https://doi.org/10.35336/VA-1516

RISK SCORE FOR DEVELOPING ARRHYTHMIA-INDUCED CARDIOMYOPATHY IN CHILDREN WITH IDIOPATHIC VENTRICULAR ARRHYTHMIAS BASED ON SINGLE CENTER DATA

K.A.Chueva, O.A.Kofeynikova, D.S.Lebedev, R.B.Tatarskiy, E.S.Vasichkina

Almazov National Medical Research Centre of the MH RF, Russia, Saint-Petersburg, 2 Akkuratova str.

Aim. To develop a predictive model and a clinical risk score for developing arrhythmia-induced cardiomyopathy (AIC) in children with idiopathic ventricular arrhythmias (VA).

Methods. The study included 492 children aged 1 to 17 years with idiopathic VA. In 392 patients demographic, clinical and diagnostic-related variables were evaluated as potential prognostic factors using binary logistic regression. The scores for each predictor were set based on the odds ratio. Validation of the model was carried out on a test group (n=100).

Results. It was found that body surface area ≥ 1,7 m^2 increases the ratio of developing AIC by 4,9 times (1 point), the premature ventricular contraction's coupling interval < 434 ms. - by 3,7 times (1 point), the burden of VA 25-29% - by 8,4 times (2 points), the burden of VA 30-34% - 11,3 times (3 points), the burden of VA ≥ 35% - 17,2 times (4 points). The specificity of the risk score was determined by the ROC curve. A low probability of developing AIC was determined with a score of up to 2 (specificity <48.1%), an average probability was determined with a score 3-4 (specificity 67.5-81.8%), a high probability was determined with a score 5-6, (specificity >95.1%). The AUC of the predictive scale was 0.805±0.037 (95% CI: 0.732-0.878), p<0.001.

The AUC of the of the predictive scale in the test group was 0.893±0.034 (95% CI: 0.827-0.96),p<0.001. The difference in the AUC of the scores in training and test groups was 0.088±0.05. The AUCs were comparable (p=0.078).

Conclusion. In this study we identified independent predictors of IAC in children with idiopathic VA. A clinical risk scale of AIC has been developed based on the obtained predictors. Routine use of the AIC risk scale will lead to personalized monitoring and treatment of each child with idiopathic VA.

Key words: idiopathic; ventricular arrhythmia; ventricular tachycardia; arrhythmia-induced cardiomyopathy; tachycardia-induced cardiomyopathy; prognosis; risk scale; children

Conflict of Interest: none.
Funding: none.
Received: 29.04.2025 **Revision received:** 16.06.2025 **Accepted:** 25.06.2025
Corresponding author: Chueva Ksenia, E-mail: kseniia.chueva@gmail.com

K.A.Chueva - ORCID ID 0000-0002-5027-0565, O.A.Kofeynikova - ORCID ID 0000-0003-4720-9023, D.S.Lebedev - ORCID ID 0000-0001-9948-7303, R.B.Tatarskiy - ORCID ID 0000-0001-6752-3306, E.S.Vasichkina - ORCID ID 0000-0001-7336-4102

The manuscript participated in the competition for the best scientific work of young scientists in clinical and fundamental arrhythmology within the framework of the XI All-Russian Congress of Arrhythmologists.

For citation: Chueva KA, Kofeynikova OA, Lebedev DS, Tatarskiy RB, Vasichkina ES. Risk score for developing arrhythmia-induced cardiomyopathy in children with idiopathic ventricular arrhythmias based on single center data. *Journal of Arrhythmology.* 2025;32(3): 14-20. https://doi.org/10.35336/VA-1516.

Ventricular arrhythmias (VA) are highly prevalent in childhood. According to screening studies, isolated premature ventricular contractions (PVCs) are recorded in approximately half of adolescents [1]. In the vast majority of cases, VA in children are idiopathic and follow a benign course [2-5]. However, long-standing VA may lead to the development of arrhythmia-induced cardiomyopathy (AIC). The incidence of cardiomyopathy associated with idiopathic VA in children does not exceed 20% [6-11].

Despite considerable interest in this issue, only a limited number of studies have been published investigating predictors of AIC in the paediatric population [6, 9, 11]. The main limitations of these studies are small patient cohorts, which result in contradictory findings and preclude their application in clinical practice. Identification of independent predictors and the development of a risk scoring system for AIC would optimise strategies for monitoring and treatment in children with idiopathic VA.

