

Outcomes of surgical repair of congenital heart disease in the Russian Federation in 2025

Ilya A. Soynov^{1,2}, Aleksey I. Kim^{1,3}, Ruben R. Movsesyan^{1,4}, Pavel V. Teplov^{1,5}, Aleksandr Yu. Miller^{1,5}, Yuriy Yu. Kulyabin^{1,2}, Aleksey N. Arkhipov^{1,2}, Anton A. Avramenko^{1,6}, Kirill V. Gorbatiykh^{1,7}, Artem V. Gorbatiykh^{1,8}, Konstantin A. Nalimov^{1,9}, Mikhail A. Abramyan^{1,10}, Maksim V. Boriskov^{1,11}, Sergey A. Kovalev^{1,12}, Andrey A. Svobodov^{1,13}, Alena V. Kauk^{1,2}, Evgeniy V. Krivoshchekov^{1,14}, Aleksey A. Shikhranov^{1,15}, Mikhail V. Plotnikov^{1,16}, Oleg A. Egunov^{1,17}, Vyacheslav A. Belov^{1,18}, Igor V. Gladyshev^{1,19}, Konstantin B. Kazantsev^{1,20}, Oleg Yu. Kornoukhov^{1,21}, Andrey V. Nokhrin^{1,22}, Denis Yu. Petrushenko^{1,23}, Evgeniy S. Efanov^{1,24}, Ivan K. Khalivopulo^{1,25}, Dmitriy V. Ryabtsev^{1,26}, Yuriy A. Sobolev^{1,27}, Vladimir N. Medvedev^{1,28}, Roman Yu. Gavrilov^{1,29}, Nikolay I. Pavlov^{1,30}, Ekaterina N. Amansakhatova², Evgeniy S. Tarasyuk²

Corresponding author: Ilya A. Soynov,
i_soynov@meshalkin.ru

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Contribution of the authors

Conception and study design: I.A. Soynov, R.R. Movsesyan, P.V. Teplov, A.A. Svobodov, E.V. Krivoshchekov, E.S. Tarasyuk
Data collection and analysis: I.A. Soynov, A.Yu. Miller, Yu.Yu. Kulyabin, A.N. Arkhipov, A.A. Avramenko, K.V. Gorbatiykh, A.V. Gorbatiykh, K.A. Nalimov, S.A. Kovalev, A.A. Svobodov, A.A. Shikhranov, M.V. Plotnikov, O.A. Egunov, V.A. Belov, I.V. Gladyshev, K.B. Kazantsev, O.Yu. Kornoukhov, A.V. Nokhrin, D.Yu. Petrushenko, E.S. Efanov, I.K. Khalivopulo, D.V. Ryabtsev, Yu.A. Sobolev, V.N. Medvedev, R.Yu. Gavrilov, N.I. Pavlov
Statistical analysis: I.A. Soynov, P.V. Teplov, K.A. Nalimov, M.A. Abramyan, S.A. Kovalev

Drafting the article: I.A. Soynov, A.Yu. Miller, Yu.Yu. Kulyabin, A.A. Avramenko, K.V. Gorbatiykh, A.V. Gorbatiykh, K.A. Nalimov, A.V. Kauk, E.V. Krivoshchekov, E.N. Amansakhatova

Critical revision of the article: A.I. Kim, R.R. Movsesyan, M.A. Abramyan, E.V. Krivoshchekov, E.S. Tarasyuk

Final approval of the version to be published: all authors

ORCID

I.A. Soynov, <https://orcid.org/0000-0003-3691-2848>

A.I. Kim, <https://orcid.org/0000-0003-0065-7419>

R.R. Movsesyan,

<https://orcid.org/0000-0003-3089-3113>

P.V. Teplov, <https://orcid.org/0000-0002-8798-4975>

A.Yu. Miller, <https://orcid.org/0000-0003-4969-4640>

¹ Interregional Public Organization of Pediatric Cardiac Surgeons "Society of Congenital Heart Disease Specialists", St. Petersburg, Russian Federation

² Meshalkin National Medical Research Center, Novosibirsk, Russian Federation

³ Bakulev National Medical Research Center for Cardiovascular Surgery, Moscow, Russian Federation

⁴ Pediatric City Multidisciplinary Clinical Specialized Center for High Medical Technologies, St. Petersburg, Russian Federation

⁵ Federal Center for Cardiovascular Surgery, Krasnoyarsk, Russian Federation

⁶ Polyakov Samara Regional Clinical Cardiology Dispensary, Samara, Russian Federation

⁷ Regional Clinical Hospital No. 1, Tyumen, Russian Federation

⁸ Almazov National Medical Research Center, St. Petersburg, Russian Federation

⁹ Federal Center for Cardiovascular Surgery, Khabarovsk, Russian Federation

¹⁰ Morozov Children's City Clinical Hospital, Moscow, Russian Federation

¹¹ Research Institute – Ochapovsky Regional Clinical Hospital No. 1, Krasnodar, Russian Federation

¹² Voronezh Regional Clinical Hospital No. 1, Voronezh, Russian Federation

¹³ L.M. Roshal Children's Clinical Center, Krasnogorsk, Russian Federation

¹⁴ Federal Center for High Medical Technologies, Kaliningrad, Russian Federation

¹⁵ Federal Center for Cardiovascular Surgery, Penza, Russian Federation

¹⁶ Federal Center for Cardiovascular Surgery, Astrakhan, Russian Federation

¹⁷ Cardiology Research Institute, branch of the Tomsk National Research Medical Center of the Russian Academy of Sciences, Tomsk, Russian Federation

¹⁸ S.G. Sukhanov Federal Center for Cardiovascular Surgery, Perm, Russian Federation

¹⁹ Federal Center for Cardiovascular Surgery, Chelyabinsk, Russian Federation

²⁰ Sverdlovsk Regional Clinical Hospital No. 1, Yekaterinburg, Russian Federation

²¹ N.F. Filatov Children's City Clinical Hospital, Moscow Healthcare Department, Moscow, Russian Federation

²² Saint Petersburg State Pediatric Medical University, St. Petersburg, Russian Federation

²³ Children's Republican Clinical Hospital, Ministry of Health of the Republic of Tatarstan, Kazan, Russian Federation

²⁴ Irkutsk Order of the Badge of Honor Regional Clinical Hospital, Irkutsk, Russian Federation

²⁵ Research Institute for Complex Issues of Cardiovascular Diseases, Ministry of Science and Higher Education of the Russian Federation, Kemerovo, Russian Federation

²⁶ Shumakov National Medical Research Center of Transplantology and Artificial Organs, Moscow, Russian Federation

²⁷ Children's City Clinical Hospital No. 1, Nizhny Novgorod, Russian Federation

²⁸ Irkutsk State Regional Children's Clinical Hospital, Irkutsk, Russian Federation

²⁹ Volgograd Regional Clinical Cardiology Center, Volgograd, Russian Federation

³⁰ Republic Hospital №1 – National Center of Medicine, Republic of Sakha (Yakutia), Yakutsk, Russian Federation

