 94^{th} percentile,) and (3) obesity (OB, ≥ 95^{th} percentile,) according to the age- and gender-specific reference values of the 2007 WHO, CDC National Growth charts.[10.11] In this study, OW and OB groups were merged and named as OW/OB group.

The adolescents with abdominal obesity (WC ≥ 90th percentile for age and sex), Waist-height ratio > 0.4 and 2 or more of the following values: TG ≥ 150 mg/dL; HDL ≤ 40 mg/dL; fasting glucose ≥ 100 mg/dL; and systolic BP ≥ 130 mmHg; or diastolic BP ≥ 85 mmHg were considered as Obesity related Metabolic Syndrome (International Diabetes Federation criteria).[12]

BP was measured twice using Dynosure Doctor Dt® mercury sphygmomanometers with an appropriate-sized cuff, and the average of the two readings was taken as the final reading.[13] The WC was measured midway between the tenth rib and the top of the iliac crest to the nearest 0.1 cm, using a non-stretchable tape measure.[14] Weight was measured to the nearest 0.1 kg with a 'Mettler Toledo' weighing machine, and height was measured to the nearest 0.1 cm using a wooden stadiometer. Weight and height were measured with the respondents wearing light school uniforms, without head or footwear, and without accessories such as purses, keys and mobile phones, to avoid overestimation.[14] BMI was calculated using the formula: weight (kg)/height squared (m^2). The calculated BMI was used to classify respondents as normal weight, overweight or obese, using the IOTF age- and sex-specific cut-off points.[11,12]

Cardiac structure and function study parameters

Echocardiography was performed in each subject with a commercially available ultrasound system (3D/4D Philips HD15 Ultrasound Machine). Echocardiography test used high-frequency sound waves (i.e., Ultrasound) to create the appropriate picture of a heart's chamber, valves, walls and the blood vessels (aorta, arteries, veins). This was a harmless process where a probe called a transducer was passed over a chest that produces sound waves which bounce off the heart and echo back to the probe. These views were presented as a picture on a video monitor. Standard, 2-dimensional measurements [end-diastolic and end-systolic LV diameters and volumes, ventricular septum and posterior wall thickness and left atrial (LA) diameters, area and volume], percent ejection fraction (EF%) and percent fractional shortening (FS%), were performed with standard procedure and precautions.[9]

Physical fitness measurement and parameters

Physical fitness was assessed using the physical activity fitness test- the modified Harvard step test.[15] Each participant was asked to place one foot on a 10 inch-high stool, step up, place both feet on the platform, straighten the legs and back, and immediately step down again, bringing down the same foot he/she first raised. This stepping up and down was continued at the rate of 20 steps per minute, following the rhythm of a metronome, for 3 minutes. Immediately after exercise the participants were allowed to sit quietly on a chair and the heart rate (pulse rate) was measured for 30 seconds after exactly one minute and at the following time points: 1 to 1.5 minutes, 2 to 2.5 minutes and 3 to 3.5 minutes after the end of exercise. Then physical fitness index (PFI) was calculated using the following equation.

Calculation of Physical fitness Index (%)

PFI=Duration of exercise in seconds x 100/2(pulse 1+2+3)

The cardiorespiratory physical fitness interpreted based on comparing the obtained score with the reference value given in the table below.

PFI Rating	Physical Fitness Index (PFI)	
	Male	Female
Excellent	> 115	> 91
Good	103-115	84-91
Fair	91-102	77-83
Poor	< 91	< 77

This study was conducted according to the guidelines of the Declaration of Helsinki and approval was taken by the institutional ethics review committee.

The data obtained were analyzed with SPSS (version 20; IBM Corporation, Armonk, NY, USA). The Shapiro-Wilk normality test was applied for all the descriptive parameters. The comparison of the anthropometric, obesity and physical parameters between the groups were done by Mann Whitney U test for the non-parametric data and student t test for the parametric data. Most of the data were non-parametric hence the Spearman's Rank correlation test was applied to see the relation among obesity, cardiometabolic, cardiac structures and physical fitness parameters. Statistical significance was considered to be $p \leq 0.05$.