Aim: to develop a prognostic model and a scoring system for assessing the probability of arrhythmia-induced cardiomyopathy in children with idiopathic VA.

METHODS

To achieve this objective, we analysed data from 492 children aged 1 to 17 years with idiopathic VA who underwent evaluation and treatment at the Centre between 2011 and 2025. Exclusion criteria were the presence of structural heart disease, active myocardial inflammation or a history of myocarditis, confirmed channelopathies, and extracardiac causes of VA. The diagnosis of idiopathic VA was made by exclusion following careful history taking and comprehensive cardiological assessment.

All patients underwent clinical and biochemical blood tests including measurement of cardiac-specific enzymes and acute-phase proteins, electrolytes, and thyroid function, as well as standard 12-lead surface electrocardiography (ECG), 24-hour Holter ECG monitoring, and echocardiography. A treadmill exercise test was performed in 403 patients, and cardiac magnetic resonance imaging (MRI) was carried out in 116 patients.

Arrhythmia-induced cardiomyopathy was defined as reduced left ventricular (LV) ejection fraction (EF) and/or LV dilatation after the onset of VA. Cardiac chamber size and myocardial contractility were assessed using standard methodology [12]. Echocardiographic parameters were indexed using the Boston Children's Hospital z-score calculator. LV dilatation was defined as an LV end-diastolic dimension z-score > +2.0. LV ejection fraction was measured using the Teichholz and Simpson methods.

In the overall cohort, 12% (59/492) of children met the criteria for AIC. Of these, 15% (n=9/59) had both LV dilatation and reduced EF, 14% (n=8/59) had dilatation without reduced EF, and 71% (n=42/59) had isolated LV systolic dysfunction.

At the first stage, we searched for predictors of AIC in the training cohort (n=392). To this end, we analysed and compared clinical parameters, medical history, and findings from instrumental examinations in relation to the presence of AIC. The results of this first stage of the study have been published previously [13].

The second stage consisted of constructing a prognostic model and a probability scoring system for AIC using variables identified in the training cohort. The developed scoring system was then validated in a test cohort that included 100 children with idiopathic VA. The size of the test cohort was determined based on an 80% to 20% split between the training and test groups. Patients in the training and test cohorts were comparable in terms of age, anthropometric parameters, and sex. The clinical characteristics of the patients are presented in Table 1.

Statistical analysis

The analysis was performed using IBM SPSS Statistics v.26. At the initial stage, in the training cohort, potential predictors of AIC were identified using univariate logistic regression. To address potential multicollinearity among predictors, a

Table 1.

Clinical characteristics of patients in the training and test cohorts

Variable	Training cohort (n=392)	Test cohort (n=100)	p
Age, years, Me [IQR]	13.0 [9.0; 15.0]	12.0 [9.0; 15.0]	0.069
BSA, m², Me [IQR]	1.48 [1.12; 1.72]	1.55 [1.37; 1.68]	0.053
Male sex, n (%)	222 (56.6)	64 (58.1)	0.183
Presence of VT, n (%)	214 (54.6)	64 (64)	0.090
VA burden, %, Me [IQR]	25.2 [16.2; 36.4]	24.0 [15.0; 36.5]	0.548
AIC, n (%)	35 (8.9)	24 (24.0)	-
Reduced EF and LV dilatation, n (%)	6 (17.1)	3 (12.5)	0.917
LV dilatation only, n (%)	5 (14.3)	3 (12.5)	
Reduced EF only, n (%)	24 (68.6)	18 (75)	

Note: throughout the text, p denotes the level of statistical significance; BSA - body surface area; VT - ventricular tachycardia; VA - ventricular arrhythmia; AIC - arrhythmia-induced cardiomyopathy; LV - left ventricle; EF - ejection fraction.

Table 2.

Characteristics of the association between model predictors and the probability of arrhythmia-induced cardiomyopathy in children

Predictors	Unadjusted		Adjusted	
	OR; 95% CI	p	OR; 95% CI	p
BSA	4.531; 1.774-11.576	0.002	5.742; 2.161-15.254	<0.001
Age	1.124; 1.015-1.245	0.025		
POS	2.455; 1.118-5.388	0.025		
Presence of VT	3.677; 1.566-8.637	0.003		
VA burden	1.049; 1.026-1.072	<0.001	1.04; 1.014-1.067	0.003
Paired PVCs	3.698; 1.309-10.445	0.014		
Mean PEI	0.956; 0.909-0.990	0.021	0.997; 0.996-0.999	0.006

Note: throughout the text, OR - odds ratio; CI - confidence interval; BSA - body surface area; POS - presence of symptoms; PVC - premature ventricular contraction; PEI - pre-ectopic interval.

