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Original Article

Reduced Left Ventricular Global Longitudinal Strain in Obese Adolescents

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Abstract

Background: Obesity in adolescents is associated with early cardiac structural and functional alterations that may progress to ventricular dysfunction later in life. Two-dimensional speckle-tracking echocardiography (2D STE) enables early identification of subclinical ventricular dysfunction. Nevertheless, its application in the adolescents remains limited. This study aimed to assess differences in left ventricular (LV) function among well-nourished, overweight, and obese adolescents using 2D STE.

Methods: A cross-sectional study was conducted among adolescents aged 15–18 years from five senior high schools in Bandung, Indonesia between June and August 2023. Participants were randomly categorized into well-nourished, overweight, and obese groups. Transthoracic echocardiographic using M-mode and 2DSTE was performed to evaluate LV function, particularly global longitudinal strain (GLS). Statistical analyses were performed using SPSS with significance defined as $p<0.05$.

Results: Sixty adolescents were included, 65% were male with a mean age of 16.4±0.6 years. Conventional echocardiography showed no significant differences in systolic or diastolic function among groups. However, obese adolescents demonstrated significantly greater LV posterior wall thickness and larger LV and right ventricular basal volumes compared with other groups. GLS analysis revealed significantly reduced LV deformation in obese group compared with overweight and well-nourished groups (–20.0±1.9 vs. –22.3±1.4 vs. –22.7±1.9, respectively; $p<0.001$).

Conclusions: Reduced LV GLS detected by 2D STE indicates early subclinical myocardial dysfunction in obese adolescents despite normal conventional echocardiographic findings. Early cardiovascular screening and lifestyle interventions, including balanced nutrition and regular physical activity, may help reduce future cardiometabolic risk.

Keywords: Adolescent, global longitudinal strain, left ventricular function, obesity, speckle-tracking echocardiography

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Introduction

The World Health Organization (WHO) has declared obesity as a global epidemic that must be addressed urgently. The prevalence of obesity among children and adolescents has seen a worldwide surge, with projections suggesting that 91 million children will be affected by obesity by 2025.[1] A majority of the global population lives in countries where being overweight and obesity result in a higher mortality rate than being underweight.[2] In West Java Province, Indonesia, the prevalence of obesity has been recorded at 4.9% for individuals aged 13 to 15 years and 4.5% for those aged 16 to 18 years in 2018.[3]

Obesity in children is commonly associated with Left Ventricular (LV) dilatation, early-stage diastolic dysfunction, and LV hypertrophy.[4] LV dysfunction stands as a predominant contributor to morbidity and mortality.[5,6] Speckle-tracking echocardiography (STE) has emerged as a fitting method for early detection of preclinical ventricular dysfunction. However, its utilization remains limited in the pediatric population.[7] The examination outcomes are presented as global longitudinal strain (GLS), with a threshold value of –20.2 in healthy children. A more negative GLS value signifies improved myocardial muscle contraction.[8] This study aimed to assess the LV function of well-nourished, overweight, and obese adolescents through the application of STE, which is anticipated to yield more precise outcomes in the early detection of cardiac remodeling in obese adolescents.

Methods

This study was a descriptive analytical study to compare GLS across various adolescent nutritional statuses. The group of obese, overweight and well-nourished adolescents were obtained through a survey conducted in five high schools near Dr. Hasan Sadikin General Hospital Bandung, Indonesia. The study was conducted from June and August 2023, recruiting 60 students aged 15 to 18 years, selected by simple random sampling. The exclusion criteria encompassed students with pre-existing conditions such as hypertension, diabetes mellitus, systemic lupus erythematosus, nephrotic syndrome, or other ailments necessitating prolonged corticosteroid treatment. Likewise, participants taking medications impacting heart function, such as lipid-lowering drugs, anticoagulants, and antihypertensives, were also excluded. Additionally, those with congenital or acquired heart diseases, individuals of short stature, and those yielding poor echocardiography windows due to obesity or a history of pulmonary tuberculosis were excluded from the study.

Enrolled participants were randomly divided into three groups, well-nourished, overweight, and obese, each containing 20 individuals. This study was approved by The Ethics Committee of the Faculty of Medicine, Universitas Padjadjaran (Number 698/UN6.KEP/EC/2023), and received research permission from Dr. Hasan Sadikin Hospital, Bandung. The study was conducted in accordance with the Declaration of Helsinki.

