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ABSTRACT

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AGE-RELATED CLINICAL AND HEMODYNAMIC FEATURES OF THE EARLY POSTOPERATIVE PERIOD IN CHILDREN AFTER CONGENITAL HEART DEFECT REPAIR

Introduction. Congenital heart defects (CHDs) remain a major cause of pediatric cardiac surgery worldwide. Despite advances in surgical techniques and perioperative care, the early postoperative period remains variable and may depend on patient age, CHD characteristics, and postoperative adaptation.

Objective. To evaluate age-related features of the early postoperative period in children after surgical correction of congenital heart defects and their association with CHD structure and postoperative adaptation.

Materials and Methods. This retrospective single-center study included 206 children aged 0–14 years who underwent CHD repair between 2015 and 2024. Patients were divided into five age groups: neonates, infants, children aged 1–3 years, 3–7 years, and 7–14 years. Clinical, laboratory, and echocardiographic parameters were assessed during the early postoperative period. Statistical analysis included descriptive statistics, one-way ANOVA, and χ^2 testing.

Results. Significant age-related differences were observed in hospitalization duration, heart rate, extracardiac comorbidity, and CHD structure. Neonates had the longest hospital stay, the highest prevalence of extracardiac comorbidity, and the greatest proportion of complex CHDs. Laboratory parameters were generally comparable between age groups and reflected a common postoperative inflammatory response. Echocardiography revealed more frequent right ventricular dilatation and pulmonary hypertension in younger patients. The distribution of CHD types differed significantly across age groups and appeared to influence postoperative adaptation. The observed differences were associated not only with age but also with CHD complexity, baseline clinical status, and perioperative factors.

Conclusions. The early postoperative period after CHD repair demonstrates clinically relevant age-related characteristics. Neonates represent the most vulnerable patient group, whereas older children generally show a more stable postoperative course. These findings should be interpreted as reflecting the combined influence of age, CHD structure, extracardiac comorbidity, and postoperative adaptation rather than an independent effect of age alone.

Keywords: congenital heart defects, children, cardiac surgery, postoperative adaptation, age-related features.

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ВІКОВІ КЛІНІЧНІ ТА ГЕМОДИНАМІЧНІ ОСОБЛИВОСТІ РАНЬОГО ПІСЛЯОПЕРАЦІЙНОГО ПЕРІОДУ У ДІТЕЙ ПІСЛЯ КОРЕКЦІЇ ВРОДЖЕНИХ ВАД СЕРЦЯ

Вступ. Вроджені вади серця (ВВС) залишаються однією з провідних причин проведення кардіохірургічних втручань у дітей у всьому світі. Незважаючи на значний прогрес у розвитку кардіохірургії, анестезіології та інтенсивної терапії, ранній післяопераційний період характеризується клінічною неоднорідністю та може залежати від віку пацієнта, структури ВВС і особливостей післяопераційної адаптації.

Мета. Оцінити вікові особливості раннього післяопераційного періоду у дітей після хірургічної корекції вроджених вад серця та визначити їх зв'язок зі структурою ВВС і післяопераційною адаптацією.

Матеріали та методи. Проведено ретроспективне одноцентрове дослідження за участю 206 дітей віком 0–14 років, яким у 2015–2024 роках виконано хірургічну корекцію ВВС. Пацієнтів розподілено на п'ять вікових груп: новонароджені, немовлята, діти 1–3 років, 3–7 років та 7–14 років. Аналізували клінічні, лабораторні та ехокардіографічні показники раннього післяопераційного періоду. Для статистичної обробки використовували описову статистику, однофакторний дисперсійний аналіз (ANOVA) та χ^2 -критерій.

Результати. Виявлено статистично значущі вікові відмінності щодо тривалості госпіталізації, частоти серцевих скорочень, поширеності екстракардіальної коморбідності та структури ВВС. Новонароджені характеризувалися найдовшим терміном перебування у стаціонарі, найбільшою частотою супутньої патології та переважанням складних форм ВВС. Лабораторні показники були відносно однорідними між групами та відображали загальну післяопераційну запально-стресову реакцію. За даними ехокардіографії, у дітей молодшого віку частіше виявляли дилатацію правого шлуночка та ознаки легеневої гіпертензії. Встановлено, що виявлені відмінності пов'язані не лише з віком, а й зі складністю ВВС, вихідним клінічним станом та периопераційними факторами.