Table 3.

Scoring system for the probability of arrhythmia-induced cardiomyopathy in children

Predictors	Change in Probability in the Presence of the Predictor		p	Points
	AOR	95% CI		
VA burden 25-29%	8.434	1.291-55.106	0.026	2
VA burden 30-34%	11.276	1.686-75.416	0.012	3
VA burden ≥35%	17.15	3.603-81.639	<0.001	4
Mean PEI ≤434 ms	3.742	1.304-10.738	0.014	1
BSA ≥1.7 m²	4.945	1.766-13.461	0.002	1

Note: AOR - adjusted odds ratio. Probability of arrhythmia-induced cardiomyopathy was classified as low (0-2 points), intermediate (3-4 points), and high (5-6 points).

correlation matrix was constructed. Spearman's correlation coefficient was used as the criterion for evaluating associations. The prognostic model was constructed using binary logistic regression. Independent predictors were selected by stepwise Wald statistics. The statistical significance of the model and its predictors was determined using the χ^2 test. The threshold probability (P) for AIC occurrence with optimal sensitivity and specificity was determined by receiver operating characteristic (ROC) curve analysis.

For the development of the risk scoring system for AIC, quantitative variables in the model were converted into categorical variables. For each predictor, odds ratios (OR) were determined by binary logistic regression. The minimum OR value obtained in the model was assigned a weight of 1 point. The score for each predictor was then calculated by dividing its OR value by the minimum OR in the model. The sum of points was calculated for each patient in the training cohort. Cut-off values of the total score, which stratified patients into groups of high, intermediate, and low probability of developing AIC, were determined using ROC curve analysis.

Risk probability was assessed according to the specificity of the total score: <50% was classified as low probability, 50-90% as intermediate probability, and >90% as high probability of AIC. For validation of the scoring system, the total score was calculated for patients in the test cohort, followed by assessment of sensitivity and specificity of the score using ROC curve analysis.

RESULTS

For the development of a multivariable model, factors with the highest prognostic potential ($p<0.05$) were included in the analysis (Table 2). In constructing the correlation matrix, significant correlations were observed between age and body surface area (BSA) ($\rho=0.849$; $p<0.001$). Predictors with significant correlations were not included simultaneously in the prognostic model. To describe the probability of arrhythmia-induced cardiomyopathy (AIC) in children with idiopathic VA as a function of the studied factors, the model with the highest sensitivity and specificity was selected. The observed relationship is described by Equation (1):

$$P = 1 / (1 + e^{-z})$$

$$z = -5{,}217 + 0{,}039*X_{PVCburden} - 0{,}003*X_{PEI} + 1{,}748*X_{BSA} \quad (1)$$

where P is the probability of developing AIC, $X_{pvc\ burden}$ = PVC burden (%), X_{pEI} = mean pre-ectopic interval (PEI) of PVCs (ms), and X^BS^A = body surface area (m²).

The regression model was statistically significant ($p<0.001$). Based on Nagelkerke's coefficient of determination, 35.3% of the variance in AIC probability was explained by the factors included in Model (1). According to the regression coefficients, BSA and PVC burden were positively associated with AIC risk, while mean PEI was inversely associated. Characteristics of each predictor are presented in Table 3.

In particular, an increase in BSA by 1 m² was associated with a 5.742-fold higher risk of AIC ($p<0.001$). An increase in PVC burden by 1% increased the risk of AIC 1.04-fold ($p=0.003$). A decrease in mean PEI by 1 ms increased the risk of AIC 1.003-fold ($p=0.006$).

Figure 1 shows adjusted odds ratios (ORs) with 95% confidence intervals (CI) for the predictors included in Model (1). The threshold value of the logistic function P was determined using ROC curve analysis. The resulting curve is shown in Figure 2a. The area under the ROC curve (AUC) was 0.833±0.042 (95% CI: 0.751-0.915). The threshold probability for AIC was 0.0655. At $P \geq 0.0655$, patients were classified as high risk for AIC; at $P < 0.0655$, patients were classified as low risk. At this cut-off, the sensitivity and specificity of Model (1) were 75.0% and 77.1%, respectively.