Yu.Yu. Kulyabin, <https://orcid.org/0000-0002-2361-5847>
A.N. Arkhipov, <https://orcid.org/0000-0003-3234-5436>
A.A. Avramenko, <https://orcid.org/0000-0002-6284-8387>
K.V. Gorbatiykh, <https://orcid.org/0000-0001-5928-1001>
A.V. Gorbatiykh, <https://orcid.org/0000-0003-4017-4198>
K.A. Nalimov, <https://orcid.org/0000-0003-2933-6336>
M.A. Abramyan, <https://orcid.org/0000-0003-4018-6287>
M.V. Boriskov, <https://orcid.org/0000-0002-7064-9935>
S.A. Kovalev, <https://orcid.org/0000-0001-6342-2209>
A.A. Svobodov, <https://orcid.org/0000-0003-2523-5212>
A.V. Kauk, <https://orcid.org/0000-0001-8290-6380>
E.V. Krivoshchekov, <https://orcid.org/0000-0002-0828-3995>
A.A. Shikhranov, <https://orcid.org/0000-0002-0235-7260>
M.V. Plotnikov, <https://orcid.org/0000-0002-3733-0789>
O.A. Egunov, <https://orcid.org/0000-0003-4023-455X>
V.A. Belov, <https://orcid.org/0000-0002-0945-8208>
I.V. Gladyshev, <https://orcid.org/0009-0000-1128-7201>
K.B. Kazantsev, <https://orcid.org/0000-0002-2253-2695>
O.Yu. Kornoukhov, <https://orcid.org/0000-0002-0471-4268>
A.V. Nokhrin, <https://orcid.org/0000-0002-2233-0516>
D.Yu. Petrushenko, <https://orcid.org/0000-0002-2004-3257>
E.S. Efanov, <https://orcid.org/0000-0002-5807-1296>
I.K. Khalivopulo, <https://orcid.org/0000-0002-0661-4076>
D.V. Ryabtsev, <https://orcid.org/0000-0002-0548-5639>
Yu.A. Sobolev, <https://orcid.org/0009-0009-6334-0639>
V.N. Medvedev, <https://orcid.org/0009-0009-6075-1563>
R.Yu. Gavrilov, <https://orcid.org/0000-0002-6237-4177>
N.I. Pavlov, <https://orcid.org/0009-0009-8496-4950>
E.N. Amansakhatova, <https://orcid.org/0009-0008-3193-4160>
E.S. Tarasyuk, <https://orcid.org/0000-0002-8353-7510>

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Abstract

Introduction: Systematic monitoring of outcomes in patients with congenital heart disease (CHD) is essential for improving the quality of care. Since 2024, a national multicenter digital registry designed to consolidate data from the country's leading expert centers has been undergoing pilot implementation in the Russian Federation.

Objective: To assess surgical volumes, the distribution of diagnoses, and in-hospital mortality associated with treatment for CHD and cardiac arrhythmias in the Russian Federation using 2025 registry data.

Methods: We retrospectively analyzed de-identified data from 15,634 patients treated at 32 cardiac surgery centers in the Russian Federation that provide care to patients younger than 18 years with CHD. Procedural complexity was assessed using the RACHS II risk-stratification system. Outcomes were analyzed by age group, including neonates with low birth weight.

Results: Overall in-hospital mortality was 1.30% (vs. 1.42% in 2024). Open surgical procedures accounted for 48.3% of interventions, transcatheter procedures for 37.6%, and procedures for cardiac arrhythmias for 12.8%. The most common CHD diagnoses were atrial septal defect (23.96%), patent ductus arteriosus (22.42%), and ventricular septal defect (15.47%). The highest mortality was observed among neonates undergoing surgery with cardiopulmonary bypass (9.5%).

Conclusion: The 2025 data confirm a sustained decline in overall mortality and support the effectiveness of implementing national standards. Further improvement in neonatal surgery for complex defects remains a priority. Implementation of a unified system enabling patient-level identification and personalized assessment of treatment effectiveness is also essential.

Keywords: congenital heart disease; database of patients undergoing surgery for cardiovascular disease; pediatric cardiac arrhythmias; pediatric cardiac surgery; pediatric cardiovascular surgery; surgical outcomes in congenital heart disease; transcatheter treatment of congenital heart disease

Результаты хирургического лечения врожденных пороков сердца в Российской Федерации за 2025 год

И.А. Сойнов^{1,2}, А.И. Ким^{1,3}, Р.Р. Мовсесян^{1,4}, П.В. Теплов^{1,5}, А.Ю. Миллер^{1,5}, Ю.Ю. Кулябин^{1,2}, А.Н. Архипов^{1,2}, А.А. Авраменко^{1,6}, К.В. Горбатилов^{1,7}, А.В. Горбатиых^{1,8}, К.А. Налимов^{1,9}, М.А. Абрамян^{1,10}, М.В. Борисков^{1,11}, С.А. Ковалев^{1,12}, А.А. Свободов^{1,13}, А.В. Каук^{1,2}, Е.В. Кривошеков^{1,14}, А.А. Шихранов^{1,15}, М.В. Плотников^{1,16}, О.А. Егунов^{1,17}, В.А. Белов^{1,18}, И.В. Гладышев^{1,19}, К.Б. Казанцев^{1,20}, О.Ю. Корноухов^{1,21}, А.В. Нохрин^{1,22}, Д.Ю. Петрушенко^{1,23}, Е.С. Ефанов^{1,24}, И.К. Халивопуло^{1,25}, Д.В. Рябцев^{1,26}, Ю.А. Соболев^{1,27}, В.Н. Медведев^{1,28}, Р.Ю. Гаврилов^{1,29}, Н.И. Павлов^{1,30}, Е.Н. Амансахатова², Е.С. Тарасюк²

Для корреспонденции: Илья Александрович Сойнов, i_sojnov@meshalkin.ru

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¹ Межрегиональная общественная организация детских кардиохирургов «Общество специалистов по врожденным порокам сердца», Санкт-Петербург, Российская Федерация

² Федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр имени академика Е.Н. Мешалкина» Министерства здравоохранения Российской Федерации, Новосибирск, Российская Федерация

³ Федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр сердечно-сосудистой хирургии имени

Нохрин А.В., Петрушенко Д.Ю., Ефанов Е.С., Халивопуло И.К., Рябцев Д.В., Соболев Ю.А., Медведев В.Н., Гаврилов Р.Ю., Павлов Н.И., Амансахатова Е.Н., Тарасюк Е.С. Результаты хирургического лечения врожденных пороков сердца в Российской Федерации за 2025 год. *Патология кровообращения и кардиохирургия*. 2026;30(3):5-35. <https://doi.org/10.21688/1681-3472-2026-3-5-35>

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Вклад авторов

Концепция и дизайн работы: И.А. Соинов, Р.Р. Мовсисян, П.В. Теплов, А.А. Свободов, Е.В. Кривошеков, Е.С. Тарасюк

Сбор и анализ данных: И.А. Соинов, А.Ю. Миллер, Ю.Ю. Кулябин, А.Н. Архипов, А.А. Авраменко, К.В. Горбатилов, А.В. Горбатых, К.А. Налимов, С.А. Ковалев, А.А. Свободов, А.А. Шихранов, М.В. Плотников, О.А. Егунов, В.А. Белов, И.В. Гладышев, К.Б. Казанцев, О.Ю. Корноухов, А.В. Нохрин, Д.Ю. Петрушенко, Е.С. Ефанов, И.К. Халивопуло, Д.В. Рябцев, Ю.А. Соболев, В.Н. Медведев, Р.Ю. Гаврилов, Н.И. Павлов

Статистическая обработка данных: И.А. Соинов, П.В. Теплов, К.А. Налимов, М.А. Абрамян, С.А. Ковалев

Написание статьи: И.А. Соинов, А.Ю. Миллер, Ю.Ю. Кулябин, А.А. Авраменко, К.В. Горбатилов, А.В. Горбатых, К.А. Налимов, А.В. Каук, Е.В. Кривошеков, Е.Н. Амансахатова

Исправление статьи: А.И. Ким, Р.Р. Мовсисян, М.А. Абрамян, Е.В. Кривошеков, Е.С. Тарасюк

Утверждение окончательного варианта статьи: все авторы

ORCID

И.А. Соинов, <https://orcid.org/0000-0003-3691-2848>

А.И. Ким, <https://orcid.org/0000-0003-0065-7419>

Р.Р. Мовсисян, <https://orcid.org/0000-0003-3089-3113>

П.В. Теплов, <https://orcid.org/0000-0002-8798-4975>

А.Ю. Миллер, <https://orcid.org/0000-0003-4969-4640>

Ю.Ю. Кулябин, <https://orcid.org/0000-0002-2361-5847>

А.Н. Архипов, <https://orcid.org/0000-0003-3234-5436>

А.А. Авраменко, <https://orcid.org/0000-0002-6284-8387>

К.В. Горбатилов, <https://orcid.org/0000-0001-5928-1001>

А.В. Горбатых, <https://orcid.org/0000-0003-4017-4198>

К.А. Налимов, <https://orcid.org/0000-0003-2933-6336>

А.Н. Бакулева» Министерства здравоохранения Российской Федерации, Москва, Российская Федерация