Висновки. Ранній післяопераційний період після корекції ВВС характеризується клінічно значущими віковими особливостями. Найбільш уразливою групою є новонароджені, тоді як у дітей старшого віку перебіг післяопераційного періоду є відносно

стабільнішим. Виявлені особливості слід розглядати як результат взаємодії віку, структури ВВС, супутньої патології та процесів післяопераційної адаптації.

Ключові слова: вроджені вади серця, діти, кардіохірургія, післяопераційна адаптація, вікові особливості.

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INTRODUCTION

Congenital heart defects (CHDs) remain one of the leading causes of hospitalization and cardiac surgery in childhood. Despite significant advances in pediatric cardiac surgery and intensive care, the early postoperative period continues to be associated with variability in the clinical course and the risk of developing hemodynamic and metabolic disturbances [1–6].

Patient age is traditionally considered one of the factors that may influence the characteristics of postoperative adaptation. At the same time, its significance remains ambiguous, since age-related differences are combined with variations in the structure of congenital heart defects, their hemodynamic significance, preoperative patient condition, and characteristics of the surgical intervention [2, 5, 7].

In the available studies, age-related features of the postoperative period are predominantly analyzed within the framework of individual parameters or nosological forms. Such an approach complicates the formation of a comprehensive understanding of the course of the early postoperative period as a complex process including clinical, laboratory, and hemodynamic components [3, 6, 8, 9].

In this regard, the issue of summarizing these parameters in the form of composite clinical and hemodynamic characteristics of the early postoperative period in children of different ages after surgical repair of CHDs remains relevant.

Objective. To evaluate age-related clinical and hemodynamic features of the early postoperative period in children after surgical repair of congenital heart defects and to assess their relationship with CHD structure and postoperative adaptation.

MATERIALS AND METHODS

A retrospective single-center study was conducted, including 206 children aged 0 to 14 years who underwent surgical repair of CHDs at the Department of Cardiovascular Surgery of the Odesa Regional Children's Clinical Hospital during 2015–2024. The data sources included inpatient medical records, laboratory test results, and echocardiography reports.

Inclusion criteria were: confirmed diagnosis of CHDs, performed surgical intervention, and availability

of complete clinical, laboratory, and echocardiographic data during the early postoperative period. Exclusion criteria were: incomplete clinical data, repeated hospitalizations due to postoperative complications, as well as patients after palliative interventions without completed repair.

The early postoperative period was defined as the interval from completion of the surgical intervention to hospital discharge. Patients were divided into five age groups: neonates (1–28 days, n=18), infants (1–12 months, n=101), children aged 1–3 years (n=25), 3–7 years (n=30), and 7–14 years (n=32). The structure of CHDs among the groups was heterogeneous, reflecting real clinical practice. Clinical and demographic characteristics, duration of hospitalization, hemodynamic parameters, laboratory and echocardiographic indicators, as well as the frequency of postoperative complications were assessed.

Statistical analysis was performed using descriptive statistical methods, one-way analysis of variance (ANOVA), and the χ^2 test. Distribution normality was assessed before the application of parametric methods. Statistical significance was accepted at $p < 0.05$. Calculations were performed using IBM SPSS Statistics and Microsoft Excel software packages. Because of the retrospective design, heterogeneous structure of congenital heart defects and relatively small sample size within individual age groups, multivariable regression analysis was not performed. Therefore, the present study should be considered exploratory and hypothesis-generating. The observed associations reflect the combined influence of age, CHD structure, extracardiac comorbidity and perioperative factors rather than independent causal effects of age.

Given the heterogeneity of the clinical sample, the results were interpreted primarily from the standpoint of descriptive and comparative analysis without establishing causal relationships. The obtained data were considered as reflecting the composite influence of age, CHD structure, preoperative condition, and characteristics of the surgical intervention.

The study was conducted using depersonalized data in accordance with the ethical principles of biomedical research. The study protocol was approved by the

Bioethics Commission of the Odesa National Medical University (Protocol No. 01 dated 14.01.2026).