For clinical application of the model, a scoring system was developed to estimate the probability of AIC. All quantitative variables were transformed into categorical variables based on medians and percentiles. The resulting scoring system is shown in Table 3.

Cut-off values for the total score separating patients into low-, intermediate-, and high-risk groups for AIC were determined using ROC curve analysis (Figure 2b). The AUC of the prognostic score was 0.805±0.037 (95% CI: 0.732-0.878). This model was statistically significant ($p<0.001$). The sensitivity and specificity of the scoring system in predicting spontaneous resolution of VA are presented in Table 4.

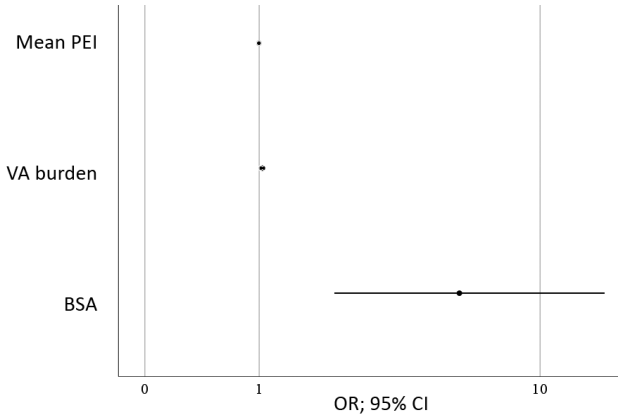

Figure 1. Odds ratio estimates with 95% confidence intervals for predictors of arrhythmia-induced cardiomyopathy in children: mean PEI (pre-ectopic interval), VA burden (ventricular arrhythmia burden), BSA (body surface area).

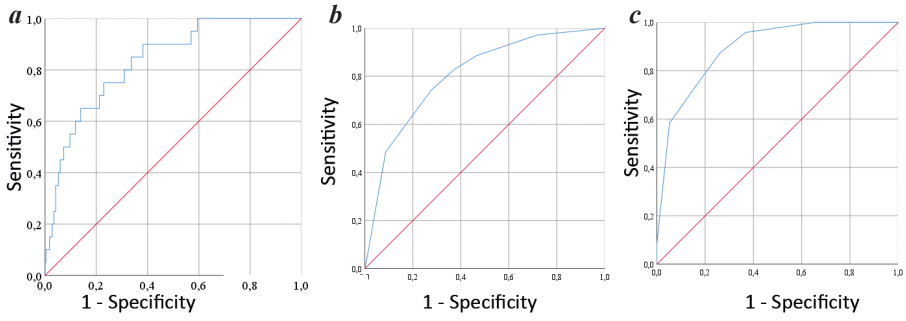

Fig. 2. ROC curves characterising the probability of arrhythmia-induced cardiomyopathy according to logistic function values (a), in the training cohort (b), and in the test cohort (c).

Accordingly, three risk groups were identified: Group 1 (low probability): total score 0-2; Group 2 (intermediate probability): total score 3-4; Group 3 (high probability): total score 5-6 (Table 3). In the training cohort, among patients with AIC, 6 children (17.1%) were classified as low probability, 12 (34.3%) as intermediate probability, and 17 (48.6%) as high probability.

For validation of the risk score, the total score was calculated for 100 children in the test cohort. A ROC curve was constructed to evaluate the sensitivity and specificity of the scoring system (Figure 2c). The AUC of the score in the test cohort was 0.893±0.034 (95% CI: 0.827-0.960), and the model was statistically significant (p<0.001). In the test cohort, among children with AIC, 1 child (4.2%) was classified as low probability, 7 (29.2%) as intermediate probability, and 16 (66.6%) as high probability. A score of 3-4 demonstrated specificity >50%, while a score ≥5 had specificity approaching 100%. The difference in AUC between the training and test cohorts was 0.088±0.05. AUCs were comparable (p=0.078).

DISCUSSION

Current clinical guidelines recommend treatment of children with idiopathic VA in the presence of symptoms, or when LV dilatation and/or reduced EF are present [14]. At the same time, identifying patients at high risk of AIC may allow modification of follow-up strategies or initiation of preventive therapy before the onset of heart failure symptoms.