⁴ Санкт-Петербургское государственное бюджетное учреждение здравоохранения «Детский городской многопрофильный клинический специализированный центр высоких медицинских технологий», Санкт-Петербург, Российская Федерация

⁵ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии» Министерства здравоохранения Российской Федерации, Красноярск, Российская Федерация

⁶ Государственное бюджетное учреждение здравоохранения «Самарский областной клинический кардиологический диспансер им. В.П. Полякова», Самара, Российская Федерация

⁷ Государственное бюджетное учреждение здравоохранения Тюменской области «Областная клиническая больница № 1», Тюмень, Российская Федерация

⁸ Федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр имени В.А. Алмазова» Министерства здравоохранения Российской Федерации, Санкт-Петербург, Российская Федерация

⁹ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии» Министерства здравоохранения Российской Федерации, Хабаровск, Российская Федерация

¹⁰ Государственное бюджетное учреждение здравоохранения города Москвы «Морозовская детская городская клиническая больница Департамента здравоохранения города Москвы», Москва, Российская Федерация

¹¹ Государственное бюджетное учреждение здравоохранения «Научно-исследовательский институт – Краевая клиническая больница № 1 им. профессора С.В. Очаповского» министерства здравоохранения Краснодарского края, Краснодар, Российская Федерация

¹² Бюджетное учреждение здравоохранения Воронежской области «Воронежская областная клиническая больница № 1», Воронеж, Российская Федерация

¹³ Государственное бюджетное учреждение здравоохранения Московской области «Детский научно-клинический центр имени Л.М. Рошала», Красногорск, Российская Федерация

¹⁴ Федеральное государственное бюджетное учреждение «Федеральный центр высоких медицинских технологий» Министерства здравоохранения Российской Федерации, Калининград, Российская Федерация

¹⁵ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии» Министерства здравоохранения Российской Федерации, Пенза, Российская Федерация

¹⁶ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии» Министерства здравоохранения Российской Федерации, Астрахань, Российская Федерация

¹⁷ Научно-исследовательский институт кардиологии, филиал Федерального государственного бюджетного научного учреждения «Томский национальный исследовательский медицинский центр Российской академии наук», Томск, Российская Федерация

¹⁸ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии имени С.Г. Суханова» Министерства здравоохранения Российской Федерации, Пермь, Российская Федерация

¹⁹ Федеральное государственное бюджетное учреждение «Федеральный центр сердечно-сосудистой хирургии» Министерства здравоохранения Российской Федерации, Челябинск, Российская Федерация

²⁰ Государственное автономное учреждение здравоохранения Свердловской области «Свердловская областная клиническая больница № 1», Екатеринбург, Российская Федерация

²¹ Государственное бюджетное учреждение здравоохранения города Москвы «Детская городская клиническая больница имени Н.Ф. Филатова Департамента здравоохранения города Москвы», Москва, Российская Федерация

²² Федеральное государственное бюджетное образовательное учреждение высшего образования «Санкт-Петербургский государственный педиатрический медицинский университет» Министерства здравоохранения Российской Федерации, Санкт-Петербург, Российская Федерация

²³ Государственное автономное учреждение здравоохранения «Детская республиканская клиническая больница» Министерства здравоохранения Республики Татарстан, Казань, Российская Федерация

²⁴ Государственное бюджетное учреждение здравоохранения «Иркутская ордена "Знак Почета" областная клиническая больница», Иркутск, Российская Федерация

²⁵ Федеральное государственное бюджетное научное учреждение «Научно-исследовательский институт комплексных проблем сердечно-сосудистых заболеваний» Министерства науки и высшего образования Российской Федерации, Кемерово, Российская Федерация

М.А. Абрамян, <https://orcid.org/0000-0003-4018-6287>
М.В. Борисков, <https://orcid.org/0000-0002-7064-9935>
С.А. Ковалев, <https://orcid.org/0000-0001-6342-2209>
А.А. Свободов, <https://orcid.org/0000-0003-2523-5212>
А.В. Каук, <https://orcid.org/0000-0001-8290-6380>
Е.В. Кривошеков, <https://orcid.org/0000-0002-0828-3995>
А.А. Шихранов, <https://orcid.org/0000-0002-0235-7260>
М.В. Плотников, <https://orcid.org/0000-0002-3733-0789>
О.А. Егунов, <https://orcid.org/0000-0003-4023-455X>
В.А. Белов, <https://orcid.org/0000-0002-0945-8208>
И.В. Гладышев, <https://orcid.org/0009-0000-1128-7201>
К.Б. Казанцев, <https://orcid.org/0000-0002-2253-2695>
О.Ю. Корнухов, <https://orcid.org/0000-0002-0471-4268>
А.В. Нохрин, <https://orcid.org/0000-0002-2233-0516>
Д.Ю. Петрушенко, <https://orcid.org/0000-0002-2004-3257>
Е.С. Ефанов, <https://orcid.org/0000-0002-5807-1296>
И.К. Халивопуло, <https://orcid.org/0000-0002-0661-4076>
Д.В. Рябцев, <https://orcid.org/0000-0002-0548-5639>
Ю.А. Соболев, <https://orcid.org/0009-0009-6334-0639>
В.Н. Медведев, <https://orcid.org/0009-0009-6075-1563>
Р.Ю. Гаврилов, <https://orcid.org/0000-0002-6237-4177>
Н.И. Павлов, <https://orcid.org/0009-0009-8496-4950>
Е.Н. Амансахатова, <https://orcid.org/0009-0008-3193-4160>
Е.С. Тарасюк, <https://orcid.org/0000-0002-8353-7510>

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²⁶ Федеральное государственное бюджетное учреждение «Национальный медицинский исследовательский центр трансплантологии и искусственных органов имени академика В.И. Шумакова» Министерства здравоохранения Российской Федерации

²⁷ Государственное бюджетное учреждение здравоохранения Нижегородской области «Детская городская клиническая больница № 1», Нижний Новгород, Российская Федерация

²⁸ Государственное бюджетное учреждение здравоохранения «Иркутская государственная областная детская клиническая больница», Иркутск, Российская Федерация

²⁹ Государственное бюджетное учреждение здравоохранения «Волгоградский областной клинический кардиологический центр», Волгоград, Российская Федерация

³⁰ Государственное автономное учреждение Республики Саха (Якутия) «Республиканская больница № 1 – Национальный центр медицины имени М.Е. Николаева», Якутск, Российская Федерация

Аннотация

Актуальность. Системный мониторинг результатов лечения врожденных пороков сердца (ВПС) является ключевым инструментом повышения качества медицинской помощи. С 2024 г. в Российской Федерации проходит апробацию национальная мультицентровая системная цифровая база данных, позволяющая консолидировать данные ведущих экспертных центров страны.

Цель. Оценить объемы хирургической помощи, структуру патологий и показатели госпитальной летальности при лечении ВПС и нарушений ритма сердца в Российской Федерации по данным регистра за 2025 г.

Методы. Проведен ретроспективный анализ деперсонализированных данных 15 634 пациентов из 32 кардиохирургических центров РФ, оказывающих помощь пациентам до 18 лет с ВПС. Оценка тяжести вмешательств проводилась по шкале RACHS II. Анализировались показатели в разных возрастных группах, включая новорожденных с низкой массой тела.

Результаты. Общая госпитальная летальность составила 1,30 % (в 2024 г. – 1,42 %). Доля открытых операций составила 48,3 %, рентгенэндоваскулярных – 37,6 %, вмешательств при нарушениях ритма сердца – 12,8 %. В структуре ВПС преобладали дефект межпредсердной перегородки (23,96 %), открытый артериальный проток (22,42 %) и дефект межжелудочковой перегородки (15,47 %). Наиболее высокая летальность отмечена в группе новорожденных при операциях в условиях искусственного кровообращения (9,5 %).

Заключение. Данные 2025 г. подтверждают устойчивую тенденцию к снижению общей летальности и эффективности внедрения национальных стандартов. Приоритетным направлением остается совершенствование неонатальной хирургии сложных пороков. Немаловажным является внедрение единой системы, позволяющей проводить персонализированную оценку эффективности на основе идентификации каждого пациента.