The data of the research have been employed from the adolescents whose parents have signed and stated their consent for using their not-identifying data for the aim of research. This study was conducted according to the guidelines of the Declaration of Helsinki and approval (ref: CMC-IRC/078/079-088) was taken by the institutional ethics review committee, Nepal.

RESULTS

The total 90 adolescents with median age -14(2) years, height - 158(8) cm and weight-60.44±7.71 kg were included in this study. Based on the BMI percentile for age and sex, the participants were divided into 1. Normal weight (NW) and 2. Overweight/obese (OW/OB) groups. The Shapiro-Wilk normality test was applied to obtain the overall distribution of descriptive parameters. The age and sex of the participants were matched between the groups. The weight, BMI percentile, Waist circumference and waist-height ratio were statistically significant between the groups, whereas the age (Normal weight Vs OW/OB:13.5(4) - 14(1) years, p=0.58) was comparable between the groups (Table 1). The cardiac function parameters including the heart rate/pulse rate (NW Vs OW/OB: 80 (9)- 91(12) beats/min, p < 0.001), SBP (NW Vs OW/OB: 117 (5) - 120(8) mmHg, p < 0.001) and DBP (NW Vs OW/OB: 74.33 ± 3.64- 80.32 ± 4.8 mmHg, p < 0.001) were significantly higher in OW/OB group than in NW group adolescents (Table 2). Among the Cardio-metabolic parameters, HDL (NW Vs OW/OB: 45.5 (8)- 40(6), p < 0.001) was lower and LDL (NW Vs OW/OB: 79 (16) - 92.5(24), p=0.007) was higher in higher among OW/OB adolescents (Table 3). Echo cardiographic parameters for cardiac structure revealed greater diameters of left atrium (LA), aorta at base and end diastolic diameter (EDD) of left ventricle in OW/OB adolescents (Table 4). Though OW/OB adolescents revealed greater LV % fractional shortening (NW Vs OW/OB: 36(5) - 37(4), p=0.002), the % LV ejection fraction (NW Vs OW/OB: 65(4) - 63(8), p=0.002) were significantly less in them. The cardiorespiratory physical fitness interpreted based on comparing the score was 'fair-poor' in both sexes of OW/OB groups while PFI rating scored for normal weight group was 'excellent-good' (table 5).

Table 1. Comparison of anthropometric/obesity parameters between normal weight (n=30) and overweight/obese (n=60) adolescents

Parameters	Normal weight Median (Interquartile Range)/ Mean±SD	OW/OB Median (Interquartile Range)/ Mean±SD	Mann-Whitney U test/ Student t-test P value
Age (Yrs)	13.5(4)	14(1)	0.58
Ht (cm)	158(8)	157(9)	0.81
Wt (Kg)	52.67±4.27	67.67±5.4	**<0.001**
BMI percentile	77.5(14)	94.5(5)	**<0.001**
WC	64(4)	83(12)	**<0.001**
WHtR	0.4(0.03)	0.52(0.08)	**<0.001**

Table 2. Comparison of Cardiac function parameters between normal weight (n=30) and overweight/obese (n=60) adolescents

Parameters	Normal weight Median (Interquartile Range)/ Mean±SD	OW/OB Median (Interquartile Range)/ Mean±SD	Mann-Whitney U test/ Student t test P value
PR	80(9)	91(12)	< 0.001
SBP	117(5)	120(8)	< 0.001
DBP	74.33±3.64	80.32±4.8	< 0.001

On Spearman's Rank correlation, the obesity markers including Wt, BMI percentiles, waist circumference (WC) and waist-height ratio (WHtR) were positively and significantly correlated with cardiovascular functional parameters- the resting heart rate or pulse rate (rho=+0.477, p < 0.001),SBP

Table 3. **Comparison of Cardio-metabolic parameters between normal weight (n=30) and overweight/obese (n=60) adolescents**