The problem of AIC has been extensively studied in adults with VA and structurally normal hearts. It has been demonstrated that arrhythmia burden plays a key role in the development of AIC in adult patients with VA. According to numerous studies, a PVC burden of 20-26% is strongly associated with AIC formation in adults [15-18]. In domestic guidelines, LV dysfunction is reported in patients with a PVC burden exceeding 15% [14]. Observational studies in children indicate that a VA burden of 15-20% rarely leads to AIC, whereas LV dysfunction usually develops at a PVC burden >26-30% [7, 8, 10, 19]. In our study, we also demonstrated that the number of premature ventricular complexes (PVCs) per day is one of the main factors influencing AIC development. With increasing VA burden, the risk of AIC rises: at 25-29% the risk increased 8-fold, at 30-34% 11-fold, and at >35% 17-fold.

Another important electrocardiographic parameter is the mean pre-ectopic interval of PVCs, which also contributes significantly to AIC development. Several studies have shown a direct relationship between PEI duration and haemodynamic indices. Shorter PEI has been associated with reduced systolic blood pressure [20] and lower LV EF [6, 11]. S. Abadir et al. reported that a mean PEI <365 ms was associated with AIC, with a sensitivity of 85.7% and specificity of 86.5% [6]. In our study, we similarly found that a shorter mean PEI increased the likelihood of AIC. Specifically, a mean PEI <434 ms increased the risk of AIC 4-fold.

It should also be noted that AIC risk depends on age and anthropometric characteristics. Both in our study and in others, LV dysfunction was more frequently observed in adolescents compared with other age groups [9, 13]. However, in constructing our prognostic model we established that anthropometric indices, particularly body surface area (BSA), had greater prognostic significance than chronological age. An increase in BSA was associated with a higher probability of AIC, and BSA >1.7 m² increased the risk 5-fold.

Table 4.

Sensitivity and specificity of the scoring system for predicting spontaneous resolution of ventricular arrhythmia in the training and test cohorts

Score	Sensitivity	Specificity	Total patients, n (%)	Patients with AIC, n (%)
Training cohort				
0	100.0%	0.0%	102 (26.0)	1 (2.9)
1	92.8%	40.9%	93 (23.7)	3 (8.6)
2	85.8%	48.1%	35 (8.9)	2 (5.7)
3	78.6%	67.5%	37 (9.4)	3 (8.6)
4	61.5%	81.8%	77 (19.6)	9 (25.7)
5	51.5%	95.1%	42 (10.7)	15 (42.9)
6	3.0%	99.5%	6 (1.5)	2 (5.7)
Test cohort				
0	100.0%	0.0%	26 (26.0)	0 (0.0)
1	97.9%	50.7%	23 (23.0)	1 (4.2)
2	95.8%	68.5%	10 (10.0)	2 (8.3)
3	89.6%	78.3%	10 (10.0)	3 (12.5)
4	72.9%	88.8%	13 (13.0)	4 (16.7)
5	35.4%	97.4%	16 (10.0)	12 (50.0)
6	4.2%	100.0%	2 (2.0)	2 (8.3)

In our multivariable analysis, three independent predictors of AIC development in children with idiopathic VA were identified: VA burden, mean PVC PEI, and BSA. Based on this model, a scoring system was developed to stratify patients into low-, intermediate-, and high-risk groups. These factors accounted for 35.3% of the variance in AIC probability. Nevertheless, the search for additional predictors of AIC remains an important task.

For validation, a test cohort was recruited with an optimal total number of patients and sufficient outcome events. Validation data confirmed the strong predictive performance of the model (AUC = 0.893±0.034; 95% CI: 0.827-0.960). Thus, the risk scoring system for AIC in children with idiopathic VA, developed in the present study, has demonstrated its effectiveness and may be applied in clinical practice. Use of this model will allow the identification of children at high risk of AIC and enable timely treatment before the development of complications.

CONCLUSION

In this study, three independent predictors of arrhythmia-induced cardiomyopathy were identified in children with idiopathic VA: VA burden >25%, mean PEI <434 ms, and BSA >1.7 m². Based on these predictors, a prognostic scoring system for AIC was developed for this patient group. The proposed score is based on data from standard clinical and instrumental examinations and does not require complex calculations. Its simplicity enables routine assessment of AIC risk and supports the development of a personalised approach to the monitoring and management of each child with idiopathic ventricular rhythm disturbances.