Ключевые слова: база данных оперированных пациентов с сердечно-сосудистыми заболеваниями; врожденные пороки сердца; детская кардиохирургия; детская сердечно-сосудистая хирургия; нарушения ритма сердца у детей; результаты хирургического лечения врожденных пороков сердца; эндоваскулярное лечение врожденных пороков сердца



Introduction

The current stage of cardiovascular surgery development in the Russian Federation is characterized by a transition from expansion in volume to qualitative transformation and consolidation of expert experience [1]. Congenital heart disease (CHD) remains one of the most complex and socially significant challenges in pediatrics and pediatric cardiac surgery, requiring both advanced treatment and systematic nationwide analysis of outcomes [2; 3].

According to global epidemiological data, the prevalence of CHD remains stable at approximately 8–10 cases per 1,000 live births [4; 5]. At the same time, improvements in prenatal diagnosis and the development of screening programs in the Russian Federation have enabled more accurate characterization of the disease spectrum and earlier initiation of treatment, often within the first hours of life [6]. This, in turn, necessitates continuous monitoring of the effectiveness of existing treatment protocols and the introduction of innovative approaches.

The year 2024 marked an important milestone in quality assurance for pediatric cardiac surgery, with the launch of a nationwide multicenter database on CHD. Developed under the auspices of the Interregional Public Organization of Pediatric Cardiac Surgeons "Society of Congenital Heart Disease Specialists," this resource made it possible, for the first time, to obtain an objective and standardized nationwide overview of surgical activity and treatment outcomes [3]. The organization played a key role in coordinating collaboration among centers, consolidating data, and organizing their analysis, thereby ensuring a high degree of comparability. Baseline data for 2024 established a foundation for longitudinal analysis and assessment of trends in the field.

In 2025, operation of the integrated digital database was continued and expanded. Whereas the preceding reporting period provided a snapshot of the service [1], the 2025 data make it possible to evaluate the persistence of identified trends, including further growth in the proportion of transcatheter procedures, the effectiveness of hybrid strategies for critical CHD, and advances in the treatment of the most vulnerable patients, particularly neonates with extremely low birth weight.

This 2025 report is based on data from leading cardiac surgery centers in the Russian Federation. Its purpose is not only to quantify specialized care and mortality, but also to identify priorities for further development of the national healthcare system. Systematic analysis of complications and RACHS II risk stratification provide a basis for uniform national standards intended to

deliver the safest and most effective care to every child, irrespective of region of residence or defect complexity.

Methods

This study was based on a retrospective analysis of data aggregated in the national multicenter database. Since 2024, the integrated digital database of patients undergoing surgery for CHD has been undergoing pilot implementation under the supervision of A.I. Kim, Chief External Expert in Pediatric Cardiovascular Surgery of the Ministry of Health of the Russian Federation.

Because this retrospective study used fully de-identified data collected within the national database, approval by a local ethics committee and informed consent from patients were not required under Russian law and the Declaration of Helsinki.

The study continues the systematic monitoring program initiated by the Interregional Public Organization "Society of Congenital Heart Disease Specialists," with methodological support from the Ministry of Health of the Russian Federation. Use of the data-collection system piloted during the preceding reporting period ensured continuity and comparability of the findings.

The analysis included de-identified clinical data from patients with CHD and cardiac arrhythmias who underwent surgical or interventional treatment between January 1 and December 31, 2025. The study encompassed leading national cardiac surgery centers designated as expert institutions. A standardized data-collection protocol introduced when the registry was established in 2024 harmonized demographic, anatomical, and procedural variables and minimized the risk of methodological variation among centers.

The study cohort included all procedures performed for CHD or cardiac arrhythmias during the reporting period, irrespective of patient age or body weight. Eligibility required open surgical repair, a transcatheter intervention, or an interventional electrophysiology procedure. Patients receiving exclusively conservative treatment were excluded.

For detailed analysis, the cohort was stratified by the following parameters:

Age: neonates (0–28 days), infants (29 days to 1 year), and older pediatric patients (1–18 years).

Procedural modality: cardiac surgery, transcatheter intervention, and procedures for arrhythmias.

Surgical status: primary versus repeat procedures (reoperations), and definitive versus palliative procedures.

Invasiveness: proportion of procedures performed using an extracorporeal circuit (cardiopulmonary bypass).

Prognostic complexity and procedural severity were assessed using the international RACHS II risk-

Table 1. Distribution of surgical volumes for CHD and cardiac arrhythmias among medical centers in the Russian Federation in 2025

Medical institution	Procedures, n
Bakulev National Medical Research Center for Cardiovascular Surgery, Moscow	2,098
Meshalkin National Medical Research Center, Novosibirsk	1,568
Federal Center for Cardiovascular Surgery, Penza	1,115
Almazov National Medical Research Center, St. Petersburg	896
Federal Center for Cardiovascular Surgery, Astrakhan	848
Morozov Children's City Clinical Hospital, Moscow	820
Cardiology Research Institute, Tomsk National Research Medical Center, Tomsk	617
S.G. Sukhanov Federal Center for Cardiovascular Surgery, Perm	603
Children's Regional Clinical Hospital, Krasnodar	596
Federal Center for Cardiovascular Surgery, Krasnoyarsk	590
Federal Center for Cardiovascular Surgery, Chelyabinsk	531
Pediatric City Multidisciplinary Clinical Specialized Center for High Medical Technologies, St. Petersburg	504
L.M. Roshal Children's Research and Clinical Center, Krasnogorsk	480
Regional Children's Clinical Hospital, Yekaterinburg	471
N.F. Filatov Children's City Clinical Hospital, Moscow	404
Federal Center for Cardiovascular Surgery, Khabarovsk	376
Saint Petersburg State Pediatric Medical University, St. Petersburg	323
Children's Republican Clinical Hospital, Kazan	321
Irkutsk Regional Clinical Hospital, Irkutsk	306
Research Institute for Complex Issues of Cardiovascular Diseases, Kemerovo	281
Regional Clinical Hospital No. 1, Tyumen	257
District Cardiology Dispensary "Center for Diagnostics and Cardiovascular Surgery," Surgut	224
Federal Center for High Medical Technologies, Kaliningrad	221
Shumakov National Medical Research Center of Transplantology and Artificial Organs, Moscow	205
V.P. Polyakov Samara Regional Clinical Cardiology Dispensary, Samara	204
Children's City Clinical Hospital No. 1, Nizhny Novgorod	178
Regional Children's Clinical Hospital, Rostov-on-Don	160
Irkutsk State Regional Children's Clinical Hospital, Irkutsk	131
Volgograd Regional Clinical Cardiology Center, Volgograd	127
Voronezh Regional Children's Clinical Hospital No. 1, Voronezh	72
Republican Hospital No. 1–National Center of Medicine, Yakutsk	70
Regional Children's Clinical Hospital, Omsk	27

stratification system [7]. The primary endpoint was in-hospital mortality, defined as death during the index hospitalization. Mortality was calculated per procedure rather than per individual patient.

Data were centralized in a secure electronic repository at the Krasnoyarsk Federal Center for Cardiovascular Surgery, which serves as the registry's central analytical hub. The database architecture ensures strict compliance with confidentiality and data-storage reliability requirements, while multistage quality control of entered variables supports the validity of the statistical findings.

Results

Overall data

In 2025, 15,634 surgical procedures for CHD and cardiac arrhythmias were performed in children at 32 cardiac surgery centers in the Russian Federation. Overall in-hospital mortality was 1.30% (203 deaths). The favorable downward trend persisted compared with 2024, when overall mortality was 1.42%. Aggregate surgical volumes by center are presented in Table 1.

The distribution of procedures by treatment modality is presented in Table 2.

Table 3 presents center-specific cardiac surgery volumes among neonates at 30 cardiac surgery centers.

Table 4 presents center-specific cardiac surgery volumes among infants excluding neonates at 32 cardiac surgery centers.

Table 5 presents center-specific cardiac surgery volumes among children older than 1 year at 32 cardiac surgery centers.