RESULTS

In order to assess the characteristics of the early postoperative period in children after surgical repair of CHDs, a comparative analysis of the main clinical and hemodynamic parameters was performed in five age groups. Taking into account the clinical heterogeneity of

the cohort and differences in the structure of CHDs, the results were interpreted as reflecting the composite influence of age, the nature of the defect, comorbid background, and postoperative adaptation.

At the first stage, the basic clinical parameters were analyzed: duration of hospitalization, heart rate (HR), systolic blood pressure (SBP), and prevalence of extracardiac comorbidity (Table 1).

Table 1– Comparative characteristics of clinical parameters in children of different age groups after repair of CHDs

Parameter	1–28 days (n=18)	1–12 months (n=101)	1–3 years (n=25)	3–7 years (n=30)	7–14 years (n=32)	p
Duration of hospitalization, days	55.1±16.3	17.2±1.0	14.3±3.8	12.8±1.8	13.8±0.8	<0.001
HR, beats/min	157.8±10.7	139.5±1.3	115.4±4.3	96.1±3.1	79.8±2.1	<0.001
SBP, mmHg	74.5±5.5	88.7±4.8	93.2±2.4	92.5±2.8	95.2±2.3	0.28
Extracardiac comorbidity	100%	77.2%	36%	40%	53.1%	<0.001

Note. Continuous variables were compared across all five age groups using one-way ANOVA. Categorical variables were analyzed using the χ^2 test. Reported p-values represent overall between-group comparisons and do not indicate pairwise differences

The most pronounced intergroup differences concerned duration of hospitalization, HR, and the frequency of extracardiac comorbidity ($p<0.001$), whereas no statistically significant differences were found for SBP ($p=0.28$).

The longest duration of inpatient treatment was observed in neonates (55.1±16.3 days), exceeding the corresponding indicators in the other age groups (12.8–17.2 days). Such a distribution may reflect a more complicated clinical course in neonates, which is consistent with a higher frequency of hemodynamically significant forms of CHDs and the need for intensive care.

Heart rate demonstrated a gradual decrease with age: the highest values were recorded in neonates and infants, whereas in older children this parameter was lower. In addition to physiological age-related characteristics, this tendency may reflect a greater degree of hemodynamic load in younger patients during the early postoperative period.

Systolic blood pressure did not show statistically significant differences between the groups, indicating relative stability of this parameter regardless of age and emphasizing the greater sensitivity of chronotropic parameters to postoperative changes.

The prevalence of extracardiac comorbidity was maximal in neonates (100%) and remained high in infants, whereas in children aged 1–7 years it was lower, followed by a moderate increase in the older age group. This may reflect both perinatal vulnerability at an early

age and accumulation of concomitant pathology in older children.

Thus, already at the level of basic clinical parameters, neonates are characterized by greater postoperative vulnerability, whereas in older children the course is relatively more stable. At the same time, these differences should be considered in the context of the heterogeneity of CHD structure and concomitant clinical background rather than as an isolated effect of age.

For a better understanding of the causes of the identified clinical differences, the structure of CHDs in different age groups was analyzed at the next stage. Comparison of the nosological feature makes it possible to assess to what extent the characteristics of the early postoperative period are associated not only with patient age, but also with the heterogeneity of cardiac pathology.

All defects were combined into two generalized categories: shunt acyanotic and other/complex forms of CHDs (Fig. 1). This approach made it possible to reduce the influence of excessive nosological detailing and to ensure correct comparison between the age groups.

The performed analysis showed that complex or combined forms of CHDs were observed more frequently in neonates: the proportion of shunt acyanotic defects in this group was 38.9%. In the subsequent age groups, an increase in the proportion of shunt CHDs was noted: 77.2% in infants, 84.0% in children aged 1–3 years, 73.3% in the 3–7-year group, and 71.9% in children aged 7–14 years. The intergroup differences were statistically significant ($\chi^2=12.04$; $p=0.016$).

The obtained results are important for the interpretation of the subsequent analysis, as they indicate differences in the baseline clinical characteristics of patients of different ages. In particular, complex forms of CHDs were more frequently represented in the youngest patients, requiring early surgical intervention and potentially being associated with a more severe postoperative course. In the older age groups, shunt acyanotic defects predominated, which are characterized by a relatively more stable preoperative condition.

