Cardiology in the Young

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Left ventricle mass index in paediatric intensive care unit acquired hypertension

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Original Article

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Abstract

Background: Hypertension acquired in paediatric critical patients is a recognised challenge, with variable reported frequency. Pain, agitation, and/or medications such as beta stimulants and corticosteroids are well-known risk factors. Sympathomimetics in septic patients can cause high blood pressure, especially with unobserved haemodynamic monitors. Beyond haemodynamic factors, several endocrinal-metabolic factors – including catecholamines, insulin, renin, angiotensin, the aldosterone system, and sodium consumption – may contribute to the left ventricular growth. It is well known that the sympathetic tone has a trophic effect on the heart muscle. *Method:* A prospective cohort study was conducted during the year 2021. The children were divided into two groups: those who were critically ill with paediatric intensive care unit-acquired hypertension (n = 59) and those without paediatric intensive care unit-acquired hypertension (n = 62). We used the American Academy of Pediatrics' 2017 definition of hypertension to diagnose paediatric intensive care unit-acquired hypertension. Measurement of cardiac output and systemic vascular resistance was performed by cardiometry. Left ventricular myocardial performance and left ventricular mass index were measured by bedside echocardiography at the onset of hypertension diagnosis. *Results:* Critically ill children with acquired hypertension had a higher cardiac index ($p = 0.0001$), systemic vascular resistance index (<0.0001), myocardial performance (0.037), and left ventricular mass index (0.009). The longer duration of stay observed in the hypertension group had no observable effect on mortality (<0.0001). *Conclusion:* Both myocardial performance and left ventricle mass index increased in critically ill children with paediatric intensive care unit-acquired hypertension.

Hypertension acquired in paediatric critical patients is a recognised challenge, with variable reported frequency. Pain, agitation, and/or medications such as beta stimulants and corticosteroids are risk factors. Moreover, using sympathomimetics in shocked patients can cause acquired high blood pressure.[1] Cardiac output and systemic vascular resistance are multiplied together to determine blood pressure. The development of hypertension may, in theory, be caused by increased myocardial contractility and excessive adrenergic stimulation, which is the most likely aetiology.[2] Treatment options are influenced by the pathophysiology of hypertension and whether systemic vascular resistance or cardiac output is the primary mechanism. Beta-blockers and calcium channel blockers, for example, have different mechanisms of action that can be useful or inappropriate depending on the unique pathophysiology of each patient.

Theoretically, an adaptation mechanism for elevated afterload is growth in left ventricular wall mass and thickness. Adult studies have revealed a poor or non-existent relationship between blood pressure and left ventricular wall mass.[4-6] This strengthens the impact of non-haemodynamic elements on left ventricular wall mass development. These include insulin, the renin-angiotensin-aldosterone system, sodium consumption, and growth factors such as catecholamines.[7] It is well known that sympathetic tone has a trophic effect on the heart muscle.[8-10] According to multicentre research, in children with newly diagnosed hypertension, abnormal left ventricular mass index occurs often, and neither the severity of hypertension nor the abnormal findings are associated with the development of left ventricular hypertrophy.[11] Ventricular wall stress occurs in hypertensive children and eventually results in left ventricular hypertrophy or remodelling.[12] The objective of this study was to evaluate the pathophysiology of acquired hypertension among paediatric critical patients in terms of cardiac index and systemic vascular resistance, as well as its influence on myocardial performance and left ventricular mass index, with the aim of guiding the choice of antihypertensive drugs. The secondary objective was to investigate whether paediatric intensive care unit-acquired hypertension was related to mortality or long hospital stay.

Method

We conducted a prospective observational cohort study on 121 critically ill infants and children aged from 1 month to 13 years who were admitted to the paediatric intensive care unit of Cairo University Children's Hospital in 2021. The study received ethical committee approval and an Institutional Review Board number.

The children were divided into two groups: those critically ill with paediatric intensive care unit-acquired hypertension (n = 59) and those without paediatric intensive care unit-acquired hypertension (n = 62). We excluded patients known to have systemic hypertension, chronic kidney disease, aortic coarctation, or steroid therapy before admission, as well as patients who received systemic steroids during their paediatric intensive care unit stay. The following data were recorded on admission to the paediatric intensive care unit: age, sex, weight, and main system failure at admission. Vital signs including heart rate, respiratory rate, temperature, and blood pressure were taken for patients on inotropic support, and a vasoactive inotropic score was calculated,[13] as was patients' cumulative fluid balance (positive balance ≥10% of body weight).