REFERENCES

1. Makarov LM. Holter monitoring. 4-th edition. Moscow «MEDPRACTICE-M»; 2017:504 (In Russ.) ISBN 978-5-98803-362-2.
2. Alexander ME, Berul CI. Ventricular arrhythmias: When to worry. *Pediatr Cardiol*. 2000;21(6): 532-41.
3. Davis AM, Gow RM, McCrindle BW, et al. Clinical spectrum, therapeutic management, and follow-up of ventricular tachycardia in infants and young children. *Am Heart J*. 1996;131(1): 186-91.
4. Şengül FS, Kafali HC, Güzeltaş A, et al. Clinical spectrum and long-term course of sustained ventricular tachycardia in pediatric patients: 10 years of experience. *Anatol J Cardiol*. 2021;25(5): 313-22.
5. Song MK, Baek JS, Kwon BS, et al. Clinical spectrum and prognostic factors of pediatric ventricular tachycardia. *Circ J*. 2010;74(9): 1951-8.
6. Abadir S, Blanchet C, Fournier A, et al. Characteristics of premature ventricular contractions in healthy children and their impact on left ventricular function. *Hear Rhythm*. 2016;13(11): 2144-8.
7. Kakavand B, Ballard HO, Disessa TG. Frequent ventricular premature beats in children with a structurally normal heart: A cause for reversible left ventricular dysfunction? *Pediatr Cardiol*. 2010;31(7): 986-90.
8. Bertels RA, Harteveld LM, Filippini LH, et al. Left ventricular dysfunction is associated with frequent premature ventricular complexes and asymptomatic ventricular tachycardia in children. *Europace*. 2017;19(4): 617-21.
9. Przybylski R, Meziab O, Gauvreau K, et al. Premature ventricular contractions in children and young adults: natural history and clinical implications. *Europace*. 2024;26(3).
10. Spector ZZ, Seslar SP. Premature ventricular contraction-induced cardiomyopathy in children. *Cardiol Young*. 2016;26(4): 711-7.
11. Sun Y, Blom NA, Yu Y, et al. The influence of premature ventricular contractions on left ventricular function in asymptomatic children without structural heart disease: An echocardiographic evaluation. *Int J Cardiovasc Imaging*. 2003;19(4): 295-9.
12. Lopez L, Saurers DL, Barker PCA, et al. Guidelines for Performing a Comprehensive Pediatric Transthoracic Echocardiogram: Recommendations From the American Society of Echocardiography. *J Am Soc Echocardiogr*. 2024;37(2): 119-70.
13. Chueva KA, Kofeynikova OA, Tatarskiy RB, et al. Risk factors for the development of tachycardia-induced cardiomyopathy in children with idiopatic ventricular arrhythmia. *Children's Heart and Vascular Diseases*. 2024; 21 (4): 297-304 (in Russ.). https://doi.org/10.24022/1810-0686-2024-21-4-297-304.
14. Lebedev DS, Mikhailov EN, Neminuschiy NM, et al. Ventricular arrhythmias. Ventricular tachycardias and sudden cardiac death. 2020 Clinical guidelines. *Russian Journal of Cardiology*. 2021;26(7): 4600. (In Russ.). https://doi.org/10.15829/1560-4071-2021-4600.
15. Baman TS, Lange DC, Ilg KJ, et al. Relationship between burden of premature ventricular complexes and left ventricular function. *Hear Rhythm*. 2010;7(7): 865-869.
16. Remme CA, Leclercq C, Behr ER. The European Cardiac Arrhythmia Genetics (ECGen) Focus Group. *European heart journal*. 2022;43(20): 1891-1894. https://doi.org/10.1093/eurheartj/ehab698.
17. Cha YM, Lee GK, Klarich KW, Grogan M. Premature ventricular contraction-induced cardiomyopathy: a treatable condition. *Circ Arrhythm Electrophysiol*. 2012;5(1): 229-236. https://doi.org/10.1161/CIRCEP.111.963348.
18. Ban JE, Park HC, Park JS., et al. Electrocardiographic and electrophysiological characteristics of premature ventricular complexes associated with left ventricular dysfunction in patients without structural heart disease. *Europace*. 2013;15(5): 735-741. https://doi.org/10.1093/europace/eus371.
19. Alekseeva K, Kruchina T, Maliarova M, et al. Hemodynamic effects of premature ventricular contractions in children. *REJR*. 2021;11(2): 143-152 (in Russ.). https://doi.org/10.21569/2222-7415-2021-11-2-143-152.
20. Shubik YuV, Korneev AB, Morozov AN. Hemodynamic significance of ventricular ectopic beats: the im- pact of coupling intervals. Journal of Arrhythmology. 2025;32(1): 64-70 (in Russ.). https://doi.org/:10.35336/VA-1390.