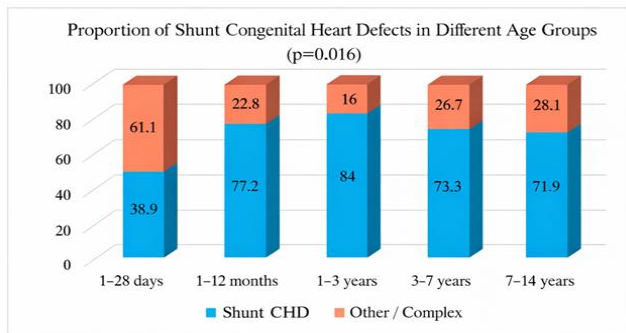


Fig. 1. Age-related distribution of the CHDs structure in different age groups, %

Table 2 – Comparative characteristics of laboratory parameters in children of different age groups after surgical repair of CHDs

Parameter	1–28 days	1–12 months	1–3 years	3–7 years	7–14 years
Hemoglobin, g/L	126.6±5.9	122.0±2.2	120.4±2.2	130.2±2.9	126.7±2.1
RBC, ×10 ¹² /L	4.0±0.2	4.5±0.2	4.6±0.2	4.5±0.1	4.4±0.1
WBC, ×10 ⁹ /L	9.6±1.3	10.4±0.3	9.7±0.4	11.3±0.5	8.8±0.4
Platelets, ×10 ⁹ /L	377.6±62.3	389.7±11.4	312.4±18.2	326.1±4.8	259.2±13.8
Hematocrit, %	36.3±1.7	36.8±0.4	36.6±0.4	39.1±0.7	36.9±0.5
Urea, mmol/L	4.9±0.1	4.9±0.3	4.9±0.3	5.3±0.7	4.8±0.4
Creatinine, μmol/L	46.5±0.6	54.2±1.5	47.7±1.4	59.6±1.8	59.6±2.2
CRP, mg/L	4.0±0.4	5.5±0.4	4.5±0.4	4.2±0.2	3.7±0.3

The leukocyte count fluctuated within relatively narrow limits, whereas the level of C-reactive protein remained moderately elevated in all groups. This indicates the presence of a systemic inflammatory-stress response as a characteristic component of the early postoperative period regardless of patient age. At the same time, neonates demonstrated a tendency toward more pronounced manifestations of an immature immune response, which may influence the overall clinical vulnerability of this group.

Parameters of nitrogen metabolism (urea, creatinine) also did not demonstrate substantial intergroup differences, allowing the renal-metabolic component of

Thus, the identified inter-age differences in clinical and hemodynamic parameters should be considered in the context of the combined influence of age-related characteristics and CHD structure. In this study, age acts as a composite characteristic reflecting the combination of clinical and morphofunctional factors rather than as an isolated predictor.

The next stage of the study involved comparison of laboratory parameters in different age groups, which made it possible to assess the characteristics of the systemic inflammatory-stress response and metabolic adaptation after cardiac surgery (Table 2).

As shown in Table 2, the laboratory parameters were generally characterized by relative homogeneity between the age groups. Hemoglobin levels in all groups ranged within 120–130 g/L, corresponding to moderate postoperative anemia typical for children after cardiac surgery. Laboratory values generally remained within the expected postoperative ranges for the corresponding age groups. Therefore, direct comparison of absolute hematological values between age groups should be interpreted with caution because of physiological age-related differences.

postoperative adaptation to be considered relatively stable within the studied cohort.

Thus, in contrast to clinical parameters, the laboratory feature of the early postoperative period appeared to be less sensitive to age-related differences and predominantly reflected the general systemic response of the organism to surgical intervention.

To assess structural and functional cardiac changes during the early postoperative period, echocardiographic comparison of the main parameters in different age groups was performed (Table 3).

Echocardiographic parameters were considered as generalized characteristics of cardiac functional status

without reference to individual nosological forms of CHDs. The obtained results reflect the cumulative effect of hemodynamic load and postoperative adaptation in a clinically heterogeneous cohort.

As shown in Table 3, in most patients after CHD

surgical repair, global left ventricular (LV) systolic function remained preserved. At the same time, neonates demonstrated relatively lower values of LV ejection fraction (EF), which is consistent with a more severe clinical course in this group.