Haemodynamic parameters, including cardiac index and systemic vascular resistance index, were recorded at the time of hypertension diagnosis using electrical cardiometry. The myocardial performance index of the left ventricle and left ventricular mass index were measured using transthoracic echocardiography. Urine output and serum creatinine were measured to estimate the burden of acute kidney injury. Days of mechanical ventilation (for ventilated patients) and paediatric sedation state scale were also recorded. Length of hospital stay and mortality risk were measured using the paediatric sequential organ failure assessment score. The adequacy of sedation among ventilated children was assessed using the COMFORT scale.[14] Cardiometry and echocardiography data collection was performed after the withdrawal of all inotropes and vasopressors to avoid effects on systemic vascular resistance index and cardiac output.

Blood pressure was measured non-invasively using automated oscillometric cuff readings from bedside paediatric intensive care unit monitors (Vismo Nihon Kohden). When hypertension was diagnosed, a verification measurement was conducted using a portable mercury device. According to one meta-analysis, automatic blood pressure monitors have strong measurement validity when compared with the mercury column.[15] Thus, these can be safely used in blood pressure measurements of children and adolescents in clinical and epidemiological studies.

Appropriate cuff size was used to avoid under- or over-estimation of readings, ensuring bladder length of 80–100% of arm circumference and bladder width of at least 40%. Measurements were taken using the right arm, which is the standard site of measurement. We used the new definition of hypertension adapted in 2017 by the American Academy of Pediatrics. For diagnosis of hypertension for patients aged under 13 years, we used a cut-off of blood pressure levels ≥95th percentile for age, sex, and height; for patients 13 and older, we used a fixed cut-off of ≥130/80 mmHg independent of age, sex, and height.

In the paediatric intensive care unit, three new systolic and/or diastolic readings events above 95th percentiles over 24 hours were required to diagnose acquired hypertension. The blood pressure levels were interpreted based on gender, age, and height and according to the American Academy of Pediatrics' 2017 definition.

Electrical cardiometry (Aesculon; Osypka Medical, Berlin, Germany) was applied to ascertain the haemodynamic parameters of cardiac output, cardiac index, heart rate, and systemic vascular resistance index. Electrical cardiometry was set to record measurements at 1-minute intervals and to define five continuous and qualified signals (i.e., signal quality index, provided by Aesculon, ≥70%) over the duration of 5 minutes.

In terms of echocardiography parameters, the myocardial performance index of the left ventricle was measured and analysed by a paediatric cardiologist. Studies were done for cases of a supine or left lateral position using a Vivid S 5 series system with a probe of 3 or 6 MHz, depending on the patient's age. The myocardial performance index of the left ventricle was measured by applying a tissue Doppler to the lateral mitral annulus. A pulsed Doppler sample volume was placed at the tips of the mitral leaflets, and the recorded transmitral velocity pattern was composed of two principal deflections used to measure ventricular relaxation: the E wave, occurring during the rapid filling phase, and the lower A wave, arising from atrial contraction. Diastolic dysfunction measured by the E/A wave ratio according to[16] left ventricular diastolic dysfunction was present if: E/A ratio <1, The isovolumic relaxation time left ventricular mass index >100 m/s, and diastolic time >220 m/s (impaired relaxation pattern); pseudo-normalization resembling the normal configuration with respect to the mitral inflow but with low diastolic time and the restrictive pattern is present when E/A ratio >2, The isovolumic relaxation time <70 m/s, and diastolic time <150 m/s.

The following calculations were used to measure myocardial performance index of the left ventricle, left ventricular wall mass, and left ventricular mass index:

Myocardial performance index of the left ventricle	(IVCT + IVRT)/ ET
Left ventricular mass index	Left ventricular wall mass/body surface area
Left ventricular wall mass	0.8{1.04[([LVEDD + IVSd +PWd]3 - LVEDD3)]} + 0.6.

LVEDD = left ventricle end-diastolic dimension (mm), IVSd = septal thickness at end-diastole (mm), and PWD = posterior wall thickness at end-diastole (mm).