The research commenced by gathering initial subject data through comprehensive health screenings. These screenings encompassed the measurement of weight and height using a SECA scales and stadiometers. Furthermore, the measurement of blood pressure, oxygen saturation , heart rate and physical examinations, all carried out on the school premises. Subsequently, upon obtaining appropriate consent, parents endorsed informed consent forms. Following this, transthoracic echocardiography examination (Philips CVx) was conducted by a paediatric cardiologist consultant at the Diagnostic and Cardiac Center of Dr. Hasan Sadikin Hospital Bandung. This conventional echocardiographic measurements adhered to the American Society of Echocardiography (ASE) guidelines and encompassed parameters such as ejection fraction (EF), fractional shortening (FS), left ventricular diastolic function (including peak E, peak A, E/A ratio, isovolumetric relaxation time (IVRT), deceleration time (DT), E velocity, A velocity, and S' wave), as well as cardiac dimensions.[9] For speckle-tracking echocardiography (STE), three apical views, such asapical 4 chambers, 2 chambers, and 3 chambers were acquired. These views yielded the global longitudinal strain (GLS) values.[8]

Categorical variables, such as gender and heart rate (classified as normal, tachycardia, and bradycardia), were presented as numbers and percentages. On the other hand, numerical data encompassing demographic and clinical attributes, along with echocardiographic parameters, were depicted using either the mean and standard deviation (SD) or the median and interquartile range (IQR), depending on the normality of data's distribution. To assess differences between groups, the Chi-Square test was applied for categorical variables such as age and the number of subjects with a specific heart rate, while the One-Way ANOVA was employed for numerical data. Alternatively, the Kruskall Wallis test was used as a substitute when required. All statistical analyses were conducted using SPSS version 25.0 for Windows, with a significance level defined at a p value of <0.05

Results

Initially, 63 students fulfilled the inclusion criteria and were asked to undergo echocardiography examination. Two subjects were excluded for being absent during the examination. One subject was excluded due to a poor echocardiographic window and this subject was obese and had a history of pulmonary tuberculosis. In total, data from 60 subjects was then incorporated into the final analysis, consisting of 65% male with mean age 16.4 (±0.6 SD) years in well-nourished (n=20) and obese group (n=20), and 16.5 (±0.6 SD) in overweight group (n=20). The well-nourished group exhibited a significantly lower body weight (56.1±7.2 kg), compared to the overweight (70.5±4.4 kg) and obese (90.5±13.2 kg) (p<0.001).

Mild valve abnormalities were detected in 5 subjects (8.3%). based on the results of conventional echocardiography, the obese

Table 1 Characteristics of Adolescents Aged 15–18 Years in the Study (n=60)

Variables	Well-nourished (n=20)	Overweight (n=20)	Obese (n=20)	p-value
Age (years), mean ± SD	16.4 ± 0.6	16.5 ± 0.6	16.4 ± 0.6	0.844
Gender, n (%)				1.000
Male	13 (65.0)	13 (65.0)	13 (65.0)	
Female	7 (35.0)	7 (35.0)	7 (35.0)	
Body weight (kg), mean ± SD	56.1 ± 7.2	70.5 ± 4.4	90.5 ± 13.2	<0.001*
Body height (cm), mean ± SD	165 ± 7	164 ± 6	166 ± 9	0.640
BMI (kg/m^2), mean ± SD	20.5 ± 1.8	26.3 ± 1.5	33.0 ± 3.6	<0.001*
Blood pressure, median (min–max)				
Systolic (mmHg)	110 (100–120)	120 (110–120)	110 (110–120)	0.282
Diastolic (mmHg)	70 (70–80)	70 (70–80)	75 (60–80)	0.224
Heart rate, n (%)				–
Normal (60–100 beats/min)	20 (100.0)	20 (100.0)	20 (100.0)	

Note: Values are presented as mean ± SD or median (min–max) unless otherwise stated. Statistically significant at p<0.05

group had a good systolic function, as shown in EF (66.9%) and FS (36.81%) and diastolic function parameters (encompassing mean E/A ratio, IVRT, DT, E velocity, A velocity, and S' wave) did not reveal significant differences between groups. The obese group showed a significant difference in elevated left ventricular posterior wall thickness both at end diastole (LVPWD) and systole (LVPWS) compared to the other groups (p=0.014 and p=0.031, respectively). Additionally, the obese group exhibited larger LV and right ventricular (RV) basal volumes compared with other groups (p<0.001 and p=0.040, respectively). During the 2DSTE examination, the obese group exhibited a significantly lower mean LV GLS compared to the overweight and well-nourished groups (−20.0±1.9 vs. −22.3±1.4 vs. −22.7±1.9, respectively; p<0.001) (Table 2).