Parameters	Normal weight Median (Inter-quartile Range)/ Mean±SD	OW/OB Median (Inter-quartile Range)/ Mean±SD	Mann-Whitney U test/ Student t test P value
FBS	83(16)	82(20)	0.32
Cholesterol	147(29)	154(17)	0.39
HDL	45.5(8)	40(6)	**< 0.001**
LDL	79(16)	92.5(24)	**0.007**
VLDL	15(8)	17.5(9)	0.31
TG	81(18)	91(45)	0.08
HbA1C	5(0)	5(1)	0.04
T3	149.5(24)	148(34)	0.87
T4	8(2)	9(3)	0.09
TSH	4(2)	3(2)	0.59
CRP	1(1)	1(1)	0.29
Serum Uric Acid (SUA)	4(2)	5(3)	0.65

Table 4. **Comparison of Cardiac structure parameters between normal weight (n=30) and overweight/obese (n=60) adolescents**

Parameters	Normal weight Median (Inter-quartile Range)/ Mean±SD	OW/OB Median (Inter-quartile Range)/ Mean±SD	Mann-Whitney U test/ Student t test P value
LA (cm)	3(1)	3.7(1)	< 0.001
EDD (cm)	4(0)	4.5(0)	0.001
EF%	65(4)	63(8)	0.002
ESD (cm)	3(1)	3(1)	0.76
FS%	36(5)	37(4)	0.002
Aorta (cm)	2(0)	2.2(1)	0.01

Percent fractional shortening FS%, percent ejection fraction EF%

Table 5. **Comparison of PFI between normal weight (n=30) and overweight/obese (n=60) adolescents**

Parameters	Normal weight Median (Inter-quartile Range)/ Mean±SD	OW/OB Median (Inter-quartile Range)/ Mean±SD	Mann-Whitney U test/ Student t test P value
PFI	1(1)	3(2)	**< 0.001**

Table 6. **Spearman's Rank Correlation of obesity parameters with cardiorespiratory and Physical fitness variables (N=60)**

Variables		PR	SBP	DBP	PFI	PFI-G
Wt.	rho	0.477	0.308	0.520	-0.537	0.670
	P value	<0.001	0.003	<0.001	<0.001	<0.001
BMI	rho	0.495	0.281	0.551	-0.624	0.732
	P value	<0.001	0.003	<0.001	<0.001	<0.001
BMI percentile	rho	0.568	0.370	0.593	-0.589	0.827
	P value	<0.001	<0.001	<0.001	<0.001	<0.001
WC	rho	0.599	0.383	0.541	-0.565	0.769
	P value	<0.001	<0.001	<0.001	<0.001	<0.001
WHtR	rho	0.599	0.355	0.519	-0.565	0.779
	P value	<0.001	0.001	<0.001	<0.001	<0.001

Table 8. **Spearman's Correlation of obesity parameters with cardiovascular structural variables (N=60)**

Variables		LA (cm)	EDD (cm)	EF%	ESD (cm)	FS%	Aorta (cm)
Wt.	rho	**0.473**	**0.283**	**-0.395**	0.074	0.074	**0.269**
	P value	**<0.001**	**0.007**	**<0.001**	0.490	0.487	**0.01**
BMI	rho	**0.490**	**0.343**	**-0.356**	0.020	0.061	**0.247**
	P value	**<0.001**	**0.001**	**0.001**	0.849	0.571	**0.019**
BMI percentile	rho	**0.473**	**0.315**	**-0.346**	-0.014	0.038	**0.249**
	P value	**<0.001**	**0.002**	**0.001**	0.893	0.722	**0.018**
WC	rho	**0.457**	**0.338**	**-0.370**	0.052	0.035	**0.396**
	P value	**<0.001**	**0.001**	**<0.001**	0.624	0.746	**<0.001**
WHtR	rho	**0.444**	**0.337**	**-0.330**	0.026	0.031	**0.396**
	P value	**<0.001**	**0.001**	**0.001**	0.808	0.775	**<0.001**

Table 7. **Spearman's correlation of obesity parameters with cardio metabolic variables (N=60)**