For each patient, the mean myocardial performance index value was calculated by dividing the sum of the two values (septum and lateral) by two. Left ventricular mass index was calculated by two-dimensional transthoracic echocardiography-guided M-mode measurements using the following equations: where LVEDD = left ventricle end-diastolic dimension (mm), IVSd = septal thickness at end-diastole (mm), and PWD = posterior wall thickness at end-diastole (mm).[17]

Studies were performed on 10 healthy children before the start of the present study to evaluate inter-observer and intra-observer reproducibility. The paediatric cardiologist and the intensivist were blinded to each other's results and alternately performed two measurements on each patient. Intra-observer reproducibility was assessed between the observations by the same observer. The intensivist performed the echocardiography, and all the stored images were reviewed by the expert paediatric cardiologist.

Statistical methods

Statistics were used to describe patient data when appropriate, including the range, mean, standard deviation, median,

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Table 1. Demographic and clinical variables between PICU-acquired hypertension and no hypertension group.

Variable	Acquired hypertension (N = 59)	No hypertension (N = 63)	P-value
Age (mo.) median (IQR)	8 (4 to 29)	12 (5 to 39)	0.428
Weight (kg) median (IQR)	6.5 (4.4 to 12.0)	9 (5 to 16)	0.335
BMI	16.4 (13.5 to 20.4)	15.9 (12.6 to 20.2)	0.666
Males	33/59 (55.9%)	30/63 (47.6%)	
Females	26/59 (44.1%)	33/63 (52.4%)	
Diagnosis, n/N (%)			
Respiratory	20/59 (33.9%)	23/63 (36.5%)	0.763
Cardiac	7/59 (11.9%)	10/63 (15.9%)	0.523
VSD and pneumonia	7-Mar	10-May	
Corrected congenital heart and pneumonia	7-Apr	10-May	
Neurological	10/59 (13.6%)	10/63 (11.1%)	0.681
Diabetic ketoacidosis	3/59 (5.1%)	7/63 (11.1%)	0.326
Haematological	2/59 (3.4%)	3/63 (4.8%)	>0.999
Postoperative	5/59 (8.5%)	2/63 (3.2%)	0.262
Poisoning	4/59 (6.8%)	1/63 (1.6%)	0.196
Others	8/59 (13.6%)	7/63 (11.1%)	0.681
pSOFA, median (IQR) on admission	14 (10 to 17)	12 (8 to 16)	0.119
HR mean (SD)	116 (11)	113 (17)	0.253
VIS, median (IQR) on admission	27.5 (20 to 50)	25 (20 to 37.5)	0.197
COMFORT score, median (IQR)	29 (25 to 34)	28 (24 to 32)	0.209
CVP(mmHg) median (IQR) on admission	7 (6 to 8)	6 (5 to 7)	0.073
Fluid balance, n/N (%)			
<10% of body BW	42 (71.2%)	50 (79.4%)	0.294‡
≥10% of body BW	17 (28.8%)	13 (20.6%)	
On admission			
On admission			
KDIGO AKI stage,			
n/N (%)	46/59 (78.0%)	55/63 (87.3%)	0.140†
No AKI	10/59 (16.9%)	7/63 (11.1%)	
Stage 1	3/59 (5.1%)	1 (1.6%)	
Stage 2			
Duration of stay in days	9 (7 to 12)	7 (5 to 9)	<0.0001

pSOFA=paediatric sequential organ failure assessment; VIS=vasoactive inotropic score; BMI=body mass index; CVP=central venous pressure; AKI=acute kidney injury; KDIGO=kidney disease improving global outcome.

frequencies (number of instances), and relative frequencies (percentages). When employing independent samples with data that were not normally distributed, the Mann–Whitney U test was used to compare quantitative variables between the research groups. The statistical significance of the difference between the two population means was evaluated using the Student's *t*-test. Comparing categorical data requires a Chi-square test. When the anticipated frequency was less than 5, an exact test was utilised in its place. Statistical significance was defined as a probability value (p) of less than 0.05. All statistical calculations were performed using Microsoft Excel 2016 (Microsoft Corporation, NY, USA) and SPSS (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA) version 15 for Microsoft Windows.

Results

Two groups of critically ill children admitted in 2021 were enrolled in the study: one group included those with paediatric intensive care unit-acquired hypertension (n = 59) while the other group did not have hypertension (n = 63). Both groups' clinical and laboratory characteristics are shown in Table 1. These patients represent 14% of total admissions in 2021.

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Table 2. Difference in haemodynamic parameters between patients with ICU-acquired hypertension and no PICU-acquired hypertension.