Age at surgery

Analysis of the 2025 age distribution showed that children older than 1 year constituted the largest group, with 10,949 procedures (70.0%). This group had the most favorable prognosis and the lowest in-hospital mortality, at 0.37%.

A total of 4,685 procedures (30.0%) were performed in children during the first year of life, including neonates. Mortality in this cohort was 3.4%, as expected higher than among older children because of the greater severity and anatomical complexity of the defects treated.

The registry placed particular emphasis on neonates (0–28 days), the most vulnerable patient group. A total of 1,507 procedures were performed in this group, accounting for 9.5% of all interventions, with a mortality rate of 6.47%.

Within the neonatal group, low-birth-weight infants weighing less than 2.5 kg were analyzed separately. They underwent 253 procedures, representing 17.1% of all neonatal procedures. Mortality in this subgroup was 4.7%,

Table 2. Distribution of procedures by treatment modality

Medical institution	Surgery	Transcatheter procedures	Arrhythmia procedures
Bakulev Center, Moscow	1,340	643	115
Meshalkin Center, Novosibirsk	660	696	212
Federal Center, Penza	415	689	11
Almazov Center, St. Petersburg	336	315	245
Federal Center, Astrakhan	421	427	0
Morozov Hospital, Moscow	183	380	257
Cardiology Research Institute, Tomsk	221	110	286
S.G. Sukhanov Federal Center, Perm	315	203	85
Children's Regional Clinical Hospital, Krasnodar	305	140	151
Federal Center, Krasnoyarsk	284	171	135
Federal Center, Chelyabinsk	281	148	102
Pediatric City Multidisciplinary Center, St. Petersburg	251	202	51
L.M. Roshal Center, Krasnogorsk	225	159	96
Regional Children's Clinical Hospital, Yekaterinburg	231	195	45
N.F. Filatov Hospital, Moscow	244	156	4
Federal Center, Khabarovsk	180	131	65
Saint Petersburg State Pediatric Medical University	144	177	2
Children's Republican Clinical Hospital, Kazan	174	146	11
Irkutsk Regional Clinical Hospital	125	90	91
Research Institute for Complex Issues of Cardiovascular Diseases, Kemerovo	122	159	0
Regional Clinical Hospital No. 1, Tyumen	127	113	17
District Cardiology Dispensary, Surgut	99	83	42
Federal Center for High Medical Technologies, Kaliningrad	152	49	20
Shumakov Center, Moscow	122	82	1
V.P. Polyakov Dispensary, Samara	110	51	43
Children's City Clinical Hospital No. 1, Nizhny Novgorod	79	99	0
Regional Children's Clinical Hospital, Rostov-on-Don	127	26	7
Irkutsk State Regional Children's Clinical Hospital	47	84	0
Volgograd Regional Clinical Cardiology Center	105	17	5
Voronezh Regional Children's Clinical Hospital No. 1	54	17	1
Republican Hospital No. 1–National Center of Medicine, Yakutsk	46	24	0
Regional Children's Clinical Hospital, Omsk	22	5	0

Note. Arrhythmia procedures comprise interventions for cardiac rhythm disorders; transcatheter procedures comprise fluoroscopy-guided diagnostic and therapeutic interventions.

slightly lower than the overall neonatal rate; this may indicate the effectiveness of specialized perioperative management and neonatal care protocols.

Among infants aged 29 days to 1 year, 3,178 procedures were performed (20.5%), with a mortality rate of 2.15%.

Types of procedures

The distribution of interventions continued to show a relative balance between open and interventional approaches, with a gradual increase in the latter. Open cardiac surgery accounted for 7,547 procedures (48.3%).

Table 3. Cardiac surgery volumes among neonates

Medical institution	Neonates (0–28 days), n
Bakulev Center, Moscow	239
Meshalkin Center, Novosibirsk	131
Almazov Center, St. Petersburg	113
N.F. Filatov Hospital, Moscow	97
Pediatric City Multidisciplinary Center, St. Petersburg	90
Regional Children's Clinical Hospital, Yekaterinburg	86
Federal Center, Astrakhan	67
Children's Regional Clinical Hospital, Krasnodar	66
L.M. Roshal Center, Krasnogorsk	60
Saint Petersburg State Pediatric Medical University	60
Federal Center, Krasnoyarsk	59
S.G. Sukhanov Federal Center, Perm	54
Morozov Hospital, Moscow	53
Irkutsk Regional Clinical Hospital	46
Federal Center, Penza	42
Children's Republican Clinical Hospital, Kazan	35
Federal Center, Chelyabinsk	31
Federal Center, Khabarovsk	30
Cardiology Research Institute, Tomsk	23
Research Institute for Complex Issues of Cardiovascular Diseases, Kemerovo	22
District Cardiology Dispensary, Surgut	22
Regional Children's Clinical Hospital, Rostov-on-Don	20
V.P. Polyakov Dispensary, Samara	17
Children's City Clinical Hospital No. 1, Nizhny Novgorod	11
Regional Clinical Hospital No. 1, Tyumen	9
Federal Center for High Medical Technologies, Kaliningrad	8
Voronezh Regional Children's Clinical Hospital No. 1	7
Volgograd Regional Clinical Cardiology Center	6
Irkutsk State Regional Children's Clinical Hospital	2
Republican Hospital No. 1–National Center of Medicine, Yakutsk	1

Table 4. Cardiac surgery volumes among infants excluding neonates

Medical institution	Children aged 29 days to 1 year, n
Bakulev Center, Moscow	521
Meshalkin Center, Novosibirsk	317
Federal Center, Penza	231
Federal Center, Astrakhan	189
Almazov Center, St. Petersburg	157
Federal Center, Krasnoyarsk	130
Children's Regional Clinical Hospital, Krasnodar	124
N.F. Filatov Hospital, Moscow	124
Pediatric City Multidisciplinary Center, St. Petersburg	120
L.M. Roshal Center, Krasnogorsk	116
Saint Petersburg State Pediatric Medical University	106
Cardiology Research Institute, Tomsk	105
Federal Center, Chelyabinsk	99
Federal Center, Khabarovsk	92
S.G. Sukhanov Federal Center, Perm	86
Morozov Hospital, Moscow	82
Regional Children's Clinical Hospital, Yekaterinburg	81
Children's Republican Clinical Hospital, Kazan	67
Federal Center for High Medical Technologies, Kaliningrad	61
Regional Clinical Hospital No. 1, Tyumen	51
Regional Children's Clinical Hospital, Rostov-on-Don	51
Irkutsk Regional Clinical Hospital	48
V.P. Polyakov Dispensary, Samara	43
Research Institute for Complex Issues of Cardiovascular Diseases, Kemerovo	39
Volgograd Regional Clinical Cardiology Center	36
Children's City Clinical Hospital No. 1, Nizhny Novgorod	29
District Cardiology Dispensary, Surgut	26
Voronezh Regional Children's Clinical Hospital No. 1	12
Shumakov Center, Moscow	11
Irkutsk State Regional Children's Clinical Hospital	10
Regional Children's Clinical Hospital, Omsk	9
Republican Hospital No. 1–National Center of Medicine, Yakutsk	5

Table 5. Cardiac surgery volumes among children older than 1 year

Medical institution	Children older than 1 year, <i>n</i>
Bakulev Center, Moscow	1,338
Meshalkin Center, Novosibirsk	1,120
Federal Center, Penza	842
Morozov Hospital, Moscow	685
Almazov Center, St. Petersburg	626
Federal Center, Astrakhan	592
Cardiology Research Institute, Tomsk	489
S.G. Sukhanov Federal Center, Perm	463
Children's Regional Clinical Hospital, Krasnodar	406
Federal Center, Krasnoyarsk	401
Federal Center, Chelyabinsk	401
L.M. Roshal Center, Krasnogorsk	304
Regional Children's Clinical Hospital, Yekaterinburg	304
Pediatric City Multidisciplinary Center, St. Petersburg	294
Federal Center, Khabarovsk	254
Children's Republican Clinical Hospital, Kazan	229
Research Institute for Complex Issues of Cardiovascular Diseases, Kemerovo	220
Irkutsk Regional Clinical Hospital	212
Regional Clinical Hospital No. 1, Tyumen	197
Shumakov Center, Moscow	194
N.F. Filatov Hospital, Moscow	183
District Cardiology Dispensary, Surgut	176
Saint Petersburg State Pediatric Medical University	157
Federal Center for High Medical Technologies, Kaliningrad	152
V.P. Polyakov Dispensary, Samara	144
Children's City Clinical Hospital No. 1, Nizhny Novgorod	138
Irkutsk State Regional Children's Clinical Hospital	119
Regional Children's Clinical Hospital, Rostov-on-Don	89
Volgograd Regional Clinical Cardiology Center	85
Republican Hospital No. 1–National Center of Medicine, Yakutsk	64
Voronezh Regional Children's Clinical Hospital No. 1	53
Regional Children's Clinical Hospital, Omsk	18

This treatment modality involves the greatest degree of surgical trauma, as reflected in a mortality rate of 2.49% (188 deaths).