Discussion

To our knowledge, this is the first study in Indonesia to assess LV function in obese adolescents using the STE method, compared with overweight and well-nourished group.

Obesity is recognized to impact multiple organ systems, including the cardiovascular system. This study found augmented LV wall thickness, as indicated by elevated LVPWD and LVPWS, along with enlarged basal LV and RV volumes in obese children. These findings align with a study showing that a group of 13-year-old children with a BMI ≥20 kg/m^2 exhibited significantly greater LVPW compared with those with a BMI <20 kg/m^2 (0.70±0.01 cm vs. 0.64±0.10 cm; p<0.01).[10] Similar observations were also recorded in a group of obese paediatric patients aged 6–15 years who displayed higher LVPWD compared to the control group (9±1 mm vs. 7±2 mm; p<0.0001).[11] The observed increases in cardiac wall thickness and volume might be attributed to the presence of obesity-related factors, such as accumulation of adipose tissue, lean mass, and blood volume leading to heightened cardiac preload; increased arterial stiffness and resistance contributing to elevated cardiac afterload; anabolic effects induced by hyperinsulinemia; release of adipocytokines; and activation of the renin-angiotensin-aldosterone system (RAS), which collectively foster vascular dysfunction and cardiac remodelling.[12–15]

Obesity has the potential to induce systolic and diastolic dysfunction. The duration of obesity is considered a major determinant of developing systolic dysfunction.[12] Cardiac profiles of obese children often show a decreased LVEF.[13] However, interestingly, this study did not show a reduction in LVEF. Previous studies have found that obese children often show normal LV systolic function, as measured by FS or EF.[7,16] Changes in diastolic function in obese adults often emerge before changes in systolic function, although this trend is less pronounced in paediatric patients.[14] In concordance with the pattern observed in systolic function, this study did not reveal significant differences in diastolic function parameters between obese and non-obese children. Another study has also reported that the majority of parameters employed to assess LV and RV diastolic function yield comparable values between obese and non-obese children.[17] These result are influenced by the fact that obese patients, especially when volume overload, may show

Table 2 Echocardiographic Characteristics of Adolescents Aged 15–18 Years (n=60)