Variable median IQR	Cases (N = 59)	Controls (N = 62)	P-value†
CI (l/min/m^2)	4.1 (3.6 to 4.9)	3.7 (3.1 to 4.0)	0.0001
SVRI (dyn/s.cm^5)	1781 (1623 to 1968)	1356 (1278 to 1449)	<0.0001
LVMPI	0.38 (0.34 to 0.42)	0.35 (0.31 to 0.42)	0.037
LVMI (g/m^2)	58 (53 to 64)	55 (48 to 59)	0.009
Diastolic dysfunction			
Nil n/N (%)	43/59 (72.9%)	52/63 (82.5%)	
Grade 1 n/N (%)	14/59 (23.7%)	9/63 (14.3%)	0.283
Grade 2 n/N (%)	2/59 (3.4%)	2/63 (3.2%)	

CI=cardiac index; SVRI=systemic vascular resistance index; LVMPI=left ventricular myocardial performance index; LVMI=left ventricular mass index.

Table 3. Results of multivariable binary logistic regression analysis for predictors of hypertension.

Variable	Coefficient	SE	Wald	P-value	Odds ratio	95% CI
Age (mo.)	0.018	0.019	0.829	0.363	1.018	0.980 to 1.057
Female sex	−0.297	0.379	0.616	0.433	0.743	0.354 to 1.561
Weight (kg)	−0.077	0.067	1.332	0.248	0.926	0.813 to 1.055
Admission diagnosis‡						
Respiratory	0.011	0.478	0.001	0.981	1.012	0.396 to 2.583
Cardiac	−0.893	0.649	1.892	0.169	0.409	0.115 to 1.462
Neurological	−0.255	0.628	0.165	0.685	0.775	0.226 to 2.654
pSOFA	0.118	0.059	3.965	0.046	1.125	1.002 to 1.264

There was no distinction between the two groups regarding age, gender, diagnosis, vasoactive inotropic score, paediatric sequential organ failure assessment score, pain score, fluid balance, or acute kidney injury. As shown in Table 1, the hypertension group had a longer duration of stay than the group with no blood pressure elevation (<0.0001), but there was no difference in mortality.

Haemodynamic parameters and echocardiography of the study group

Critically ill children with paediatric intensive care unit-acquired hypertension had a higher cardiac index (p = 0.0001), systemic vascular resistance index (<0.0001), left ventricular performance (0.037), and left ventricular mass index (0.009) compared to critical children without paediatric intensive care unit-acquired hypertension. Grade 1 diastolic dysfunction was observed more in patients with acquired blood pressure elevation, but with no statistical significance (Table 2).

The multivariate logistic regression analysis showed that the paediatric sequential organ failure assessment score was the only predictor for the development of acquired hypertension (Table 3).

Discussion

The results of our study showed an incidence of paediatric intensive care unit-acquired elevated blood pressure of 14% over a 1-year study period. Data about the prevalence of hypertension in paediatric intensive care units are scant. A prevalence of 25% was reported by Ehrmann et al.,[18] In another study of neonatal hypertension, the prevalence was found to be 4.7% in NICUs.[19]

In our study, the only contributing factor for the development of hypertension in the paediatric intensive care unit was the severity of multiple organ dysfunction, expressed by paediatric sequential organ failure assessment score. This is probably linked to the overactive sympathetic nervous system, which raises the risk of developing hypertension and cardiac remodelling.[20]

The respiratory diagnosis was a predictor of systemic hypertension in the paediatric intensive care unit. Maggiore et al.[21] reported that excessive suction is associated with many adverse effects, including high blood pressure. The dynamic involvement of oxygen sensors found in peripheral tissue, which directly alters the cardiovascular response to the effects of hypoxia, is a different theory. Critical illness is characterised by sympathetic nervous system stimulation that may on some occasions exceed its beneficial effects, which may affect several organ systems. The heart appears to be one organ that is susceptible to sympathetic overshooting.[22] According to Tank et al.,[23] sustained elevation of circulating catecholamines for a prolonged time can also produce pathological conditions, such as cardiac hypertrophy and hypertension. This may explain why children with a longer duration of stay were more susceptible to hypertension.

In this study, critical children with acquired blood pressure elevation had a higher cardiac index and systemic vascular resistance index than the control group. Excess sympathetic stimulation may be a key mechanism in the pathophysiology of that type of hypertension.

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According to Ye Li et al.'s[24] investigation of the pathophysiology of hypertensive children, higher heart rate and cardiac output, rather than increased systemic vascular resistance, are better explanations for systemic hypertension in young patients. Cardiac performance was higher in hypertensive children, as expressed by myocardial performance index of the left ventricle. The isovolumetric contraction time increases because the left ventricle needs more time to overcome high systemic blood pressure to open the aortic valve. Gupta-Malhotra et al.[25] reported that in children with hypertension, myocardial performance index of the left ventricle was associated with increased mean systolic blood pressure.