Table 3 – Main echocardiographic parameters in children after surgical repair of CHD

Parameter	1–28 days	1–12 months	1–3 years	3–7 years	7–14 years
LVEF (%)	57±3	72±5	71±4	69±4	63±3
LA dilatation (%)	–	35.6	–	26.7	18.8
LV dilatation (%)	–	25.7	4.0	13.3	6.3
RA dilatation (%)	44.4	–	20.0	23.3	37.5
RV dilatation (%)	55.6	33.7	24.0	30.0	31.3
Signs of pulmonary hypertension (%)	22.2	9.9	4.0	6.7	9.4
Pericardial effusion (%)	5.6	3.0	4.0	3.3	3.1

Note. Echocardiographic parameters are presented as descriptive characteristics of the study groups. Reported percentages indicate the frequency of findings within each age category. Statistical comparisons represent overall between-group differences and should be interpreted in the context of heterogeneous CHD structure

The most characteristic echocardiographic feature was dilatation of the right heart chambers, primarily the right ventricle (RV), which was more frequently observed in neonates and infants. Signs of pulmonary hypertension were also more pronounced in the youngest patients.

The obtained data indicate that intergroup differences may be associated not only with the condition of LV systolic function, but also with the characteristics of right ventricular load and pulmonary vascular adaptation. At the same time, given the heterogeneity of CHD structure, these results should be

interpreted as a generalized functional feature rather than as characteristics of individual nosological forms.

Taken together, the clinical, laboratory, and echocardiographic data allow neonates to be considered a group with increased postoperative vulnerability, whereas older children demonstrate a relatively more stable adaptation feature.

To clarify the clinical significance of the identified differences, the structure of the main postoperative complications in different age groups was additionally analyzed (Fig. 2).

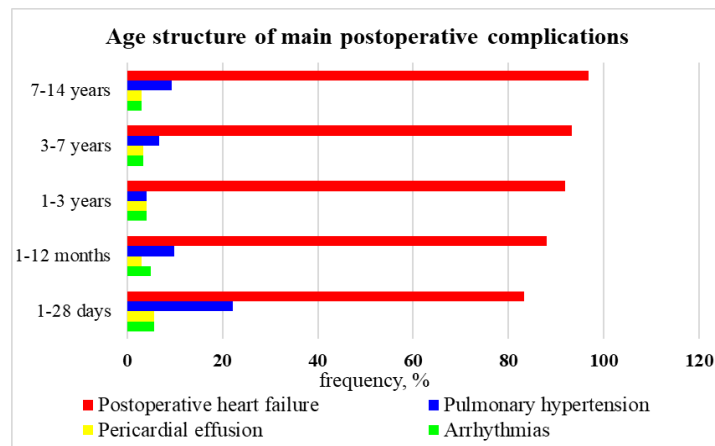


Fig. 2. Age-related structure of the main postoperative complications in children after surgical repair of CHDs

The performed analysis showed that signs of postoperative heart failure of varying severity were registered in all age groups. Signs of pulmonary hypertension were more frequently observed in neonates, whereas pericardial effusion and rhythm

disturbances were characterized by relatively low frequency without substantial intergroup differences.

Interpretation of the obtained data requires caution. The identified syndromes likely reflect not only age-related characteristics, but also differences in baseline

hemodynamics, duration of preoperative overload, and CHD structure. Accordingly, the structure of postoperative instability in different age groups may be considered as the result of the combined influence of age-related, anatomical, and hemodynamic factors.

Thus, the study results indicate that the early postoperative period after surgical repair of CHDs in children is characterized by the formation of clinical and hemodynamic characteristics with certain age-related features. At the same time, it is advisable to interpret them not as an isolated effect of age, but as a reflection of the complex interaction between age-related characteristics, CHD structure, concomitant pathology, and mechanisms of postoperative adaptation.

DISCUSSION

The obtained results indicate the presence of intergroup differences in the course of the early postoperative period in children after surgical repair of CHDs. The most severe clinical pattern was observed in neonates, who were characterized by longer duration of hospitalization, high frequency of extracardiac comorbidity, a considerable proportion of complex forms of CHDs, and signs of hemodynamic instability. Such a distribution is consistent with current concepts regarding the limited adaptive reserves of the cardiovascular system during the neonatal period [1, 2, 5].