Parameter	Well-nourished (n = 20) Mean ± SD	Overweight (n = 20) Mean ± SD	Obese (n = 20) Mean ± SD	p-value
Conventional LV systolic function				
EF (%)	66.13 ± 5.64	66.72 ± 6.33	66.69 ± 5.55	0.937
FS (%)	36.56 ± 4.27	37.13 ± 4.77	36.81 ± 4.10	0.919
Conventional LV diastolic function				
Peak E (cm/s)	1.02 ± 0.25	0.95 ± 0.28	0.99 ± 0.17	0.711
Peak A (cm/s)	0.51 ± 0.09	0.55 ± 0.11	0.54 ± 0.10	0.291
E/A ratio	1.94 ± 0.37	1.82 ± 0.38	1.87 ± 0.42	0.621
IVRT (ms)	62.95 ± 7.55	64.55 ± 7.67	63.40 ± 7.49	0.789
DT (ms)	155.2 ± 21.9	168.0 ± 20.8	155.5 ± 22.1	0.113
E′ lateral (cm/s)	18.1 ± 2.8	19.1 ± 3.8	16.7 ± 3.5	0.087
A′ lateral (cm/s)	6.2 ± 1.6	6.9 ± 2.0	6.6 ± 1.6	0.435
S′ lateral (cm/s)	14.9 ± 1.73	10.2 ± 1.7	10.1 ± 2.0	0.230
E′ septal (cm/s)	12.1 ± 2.0	12.1 ± 1.7	11.6 ± 2.1	0.647
A′ septal (cm/s)	4.9 ± 1.1	5.5 ± 1.3	5.8 ± 1.3	0.053
S′ septal (cm/s)	7.9 ± 1.2	8.1 ± 1.2	7.6 ± 1.1	0.324
E′ free wall (cm/s)	15.0 ± 3.2	13.4 ± 2.8	13.2 ± 2.5	0.091
A′ free wall (cm/s)	8.0 ± 2.2	10.1 ± 2.7	9.7 ± 3.6	0.055
S′ free wall (cm/s)	13.4 ± 2.0	13.7 ± 1.9	12.9 ± 2.0	0.437
Cardiac dimensions				
LV mass index	77.0 ± 12.3	76.6 ± 11.0	73.0 ± 10.2	0.466
LVPWd (mm)	8.0 ± 1.0	8.5 ± 1.1	9.0 ± 1.0	0.014*
LVPWs (mm)	13.3 ± 1.3	13.9 ± 1.4	14.5 ± 1.6	0.031*
IVSd (mm)	8.5 ± 1.1	8.8 ± 0.8	9.1 ± 0.8	0.087
IVSs (mm)	12.3 ± 2.7	12.6 ± 1.8	13.1 ± 1.1	0.411
LVEDD (mm)	45.4 ± 4.7	46.6 ± 2.6	47.1 ± 4.5	0.416
LVESD (mm)	30.2 ± 4.9	29.1 ± 2.8	29.8 ± 4.1	0.721
LA/Ao ratio	1.4 ± 0.1	1.3 ± 0.1	2.1 ± 3.3	0.382
LA volume (mL)	17.2 ± 4.8	14.7 ± 3.8	16.0 ± 3.6	0.168
RV basal (mm)	31.0 ± 2.8	31.3 ± 3.6	33.8 ± 4.5	0.040*
LV basal (mm)	34.5 ± 4.0	37.0 ± 3.0	41.1 ± 4.4	<0.001*
RV/LV basal ratio	0.91 ± 0.14	0.85 ± 0.09	0.83 ± 0.13	0.084
2D Speckle-tracking echocardiography				
GLS LV (%)	−22.7 ± 1.9	−22.3 ± 1.4	−20.0 ± 1.9	<0.001*

Note: Statistically significant at p<0.05. EF= ejection fraction; FS= fractional shortening; IVRT= isovolumetric relaxation time; DT= deceleration time; LV= left ventricle; LVPWd/LVPWs= left ventricular posterior wall (diastolic/systolic); IVSd/IVSs= interventricular septum (diastolic/systolic); LVEDD/LVESD= left ventricular end-diastolic/systolic diameter; LA= left atrium; Ao= aorta; RV= right ventricle; GLS= global longitudinal strain.

variable diastolic function values. The normal increase in left atrial pressure induced by intravascular volume could potentially conceal early-phase changes associated with abnormal diastolic relaxation.[17] This finding suggests that further studies, with longer follow-up periods, may be important to adequately track potential changes in systolic and diastolic function that may emerge at later stages in this patient population.

Myocardial deformation imaging, including strain and strain rate, has attracted attention for its high sensitivity in detecting early changes in myocardial mechanics.[18] In this study, LV GLS showed a decreasing trend with increasing patient BMI, reaching its lowest point in the obese group. It is noteworthy that this group showed LVEF values that were relatively comparable to those of the control group. This finding is in line with a study that observed lower LV GLS values in obese children compared to non-obese children.[19] Another study has reported similar results, with obese patients having lower GLS LV values compared to non-obese patients.[20] A study documented a 16.3% decreased in LV GLS among obese adolescents compared to non-obese adolescents.[21] In another study, mid and apical regional GLS and LS values measured by 2D STE correlated significantly with the

BMI z-score.[22] Collectively, these findings demonstrate a consistent association between obesity and decreased LV GLS, highlighting the potential of myocardial deformation imaging to identify early changes in myocardial function in obesity.