Higher left ventricular mass index was found in the hypertensive group, a finding that correlates with Lande et al.,[26] who found higher left ventricular mass index in children with transient white coat hypertension. Similar results were also demonstrated by Kavey,[27] who discovered that children and teenagers with systemic hypertension have higher left ventricular mass index.

Based on these results, we suggest that the use of beta-blockers is a suitable pathophysiological option for the treatment of children with paediatric intensive care unit-acquired hypertension.

The duration of stay was longer in the paediatric intensive care unit-acquired hypertension group than the non-hypertension group. According to Tran Cl et al.,[28] about 1% of hospital discharges in the USA are associated with hypertension and with a longer hospital stay. The relation between hypertension and longer hospital stay may be related to those children's higher severity of illness from the start.

Conclusion

Cardiac index, vascular resistance, myocardial performance, and left ventricle mass index increased in critically ill children with paediatric intensive care unit-acquired hypertension. The choice of antihypertensive medication needs to be influenced by each individual patient's haemodynamics.

Limitations

We referenced left ventricular mass in relation to body surface area as most of our patients were not obese; however, indexing left ventricular mass by lean body mass needs to be considered in future studies. The methods used in this study to assess left ventricular dysfunction are limited by the effects of some parameters including left ventricular relaxation and atrial filling pressure. The technique, tissue Doppler imaging, could have also been used for a more accurate evaluation of diastolic dysfunction as the pulsed wave Doppler still needs validation in critical paediatric patients.

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Competing interest. None.

Ethical standards. The study was approved by the Ethical Committee of Cairo University.

References

1. Olgun G, John E. Hypertension in the pediatric intensive care unit. J Pediatr Intensive Care 2016 Jun; 5: 50–58.
2. Salgado DR, Silva E, Vincent JL. Control of hypertension in the critically ill: a pathophysiological approach. Ann. Intensive Care 2013; 3: 17.
3. Daniels SD, Meyer RA, Loggie JMH. Determinants of cardiac involvement in children and adolescents with essential hypertension. Circulation 1990; 82: 1243–1248.
4. de la Sierra A, Coca A, Pare JC, Sanchez M, Valls V, Urbano-Marquez A. Erythrocyte ion fluxes in essential hypertensive patients with left ventricular hypertrophy. Circulation 1993; 88: 1628–1633.
5. Korner PI, Jannings GL. Assessment of prevalence of left ventricular hypertrophy in hypertension. J Hypertens 1998; 16: 715–723.
6. Palatini P, Majahalme S, Amerena J, et al. Determinants of left ventricular structure and mass in young subjects with sympathetic over-activity. The Tecumseh Offspring Study. J Hypertens 2000; 18: 769–775.
7. Yamori Y, Mori C, Nishio T, et al. Cardiac hypertrophy in early hypertension. Am J Cardiol 1979; 44: 964–969.
8. Simpson P. Norepinephrine-stimulated hypertrophy of cultured rat myocardial cells in an alpha 1 adrenergic response. J Clin Invest 1983; 72: 732–738.
9. Ferrara LA, Mancini M, de Simone G, et al. Adrenergic nervous system and left ventricular mass in primary hypertension. Eur Heart J 1989; 10: 1036–1040.
10. Kaypakli O, Gür M, Gözükara M, et al. Association between high-sensitivity troponin T, left ventricular hypertrophy, and myocardial performance index. Herz 2015; 40: 1004–1010.
11. Liu W, Hou C, Hou M, et al. Ultrasonography to detect cardiovascular damage in children with essential hypertension. Cardiovasc Ultrasound 2021; 19: 26.
12. Mclntosh AM, Tong S, Deakyne SJ, Davidson JA, Scott HF. Validation of the vasoactive-inotropic score in pediatric sepsis. Pediatr Crit Care Med 2017; 18: 750–757.
13. Suprawoto DN, Nurhaeni N, Waluyanti FT. Comfort Behavior Scale instrument: validity and reliability test for critically ill pediatric patients in Indonesia. Pediatr Rep 2020; 12: 8690.
14. Araujo-Moura K, Souza LG, Mello GL, et al. Blood pressure measurement in pediatric population: comparison between automated oscillometric devices and mercury sphygmomanometers—a systematic review and meta-analysis. Eur J Pediatr 2022; 181: 9–22. DOI 10.1007/s00431-021-04171-3.
15. Nagueh SF, Smiseth OA, Appleton CP. Recommendations for the evaluation of left ventricular diastolic function by echocardiography: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Eur Heart J Cardiovasc Imaging. 2016; 17: 1321–1360.
16. Mizukoshi K, Takeuchi M, Nagata Y, Addetia K, Lang RM, Akashi YJ, Otsuji Y. Normal values of left ventricular mass index assessed by transthoracic three-dimensional echocardiography. J Am Soc Echocardiogr 2016; 29: 51–61.
17. Ehrmann BJ, Selewski DT, Troost JP, Hieber SM, Gipson DS. Hypertension and health outcomes in the PICU. Pediatr Crit Care Med 2014; 15: 417–427.
18. Balestracci A, Capone MA, Toledo I, Sticotti S. Prevalencia de hipertension arterial en una unidad de cuidados intensivos neonatales [Prevalence of arterial hypertension in a neonatal intensive care unit]. Rev Chil Pediatr 2020; 91: 891–898.
19. Cowburn AS, Macias D, Summers C, Chilvers ER, Johnson RS. Cardiovascular adaptation to hypoxia and the role of peripheral resistance. ELife 2017; 6: e28755.
20. Maggiore SM, Lellouche F, Pignataro C, et al. Decreasing the adverse effects of endotracheal suctioning during mechanical ventilation by changing practice. Respir Care 2013; 58: 1588–1597.
21. Dunser MW, Hasibeder WR. Sympathetic overstimulation during critical illness: adverse effects of adrenergic stress. J Intensive Care Med 2009; 24: 293–316.
22. Tank AW, Lee Wong D. Peripheral and central effects of circulating catecholamines. Compr Physiol 2015 Jan; 5: 1–15.
23. Li Y, Gu H, Sinha MD, Chowienczyk P. Hemodynamic characterization of primary hypertension in children and adolescents. J Am Heart Assoc 2020; 9: e015097.