Our findings are consistent with contemporary reports indicating that neonates represent the most vulnerable group after congenital heart surgery. Elassal et al. [2] demonstrated that neonatal cardiac surgery is associated with a higher incidence of postoperative complications and prolonged recovery due to limited physiological reserve and the greater prevalence of complex congenital heart defects.

The observed association between younger age and a more complicated postoperative course should be interpreted cautiously. Large multicenter studies have shown that postoperative outcomes are influenced not only by age but also by the anatomical complexity of CHD, preoperative condition and surgical characteristics. Pasquali et al. [5] reported substantial variation in outcomes across congenital heart surgery programs, emphasizing the importance of disease complexity and perioperative management.

In our cohort, laboratory parameters were relatively homogeneous across age groups, whereas echocardiographic indicators demonstrated greater variability. This observation is partly consistent with studies showing that hemodynamic adaptation and right ventricular loading conditions may be more sensitive markers of postoperative recovery than routine laboratory parameters.

Recent studies increasingly support the use of multivariable and machine-learning approaches for

postoperative risk assessment in pediatric cardiac surgery. However, such models require large and homogeneous datasets. Therefore, the present study should be viewed as an exploratory analysis that identifies clinically relevant age-related features and may serve as a basis for future predictive modelling.

At the same time, the obtained differences should be considered not as an isolated effect of age, but as the result of the combined influence of several factors. Complex and hemodynamically significant forms of CHDs are more frequently represented in the younger age groups, whereas in older children shunt acyanotic defects with a more stable preoperative course predominate. In this context, patient age may be regarded as a composite characteristic reflecting the anatomical complexity of the defect, baseline hemodynamic status, and conditions of surgical intervention.

From a pathophysiological point of view, the obtained results may be associated with immaturity of regulatory mechanisms in neonates, including limited myocardial reserves, peculiarities of neurohumoral regulation, and increased pulmonary vascular reactivity. The combination of these factors may determine greater sensitivity to postoperative stress and the development of hemodynamic instability [2, 5, 7].

Laboratory parameters in all age groups reflected a typical systemic inflammatory-stress response to cardiac surgery and did not demonstrate substantial intergroup differences, indicating the relative universality of this reaction. At the same time, echocardiographic changes proved to be more sensitive to intergroup characteristics: signs of right ventricular overload and pulmonary hypertension were more frequently observed in neonates, emphasizing the role of the pulmonary vascular component in the development of early postoperative instability [8–10].

The obtained results suggest the presence of age-related differences in postoperative adaptation rather than distinct adaptation profiles. Neonates are more commonly characterized by a feature of increased postoperative vulnerability, whereas in older children the course is relatively more stable. At the same time, these observations should be interpreted taking into account the heterogeneity of the studied cohort.

Fig. 3 summarizes the multifactorial nature of postoperative adaptation and reflects the interaction between CHD structure, comorbidity, hemodynamic characteristics, and adaptive capabilities of the organism.

The practical significance of the obtained results should be considered taking into account the above-mentioned limitations. The presented data do not replace individualized clinical assessment; however,

they may be useful for increasing clinical awareness regarding high-risk patients, primarily among neonates and young children.

The present study should be interpreted in the context of several limitations, including its retrospective single-center design, heterogeneity of congenital heart defects and surgical procedures, and the absence of multivariable adjustment for potential confounding

factors. Consequently, the identified age-related differences likely reflect the interaction between age, CHD structure, baseline clinical status, and perioperative characteristics. Nevertheless, the findings provide clinically relevant information regarding postoperative adaptation in different pediatric age groups and may serve as a basis for future prospective studies.