Transcatheter interventions accounted for 5,987 procedures (37.6%) and demonstrated a favorable safety profile, with mortality of only 0.2% (13 deaths).

Procedures for cardiac arrhythmias accounted for 12.8% of the total (2100 procedures). A key achievement during the reporting period was zero mortality in this category, confirming the high degree of technical maturity of interventional electrophysiology.

Procedural characteristics

According to registry data, 54.0% of procedures (*n* = 7,599) were primary interventions, whereas repeat procedures accounted for 13.6% (*n* = 1,908). As in the preceding reporting period, information on whether the intervention was primary was unavailable for a proportion of procedures.

Among open procedures with a verified surgical-strategy status (7,547 cases in total), the great majority were definitive operations (*n* = 5,879; 77.9%). Palliative procedures accounted for 22.1% (*n* = 1,668).

This calculation applies only to open procedures for which the relevant registry information was available. The absence of complete classification for some cases indicates that this variable remains incompletely documented.

Procedures performed with cardiopulmonary bypass

The use of cardiopulmonary bypass (CPB) is an established indicator of high procedural complexity and surgical invasiveness. In 2025, 5,945 procedures (38% of all interventions) were performed with CPB. In-hospital mortality in this group was 2.6% (160 deaths).

Detailed analysis confirmed a direct association between outcomes after CPB procedures and patient age.

Neonates: 645 procedures were performed with CPB; mortality was 9.5%, reflecting the extreme severity of illness in this patient group.

Children younger than 1 year overall: 2,088 procedures were performed with CPB; mortality was 3.9%.

Children older than 1 year: 2,994 procedures were performed with CPB; this group had the lowest mortality among open procedures, at 1.2% (37 deaths).

Thus, the 2025 data confirm that high standards of care have been maintained, while the greatest potential for further reduction in mortality lies in neonatal surgery performed with CPB.

In 2025, 10,499 cases of CHD were newly diagnosed. The distribution of diagnostic categories is presented in Table 6.

As shown in Table 6, the most common CHD diagnoses were atrial septal defect (23.96%), patent ductus arteriosus

Table 6. Types of congenital heart disease diagnosed in 2025

CHD diagnosis	Patients, <i>n</i>	Percentage of total, %
Atrial septal defect	2,516	23.96
Patent ductus arteriosus	2,354	22.42
Ventricular septal defect	1,624	15.47
Coarctation of the aorta	716	6.82
Valvular pulmonary stenosis	557	5.31
Tetralogy of Fallot	395	3.76
Transposition of the great arteries	289	2.75
Atrioventricular septal defect	247	2.35
Vascular ring	219	2.09
Single ventricle	219	2.09
Aortic valve stenosis	218	2.08
Partial anomalous pulmonary venous connection	210	2.00
Pulmonary atresia with ventricular septal defect	142	1.35
Total anomalous pulmonary venous connection	106	1.01
Right ventricular outflow tract obstruction	76	0.72
Double-outlet right ventricle	70	0.67
Aortic regurgitation	63	0.60
Hypoplastic left heart syndrome	53	0.50
Left ventricular outflow tract obstruction	48	0.46
Interrupted aortic arch	47	0.45
Mitral regurgitation	39	0.37
Pulmonary atresia with intact ventricular septum	35	0.33
Anomalous origin of a coronary artery from the pulmonary artery	35	0.33
Mitral stenosis	34	0.32
Ascending aortic aneurysm	32	0.30
Supravalvar aortic stenosis	26	0.25
Supravalvar mitral ring	25	0.24
Ebstein anomaly	24	0.23
Cor triatriatum sinister	23	0.22
Hypertrophic cardiomyopathy	19	0.18
Aortopulmonary window	17	0.16
Congenitally corrected transposition of the great arteries	5	0.05
Systemic venous anomalies	4	0.04
Aorta–left ventricular tunnel	4	0.04
Anomalous origin of a pulmonary artery from the aorta	4	0.04
Common arterial trunk	4	0.04
Total	10,499	100

Note. CHD, congenital heart disease.

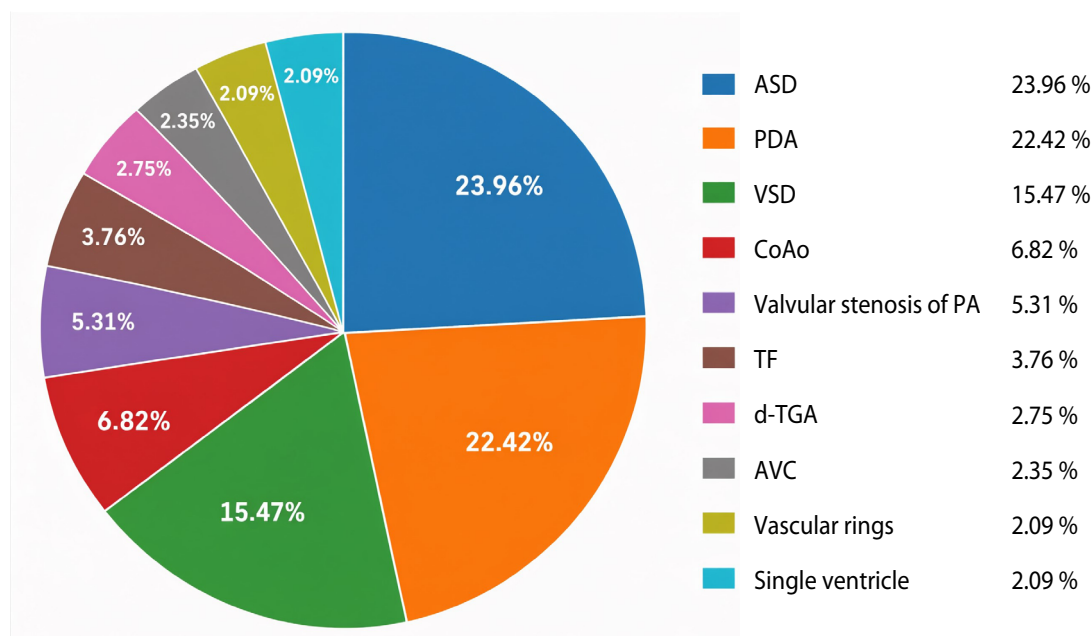


Fig. 1. Most common congenital heart diseases

Note. ASD, atrial septal defect; PDA, patent ductus arteriosus; VSD, ventricular septal defect; CoAo, coarctation of the aorta; PA, pulmonary artery; TF, tetralogy of Fallot; TGA, transposition of the great arteries; AVC, atrioventricular canal; SV, single ventricle.

(22.42%), ventricular septal defect (15.47%), coarctation of the aorta (6.82%), valvular pulmonary stenosis (5.31%), tetralogy of Fallot (3.76%), transposition of the great arteries (2.75%), atrioventricular septal defect (2.35%), vascular rings (2.09%), and single ventricle (2.09%) (Fig. 1).

All procedures were assigned to risk categories according to the RACHS II risk stratification system. The distribution of procedures in RACHS II risk category 1 is presented in Table 7.

As shown in Table 7, a total of 9,098 category 1 procedures were performed, with a mortality rate of 0.30% (27 patients).