https://doi.org/10.1017/S1047951123000781 Published online by Cambridge University Press

24. Gupta-Malhotra M, Hamzeh RK, Poffenbarger T, McNiece-Redwine K, Hashmi SS. Myocardial performance index in childhood-onset essential hypertension and white coat hypertension. Am J Hypertens 2016; 29: 379–387.
25. Lande MB, Meagher CC, Fisher SG, Belani P, Wang H, Rashid M. Left the ventricular mass index in children with white coat hypertension. J Pediatr 2008; 153: 50–54.
26. Kavey REW. Left ventricular hypertrophy in hypertensive children and adolescents: predictors and prevalence. Curr Hypertens Rep 2013; 15: 453–457.
27. Tran CL, Ehrmann BJ, Messer KL, et al. Recent trends in healthcare utilization among children and adolescents with hypertension in the United States. Hypertension 2012; 60: 296–302.
28. Brady TM, Fivush B, Flynn JT, Parekh R. Ability of blood pressure to predict left ventricular hypertrophy in children with primary hypertension. J Pediatr 2008; 152: 73–78.
29. Schlaich MP, Kaye DM, Lambert E, Sommerville M, Socratous F, Esler MD. Relation between cardiac sympathetic activity and hypertensive left ventricular hypertrophy. Circulation 2003; 108: 560–565.
30. Dünser MW, Hasibeder WR. Sympathetic overstimulation during critical illness: adverse effects of adrenergic stress. J Intensive Care Med 2009; 24: 293–316. DOI 10.1177/0885066609340519 Epub 2009 Aug 23. Erratum in: J Intensive Care Med.2016 Sep.
31. Tei C, Ling LH, Hodge DO, et al. New index of combined systolic and diastolic myocardial performance: a simple and reproducible measure of cardiac function-a study in normals and dilated cardiomyopathy. J Cardiol. 1995; 26: 357–366.
32. Vlahović A, Popović AD. Procena dijastolne funkcije leve komore Doplerehokardiografijom [Evaluation of left ventricular diastolic function using Doppler echocardiography]. Med Pregl 1999; 52: 13–18, Croatian. PMID: 10352498.
33. Stergiou GS. Accuracy of automated blood pressure measurement in children evidence, issues, and perspectives. Nadia Boubouchairopoulou and Anastasios Kollias. Hypertension 2017; 69: 1000–1006.

https://doi.org/10.1017/S1047951123000781 Published online by Cambridge University Press