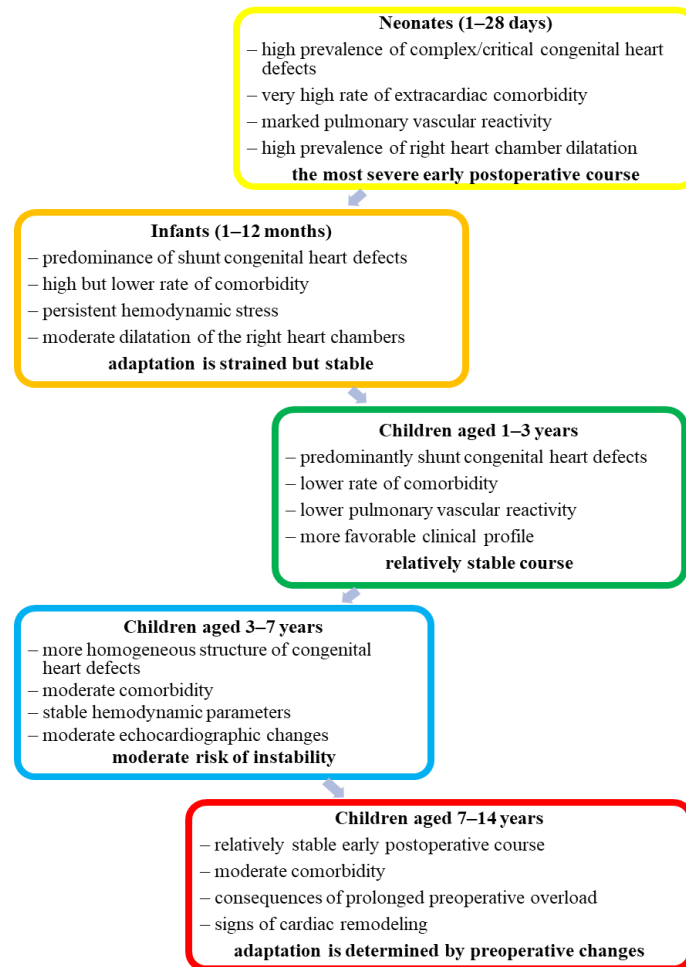


Fig. 3. Age-related features of postoperative adaptation after CHD repair

CONCLUSIONS

1. The early postoperative period after surgical repair of congenital heart defects in children is characterized by age-related clinical and hemodynamic features reflecting differences in postoperative adaptation.

2. The most severe course is observed in neonates and is accompanied by longer duration of hospitalization, high frequency of extracardiac comorbidity, and signs of hemodynamic instability.

3. In the older age groups, the early postoperative period has a relatively more stable course.

4. Age-related differences in postoperative

adaptation were associated with variations in CHD structure, extracardiac comorbidity, and baseline clinical status across the studied groups.

5. Neonates demonstrated the most vulnerable postoperative course and should be considered a priority group for intensive monitoring and early prevention of postoperative complications.

6. Recognition of age-associated clinical and hemodynamic characteristics may improve perioperative decision-making and support the development of individualized postoperative management strategies in pediatric cardiac surgery.

PROSPECTS FOR FUTURE RESEARCH

Further studies should be aimed at the analysis of more homogeneous patient groups taking into account CHD structure and characteristics of the surgical intervention.

AUTHOR CONTRIBUTIONS

The authors of the manuscript certify that the work used the results of their own clinical studies, which were systematized and analyzed by the authors.

M.A. Kashtalian — study concept and design.

M.H. Melnychenko — collection and processing of materials, analysis of the obtained data, writing of the article text, reviewing.

V.P. Buzovskyi — processing of literature sources, analysis of the obtained data, writing of the article text.

Ye.A. Kvasnevskiy — collection and processing of materials.

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CONFLICT OF INTEREST

The authors declare the absence of conflict of interest and personal financial interest in the preparation of this article.

ARTIFICIAL INTELLIGENCE DISCLOSURE

The authors confirm that AI technologies were not used during the writing or editing of the manuscript.

ETHICAL CONSIDERATIONS

The authors of the manuscript certify that the study was conducted using data from primary medical documentation. The study was performed in accordance with the ethical standards of the Declaration of Helsinki of the World Medical Association on ethical principles for medical research involving human subjects, Directive 86/609 of the European Society regarding human participation in biomedical research, as well as Order No. 690 of the Ministry of Health of Ukraine dated 23.09.2009.

The Bioethics Commission of the Odesa National Medical University reviewed the study materials and revealed no violations of ethical standards set forth in the current regulatory documents, including the Declaration of Helsinki and the Convention on Human Rights and Biomedicine of the Council of Europe (Protocol No. 01 dated 14.01.2026).

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