Variables		FBS	Chl	HDL	LDL	VLDL	TG	Hb1AC	T3	T4	TSH	CRP	SUA
Wt.	rho	0.172	0.233	-0.325	0.233	0.063	0.025	0.180	0.063	0.154	-0.022	0.111	0.203
	P value	0.106	0.027	0.002	0.027	0.554	0.815	0.089	0.557	0.147	0.839	0.299	0.055
BMI	rho	0.144	0.303	-0.343	0.234	0.032	0.155	0.195	0.098	0.172	-0.012	0.078	0.097
	P value	0.175	0.004	0.001	0.027	0.763	0.145	0.066	0.359	0.106	0.910	0.464	0.365
BMI percentile	rho	0.127	0.248	-0.361	0.244	0.027	0.154	0.134	0.047	0.148	0.001	0.083	0.029
	P value	0.232	0.018	<0.001	0.021	0.797	0.148	0.208	0.661	0.165	0.989	0.436	0.783
WC	rho	0.178	0.148	-0.402	0.230	0.075	0.188	0.170	-0.05	0.181	-0.015	0.084	0.082
	P value	0.093	0.164	<0.001	0.029	0.480	0.075	0.109	0.637	0.088	0.888	0.430	0.441
WHtR	rho	0.167	0.153	-0.406	0.231	0.031	0.244	0.152	-0.063	0.179	0.016	0.068	0.035
	P value	0.155	0.150	<0.001	0.029	0.769	0.02	0.153	0.553	0.091	0.881	0.527	0.744

(rho=+0.308, p=0.003) and DBP (rho=+0.520, p<0.001). Moreover, Thickness and dimensions of the cardiovascular structural parameters including LA, EDD and Aorta revealed positive association with all the obesity markers included in this study (Table 8). However, the percent left ventricle ejection fraction (EF %) was found with strong negative correlation with increasing obesity indices. Overall cardiovascular structural and functional variables including physical fitness parameters revealed negative impact of adolescent's obesity indices (tables 6, 7 and 8).

DISCUSSION

This study observed that the most fundamental and vital cardiovascular functions including the basal heart rate/ pulse rate and systemic arterial blood pressures (SBP and DBP) were significantly higher in OW/OB adolescents. On correlation, these cardiovascular functional parameters positively associated with increasing adolescent's obesity indices including BMI percentiles, WC and WHtR. These findings with associations between obesity markers and elevated BP in children or adolescents were reported by several researchers.[16,17] However, these studies yielded inconsistent findings. In contrast, Guoet al. found no significant association between high BMI percentile and high systemic blood pressure in them.[18]

Like this study, previous reports had observed the relation between elevated resting heart rate/PR and high BP in early age populations suggesting that elevated RHR could be a marker of cardiovascular disease in young age, mediated by the important cardiovascular risk factors such as obesity, which through inflammatory substances, could raise the resting heart rate.[19,20]

This study suggested unfavorable shifting of lipid profile among OW/OB groups resulting lower HDL (NW Vs OW/ OB: 45.5 (8) Vs 40(6), p < 0.001) and higer LDL (NW Vs OW/ OB: 79 (16) Vs 92.5(24), p=0.007) in them. However, total serum cholesterol and TG were comparable between the groups. The relationship between the obesity markers and the lipid profile, especially HDL and LDL were hostile. Though these findings were partly favored by several other previous studies, the findings with higher Serum cholesterol and TG obese children and adolescents were not consistent with our findings.[21,22]

The best predictor of lipid or lipoprotein levels in adulthood is the level of HDL observed in childhood, although the cutoff for defining dyslipidemia in children remains controversial. The total/high-density lipoprotein (HDL) cholesterol ratio and the low-density lipoprotein/HDL cholesterol ratio are 2 important indicators of vascular risk, with a predictive value greater than the single variables. Abnormal HDL and LDL have more values towards detrimental effect on cardiovascular health and development of obesity-related morbidity.[23]

TSH, T3, T4 levels were comparable between the groups. In contrast to this study, Ghergherehchi R24 reported increased T4 and TSH in children who are overweight or obese. However, Grandone A, 25 mentioned a moderate elevation of TSH concentration is in obese children and is not associated to increased metabolic risk.