The distribution of procedures in RACHS II risk category 2 is presented in Table 8.

As shown in Table 8, a total of 4,886 category 2 procedures were performed, with a mortality rate of 1.04% (51 patients).

The distribution of procedures in RACHS II risk category 3 is presented in Table 9.

As shown in Table 9, a total of 680 category 3 procedures were performed, with a mortality rate of 7.2% (49 patients).

The distribution of procedures in RACHS II risk category 4 is presented in Table 10.

As shown in Table 10, a total of 903 category 4 procedures were performed, with a mortality rate of 6.42% (58 patients).

The distribution of procedures in RACHS II risk category 5 is presented in Table 11.

As shown in Table 11, a total of 67 category 5 procedures were performed, with a mortality rate of 26.86% (18 patients).

The graphical representation of RACHS II risk stratification for surgical repair across all age groups is shown in Fig. 2.

RACHS II risk stratification in neonates (≤ 28 days of age)

A total of 1,507 procedures were performed in neonates. Overall mortality was 6.1% (92 patients). Of these procedures, 667 (45%) were performed with cardiopulmonary bypass (CPB); mortality in this subgroup was 9.5%. The distribution of procedures in RACHS II risk category 1 among neonates is presented in Table 12.

As shown in Table 12, a total of 470 category 1 procedures were performed, with a mortality rate of 1.06% (5 patients).

The distribution of procedures in RACHS II risk category 2 is presented in Table 13.

As shown in Table 13, a total of 338 category 2 procedures were performed, with a mortality rate of 4.43% (15 patients).

The distribution of procedures in RACHS II risk category 3 is presented in Table 14.

Table 7. RACHS II risk category 1 for surgical repair of congenital heart disease

Procedure	Number of procedures	Mortality, <i>n</i> (%)
ASD closure	1,868	1 (0.05)
Radiofrequency ablation of accessory pathways	1,642	0 (0)
VSD closure	1,299	10 (0.76)
Transcatheter ASD closure with an occluder	925	0 (0)
Coarctation of the aorta repair	501	7 (1.39)
Occlusion of major aortopulmonary collateral arteries	439	0 (0)
Balloon pulmonary valvuloplasty	342	0 (0)
Vascular ring division	215	0 (0)
Partial anomalous pulmonary venous return repair	213	0 (0)
Epicardial permanent pacemaker implantation	207	0 (0)
Aortic valve repair	171	1 (0.58)
Partial atrioventricular septal defect repair	123	1 (0.81)
Transvenous permanent pacemaker implantation	114	0 (0)
Aortic valve replacement	110	2 (1.8)
Pulmonary valve replacement	96	0 (0)
Transcatheter VSD closure with an occluder	70	0 (0)
Veno-venous collateral occlusion	59	0 (0)
Pulmonary valvotomy	59	0 (0)
Tricuspid valve repair	55	0 (0)
Resection of a fibromuscular membrane	55	0 (0)
Cone reconstruction for Ebstein anomaly	54	1 (1.9)
Balloon aortic valvuloplasty	53	1 (2)
Main pulmonary artery reconstruction	48	1 (2.08)
Supravalvar aortic stenosis repair	48	0 (0)
Extended LVOT myectomy	42	2 (4.7)
Relief of LVOT obstruction	37	0 (0)
Resection of the narrowed aortic segment with aortic graft replacement	28	0 (0)
Implantable cardioverter-defibrillator implantation	26	0 (0)
Repair of a left atrial membrane	24	0 (0)
Ozaki procedure	18	0 (0)
Implantable loop recorder implantation	15	0 (0)
Complete repair of PAPVR to the inferior vena cava	11	0 (0)
Aorto–left ventricular tunnel repair	7	0 (0)
VSD closure in ccTGA	6	0 (0)
Closure of previously created fenestrations	4	0 (0)
Pericardiectomy	3	0 (0)
Surgical repair of cardiac and great-vessel trauma	3	0 (0)
Other procedures	108	0 (0)

Note. ASD, atrial septal defect; AVSD, atrioventricular septal defect; ccTGA, congenitally corrected transposition of the great arteries; LVOT, left ventricular outflow tract; MAPCAs, major aortopulmonary collateral arteries; PAPVR, partial anomalous pulmonary venous return; VSD, ventricular septal defect.

Table 8. RACHS II risk category 2 for surgical repair of congenital heart disease

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Transcatheter PDA closure with an occluder or coil	1,968	0 (0)
PDA ligation or clipping	949	1 (0.10)
Balloon angioplasty or stenting of the great vessels	318	1 (0.3)
Balloon angioplasty of the pulmonary artery branches	275	1 (0.4)
Right ventricle-to-pulmonary artery conduit implantation	197	4 (2.03)
Complete repair of tetralogy of Fallot with a transannular patch	170	6 (3.52)
Complete atrioventricular septal defect repair	154	5 (3.24)
Arterial switch operation	144	13 (9.02)
Bidirectional cavopulmonary anastomosis	110	4 (3.63)
Complete repair of tetralogy of Fallot with preservation of the pulmonary valve annulus	107	0 (0)
Relief of RVOT obstruction	101	5 (4.95)
Mitral valve repair	60	1 (1.6)
Fontan procedure	60	1 (1.66)
Pulmonary artery branch stenting	53	3 (5.7)
Repair of anomalous origin of a coronary artery from the pulmonary artery	38	1 (2.63)
Coarctation repair with VSD closure	37	2 (5.4)
Pulmonary artery branch reconstruction	34	1 (2.94)
Resection of a supravalvular mitral ring	25	0 (0)
Complete repair of tetralogy of Fallot with pulmonary artery conduit implantation	23	1 (4.3)
Removal of intracardiac foreign bodies	18	0 (0)
Systemic venous stenting	14	0 (0)
Coronary fistula closure	6	0 (0)
Hemi-Fontan procedure	5	1 (20)
Thrombectomy from the cardiac chambers	4	0 (0)
Repair of anomalous origin of a pulmonary artery from the aorta	4	0 (0)
Left ventricular aneurysm resection	3	0 (0)
RVOT aneurysm resection	3	0 (0)
Kawashima procedure	2	0 (0)
Coronary artery bypass grafting	2	0 (0)
Senning procedure	1	0 (0)
Mustard procedure	1	0 (0)

Note. AVSD, atrioventricular septal defect; PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Table 9. RACHS II risk category 3 for surgical repair of congenital heart disease

Procedure	Number of procedures	Mortality, n (%)
Rashkind procedure	86	7 (8.13)
Redo pulmonary valve replacement	68	0 (0)
Ross procedure	56	3 (5.4)
Arterial switch operation with VSD closure	56	6 (10.7)
Aortic root replacement	53	5 (9.43)
Aortic arch reconstruction for interrupted aortic arch	52	2 (3.84)
Complete repair of pulmonary atresia with VSD	51	9 (17.64)
Mitral valve replacement	42	2 (4.7)
Complete repair of transposition of the great arteries with VSD and LVOT obstruction	27	4 (14.8)
Construction of a left ventricle-to-aorta tunnel	26	0 (0)
Heart transplantation	23	3 (13)
Resection of cardiac tumors	22	0 (0)
Unifocalization of the pulmonary arteries	17	1 (5.88)
Redo mitral valve replacement	14	0 (0)
Redo tricuspid valve replacement	14	0 (0)
ASD stenting	12	0 (0)
Left ventricular assist device implantation	12	2 (16.7)
Rastelli procedure	12	0 (0)
Nikaidoh procedure	8	5 (62.5)
Double-switch procedure	6	0 (0)
Tricuspid valve replacement	5	0 (0)
One-and-a-half ventricular repair	4	0 (0)
Redo aortic valve replacement	4	0 (0)
Systemic AV valve replacement in ccTGA	4	0 (0)
Yamagishi procedure	2	0 (0)
Multiple redo valve replacement	2	0 (0)
Tricuspid valve replacement with a valved homograft	1	0 (0)
Mitral valve replacement with a valved homograft	1	0 (0)

Note. ASD, atrial septal defect; AV, atrioventricular; ccTGA, congenitally corrected transposition of the great arteries; LVOT, left ventricular outflow tract; VSD, ventricular septal defect.