The observations made in this study appeared to be related to the pressure overload and a sustained hypertrophic response associated with obesity. Modifications in tissue deformation characteristics may also coincide with structural changes in the myocardium, possibly due to intramyocardial fat accumulation. In this study, obese subjects demonstrated reduced LV GLS as determined by STE, while their systolic function remained within the normal range on conventional echocardiography. This interesting differences in LV GLS suggest that myocardial deformation parameters assessed through 2DSTE may indicate early stages of myocardial dysfunction that may not be visible on conventional echocardiography, particularly when focusing on LVEF. This highlights STE's increased sensitivity in detecting subtle myocardial abnormalities associated with obesity, potentially providing insights into cardiac function that might otherwise gone undetected.[11,20]

Several limitations must be acknowledged inherent in this study that may influence the interpretation and generalization of the findings. Future long-term investigations may provide insights into the causal pathways and mechanisms underlying the observed associations. Laboratory examinations were not carried out in this study. Factors such as lipid profiles, blood glucose levels, and insulin concentrations can independently influence cardiac function, regardless of weight status. Lack of information raises the possibility of confounding factors that were not taken into account in the analysis. The sample size in this study is relatively small compared to previous studies, potentially affecting the study's statistical power and generalizability.[19–22] This study involved only 5 high schools in Bandung, Indonesia, which may result in a low level of external validity.

In conclusion, LV function, as measured by STE is lower in obese adolescents than in overweight and well-nourished adolescents. The use of LV GLS parameters derived from 2D STE allows detection of subclinical myocardial dysfunction, even in cases where conventional echocardiography shows normal systolic function, particularly of the LVEF. These findings highlight the importance of early cardiovascular screening in overweight and obese adolescents, emphasizing the need for preventive measures such as maintaining a healthy lifestyle through balanced nutrition and regular physical activity. Detecting early signs of myocardial dysfunction can help mitigate long-term cardiovascular risks, including hypertension, heart failure, and other aging-related diseases. Integrating cardiovascular monitoring with lifestyle interventions may improve heart health and overall wellness from adolescence into adulthood.

Authors' Contributions

RDF contributed to study design, field data collection, data analysis, and manuscript preparation; TH supervised the research, provided conceptual input, and contributed to manuscript preparation; SER, RBK, and PRA provided expert input in pediatric cardiology and echocardiography and contributed to manuscript preparation; DDLH provided additional research input and manuscript review; DAG provided expert input in pediatric nutrition and contributed to manuscript review.

Conflict of Interest

The authors declare no conflicts of interest.

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Generative AI Disclosure Statement

The authors confirm that no generative AI tools were used in the preparation of this manuscript.

References

1. Lindberg L, Danielsson P, Persson M, Marcus C, Hagman. Association of childhood obesity with risk of early all-cause and cause-specific mortality: a swedish prospective cohort study. PLoS Med. 2020;17(3):1–14. doi: 10.1371/journal.pmed.1003078.
2. World Health Organization. Obesity and overweight. WHO [Internet]. 2021 [cited 2022 May 12]. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
3. Ministry of Health, Republic of Indonesia. Laporan Provinsi Jawa Barat, Riskesdas 2018. Jakarta: Lembaga Penerbit Badan