On structural assessment of heart and related structures through echocardiography, we found dramatically increased diameters and thickness of left atrium (LA), aorta at base and end diastolic diameter (EDD) of left ventricle in OW/OB adolescents. Moreover, OW/OB adolescents had greater LV % fractional shortening (NW Vs OW/OB: 36(5) Vs 37(4), p=0.002) with significantly reduced % LV ejection fraction (NW Vs OW/OB: 65(4) Vs 63(8), p=0.002). Further on correlation, thickness and dimensions of the cardiovascular structural parameters including LA, EDD and Aorta associated positively with all the obesity markers. Unfortunately, the percent left ventricle ejection fraction (EF %) was found with strong negative correlation with increasing obesity indices. This study suggests that early age overweight/obesity brings structural modification of cardiovascular health which lead to cardiovascular functional abnormality with decreased percent ejection fraction of left ventricle. These findings are supported by some other studies mentioning that distal aorta, both LV cavity size and wall thickness are increased in obesity, although early studies reported an association with only eccentric left ventricular (LV) remodelling.[26-28] EDD and % ejection fraction explains the diastolic and systolic function of ventricle. In this study, both the EDD and % ejection fraction were in the direction of abnormality. Despite the mechanisms behind diastolic dysfunction in obesity are poorly understood, such symptomatic or asymptomatic diastolic functional abnormality is associated with the development of heart failure or future cardiomyopathy.[29,30]

Similar to this study, Koopman et al. reported that obese children have been shown to have larger left atrial and ventricular dimensions, and increased left ventricular mass compared to normal weight controls.[9] However, they also mentioned that in contrast to the adult population, heart failure and significant ventricular dysfunction with reduced ejection fraction has not been reported in obese children. Several studies suggest the presence of sub-clinical myocardial dysfunction with reduced tissue Doppler velocities and myocardial deformation (strain and strain rate) in obese children which may develop obesity-cardiovascular morbidity in future life.

The present study was undertaken to assess the physical fitness index using Modified Harvard Step Test in adolescents which measures the physical fitness for Muscular work and the ability to recover from the work, especially recovery of cardiorespiratory function to resting level after the test. These physical fitness for normal weight adolescents was rated as 'good to excellent' whereas rating was 'poor to fair' for OW/OB adolescents. Obese children and adolescents usually have lower overall physical abilities and especially lower cardiorespiratory fitness (CRF) when compared to their normal-weight peers. This is mainly because of the increased effort required to move their larger body mass and carry an excessive amount of body fat.[31] Although cardio-respiratory fitness has long been considered as the primary factor supporting good health, musculoskeletal fitness is now recognized as a crucial component in maintaining overall health and fitness.[32] Though the limited data are available concerning musculoskeletal fitness, Smith and collaborators in their systemic review and meta-analysis found the strong evidence for an inverse association between muscular fitness and adiposity (total and central) in children and adolescents.[32]

This study also supported with the findings of previous reports with an inverse and significant relation between 12-15 years old obese adolescents CRF and their body fat mass using Queen's college step test conducted to exhaustion and the measurement of VO_{2max}.[33,34] Excessive body fat is also thought to contribute to exercise intolerance and low CRF in obese youth.[33] However, some studies suggest different effects of obesity in girls and boys, as Mota et al. did not observe any CRF difference between lean, overweight or obese 8 years old boys, whereas overweight and obese girls were more likely to be unfit compared to normal weight girls.[35] Though some inconsistency in observations, obesity has negative impact over all physical fitness in both sexes even at early ages.[36]

The limitations to our study could be the more detailed physical activity test based on aerobic capacity and their daily normal food consumption.

CONCLUSION

Early-onset obesity in adolescents has been found to have profound implications, not only on metabolic, and biochemical parameters but also on the structural integrity of the cardiovascular system. These consequences culminate in a significant decline in overall physical fitness. In overweight or obese adolescents, notable deviations in lipid profiles, resting heart rate, and both systolic and diastolic blood pressures have been observed. Consequently, these aberrations contribute to substantial cardiovascular structural adaptations, characterized by increased thickness and dimensions of key cardiac components such as the left atrium (LA), left ventricle (LV), and aortic base. These structural alterations, in turn, are accompanied by a reduction in the percentage of blood ejected from the heart (ejection fraction), which demonstrates a robust correlation with elevated markers of obesity. Thus, it is evident from this study that early-age obesity constitutes a potent risk factor for the development of cardiovascular and metabolic disorders, ultimately compromising physical fitness and posing significant implications for morbidity and mortality later in life.

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