Penelitian dan Pengembangan Kesehatan; 2019.
4. Zhang C, Deng Y, Liu Y, Xu Y, Liu Y, Zhang L, et al. Preclinical cardiovascular changes in children with obesity: a real-time 3-dimensional speckle tracking imaging study. PLoS One. 2018;13(10):1–14. doi: 10.1371/journal.pone.0205177.
5. Binnetoğlu FK, Yıldırım Ş, Topaloğlu N, Tekin M, Kaymaz N, Aylanç H, et al. Early detection of myocardial deformation by 2D speckle tracking echocardiography in normotensive obese children and adolescents. Anadolu Kardiyol Derg. 2015;15(2):151–7. doi: 10.5152/akd.2014.5189.
6. Ayer J, Charakida M, Deanfield JE, Celermajer DS. Lifetime risk: childhood obesity and cardiovascular risk. Eur Heart J. 2015;36(22):1371–6. doi: 10.1093/eurheartj/ehv089.
7. Barbosa JA, Mota CC, Simões E Silva AC, Nunes Mdo C, Barbosa MM. Assessing pre-clinical ventricular dysfunction in obese children and adolescents: the value of speckle tracking imaging. Eur Heart J Cardiovasc Imaging. 2013;14(9):882–9. doi: 10.1093/ehjci/jes294.
8. Levy PT, Machefsky A, Sanchez AA, Patel MD, Rogal S, Fowler S, et al. Reference ranges of left ventricular strain measures by two-dimensional speckle-tracking echocardiography in children: a systematic review and meta-analysis. J Am Soc Echocardiogr. 2016;29(3):209–25. doi: 10.1016/j.echo.2015.11.016.
9. Lopez L, Colan SD, Frommelt PC, Ensing GJ, Kendall K, Younoszai AK, et al. Recommendations for quantification methods during the performance of a pediatric echocardiogram: a report from the pediatric measurements writing group of the american society of echocardiography pediatric and congenital heart sisease council. J Am Soc Echocardiogr. 2010;23(5):465–95. doi: 10.1016/j.echo.2010.03.019.
10. Sivanandam S, Sinaiko AR, Jacobs DR, Steffen L, Moran A, Steinberger J. Relation of increase in adiposity to increase in left ventricular mass from childhood to young adulthood. Am J Cardiol. 2006;98(3):411–5. doi: 10.1016/j.amjcard.2006.02.044.
11. Di Salvo G, Pacileo G, Del Giudice EM, Natale F, Limongelli G, Verrengia M, et al. Abnormal myocardial deformation properties in obese, non-hypertensive children: An ambulatory blood pressure monitoring, standard echocardiographic, and strain rate imaging study. Eur Heart J. 2006;27(22):2689–95. doi: 10.1093/eurheartj/ehl163
12. Cote AT, Harris KC, Panagiotopoulos C, Panagiotopoulos C, Sandor GG, Devlin AM. Childhood obesity and cardiovascular dysfunction. J Am Coll Cardiol. 2013;62(15):1309–19. doi: 10.1016/j.jacc.2013.07.042.
13. Kumar TA, Pande V, Agarkhedkar S, Surana M. Cardiac functions & lipid profile in obese children & adolescents. VIMS Health Science Journal. 2020;7(1):13–6. doi: 10.46858/vimshsj.7104.
14. Sanchez AA, Singh GK. Early ventricular remodeling and dysfunction in obese children and adolescents. Curr Treat Options Cardiovasc Med. 2014;16(10):1–10. doi: 10.1007/s11936-014-0340-3.
15. Koopman LP, Mertens LL. Impact of childhood obesity on cardiac structure and function. Curr Treat Options Cardiovasc Med. 2014;16(11):1–20. doi: 10.1007/s11936-014-0345-y.
16. Mercea D, Ianos R, Pop C, Lazar AL, Sitar-Tăut A, Orășan O, et al. The impact of obesity on left ventricular hypertrophy and diastolic function in caucasian Children. Metab Syndr Relat Disord. 2021;19(4):218–24. doi:10.1089/met.2020.0056
17. Thomas L, Marwick TH, Popescu BA, Donal E, Badano LP. Left atrial structure and function, and left ventricular diastolic dysfunction. Journal of the American College of Cardiology. 2019;73(15):1961–77. doi:10.1016/j.jacc.2019.01.059.
18. Ebada MH, Yaseen R, Abdelazez W, Alkersh A. Effects of isolated obesity on left ventricular function: a longitudinal strain imaging study. Menoufia Med J. 2014;27(1):130. doi: 10.4103/1110-2098.132785
19. Singh GK, Vitola BE, Holland MR, Sekarski T, Patterson BW, Magkos F, et al. Alterations in ventricular structure and function in obese adolescents with nonalcoholic fatty liver disease. J Pediatr. 2013;162(6):1160–8.e1. doi: 10.1016/j.jpeds.2012.11.024
20. Šileikienė R, Adamonytė K, Ziutelienė A, Ramanauskienė E, Vaškelytė JJ. Atrial and ventricular structural and functional alterations in obese children. Med. 2021;57(6):1–12. doi: 10.3390/medicina57060562
21. Ingul CB, Tjonna AE, Stolen TO, Stoylen A, Wisloff U. Impaired cardiac function among obese adolescents. Arch Pediatr

Adolesc Med. 2010;164(9):852–9. doi: 10.1001/archpediatrics.2010.158.

22. Paysal J, Merlin E, Rochette E, Terral D, Nottin S. Impact of BMI z-score on left ventricular mechanics in adolescent girls. Front Pediatr. 2023;11(July):1–9. doi:10.3389/fped.2023.1165851.