Table 10. RACHS II risk category 4 for surgical repair of congenital heart disease

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Pulmonary artery banding	320	10 (3.12)
Systemic-to-pulmonary artery shunt	118	11 (9.32)
Complete repair of total anomalous pulmonary venous return	99	11 (11.11)
Resection of the narrowed aortic segment with main pulmonary artery banding	84	5 (6)
PDA stenting	71	1 (1.40)
Pulmonary artery branch banding with PDA stenting	41	7 (17.07)
Direct aortopulmonary anastomosis	38	6 (15.8)
RVOT stenting	26	1 (3.8)
Complete repair of common arterial trunk	25	3 (12)
Pulmonary vein stenosis repair	23	3 (13)
Pulmonary artery debanding	19	0 (0)
Aortopulmonary window repair	16	0 (0)
Right ventricle-to-pulmonary artery shunt	9	0 (0)
Repair of systemic venous return anomalies	7	0 (0)
Repair of common arterial trunk with interrupted aortic arch	3	0 (0)
Systemic-to-pulmonary artery shunt closure	2	0 (0)
Fontan takedown	2	0 (0)

Note. PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract.

Table 11. RACHS II risk category 5 for surgical repair of congenital heart disease

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Norwood procedure	52	15 (28.84)
Damus–Kaye–Stansel procedure	13	3 (23.1)
Yasui procedure	2	0 (0)

As shown in Table 14, a total of 188 category 3 procedures were performed, with a mortality rate of 9.57% (18 patients).

The distribution of procedures in RACHS II risk category 4 is presented in Table 15.

As shown in Table 15, a total of 466 category 4 procedures were performed, with a mortality rate of 8.79% (41 patients).

The distribution of procedures in RACHS II risk category 5 is presented in Table 16.

As shown in Table 16, a total of 45 category 5 procedures were performed, with a mortality rate of 28.9% (13 patients).

The graphical representation of RACHS II risk stratification in neonates is shown in Fig. 3.

RACHS II risk stratification in infants (29 days to 12 months of age)

A total of 3,178 procedures were performed in infants, with an overall mortality rate of 2.22% (70 patients). Of these, 2,088 procedures (65.3% of the total) were performed with cardiopulmonary bypass (CPB); mortality

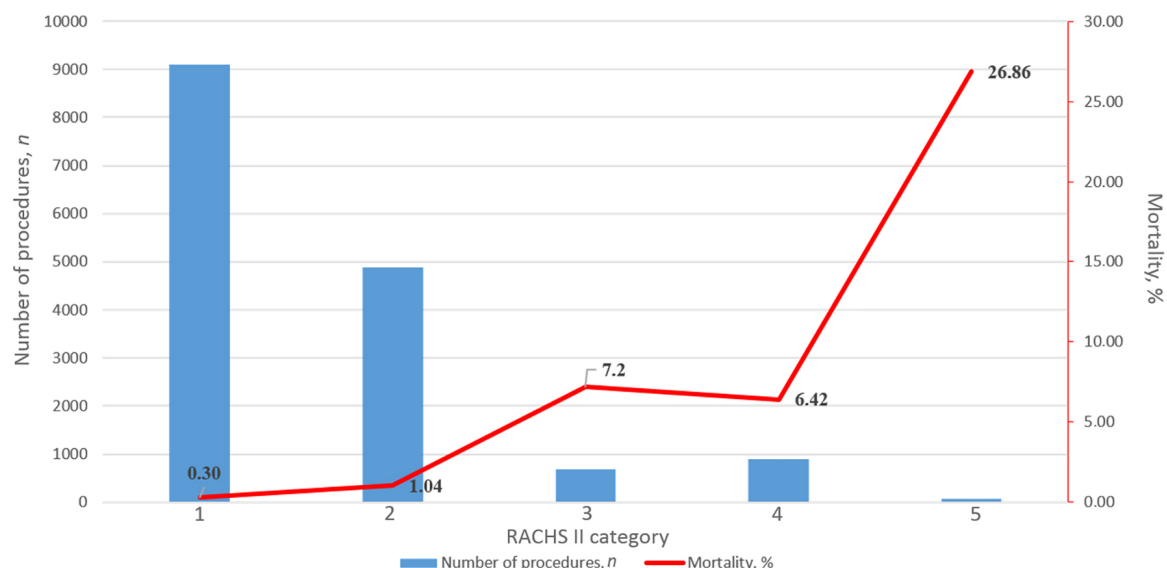


Fig. 2. RACHS II risk stratification for surgical repair across all age groups

Note. Mortality percentages were calculated relative to the total number of procedures in each category.

Table 12. RACHS II risk category 1 for surgical repair of congenital heart disease in neonates

Procedure	Number of procedures	Mortality, n (%)
Coarctation of the aorta repair	266	4 (1.5)
Balloon pulmonary valvuloplasty	65	0 (0)
Aortic valve repair	27	0 (0)
VSD closure	22	0 (0)
Balloon aortic valvuloplasty	20	0 (0)
Vascular ring division	19	0 (0)
Occlusion of MAPCAs	5	0 (0)
Epicardial permanent pacemaker implantation	5	0 (0)
Pulmonary valvotomy	4	0 (0)
VSD closure in ccTGA	3	0 (0)
Transvenous permanent pacemaker implantation	2	0 (0)
Cone reconstruction for Ebstein anomaly	2	0 (0)
Radiofrequency ablation of accessory pathways	1	0 (0)
Tricuspid valve repair	1	1 (100)
PAPVR repair	1	0 (0)
Veno-venous collateral occlusion	1	0 (0)
Resection of the narrowed aortic segment with aortic graft replacement	1	0 (0)
Other procedures	25	0 (0)

Note. ccTGA, congenitally corrected transposition of the great arteries; MAPCAs, major aortopulmonary collateral arteries; PAPVR, partial anomalous pulmonary venous return; VSD, ventricular septal defect.

Table 13. RACHS II risk category 2 for surgical repair of congenital heart disease in neonates

Procedure	Number of procedures	Mortality, n (%)
Arterial switch operation	138	11 (8)
PDA ligation or clipping	121	1 (0.8)
Balloon angioplasty or stenting of the great vessels	31	1 (3.2)
Coarctation repair with VSD closure	15	1 (6.7)
Relief of RVOT obstruction	10	1 (10.0)
Complete repair of TOF with a transannular patch	7	0 (0)
Transcatheter PDA closure with an occluder or coil	4	0 (0)
Balloon angioplasty of the pulmonary artery branches	2	0 (0)
Repair of anomalous origin of a coronary artery from the pulmonary artery	3	0 (0)
Repair of anomalous origin of a pulmonary artery from the aorta	2	0 (0)
Right ventricle-to-pulmonary artery conduit implantation	1	0 (0)
Complete AVSD repair	1	0 (0)
Mitral valve repair	1	0 (0)
Thrombectomy from the cardiac chambers	1	0 (0)
Pulmonary artery branch reconstruction	1	0 (0)

Note. AVSD, atrioventricular septal defect; PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Table 14. RACHS II risk category 3 for surgical repair of congenital heart disease in neonates

Procedure	Number of procedures	Mortality, n (%)
Rashkind procedure	70	6 (8.6)
Arterial switch operation with VSD closure	44	3 (6.8)
Aortic arch reconstruction for interrupted aortic arch	39	2 (5.1)
Complete repair of transposition of the great arteries with VSD and LVOT obstruction	8	3 (37.5)
Resection of cardiac tumors	5	0 (0)
Complete repair of pulmonary atresia with VSD	4	0 (0)
ASD stenting	4	0 (0)
Nikaidoh procedure	4	3 (75)
Aortic root replacement	3	1 (33.3)
Redo pulmonary valve replacement	2	0 (0)
Unifocalization of the pulmonary arteries	2	0 (0)
Ross procedure	1	0 (0)
Construction of a left ventricle-to-aorta tunnel	1	0 (0)
Yamagishi procedure	1	0 (0)

Note. ASD, atrial septal defect; LVOT, left ventricular outflow tract; VSD, ventricular septal defect.

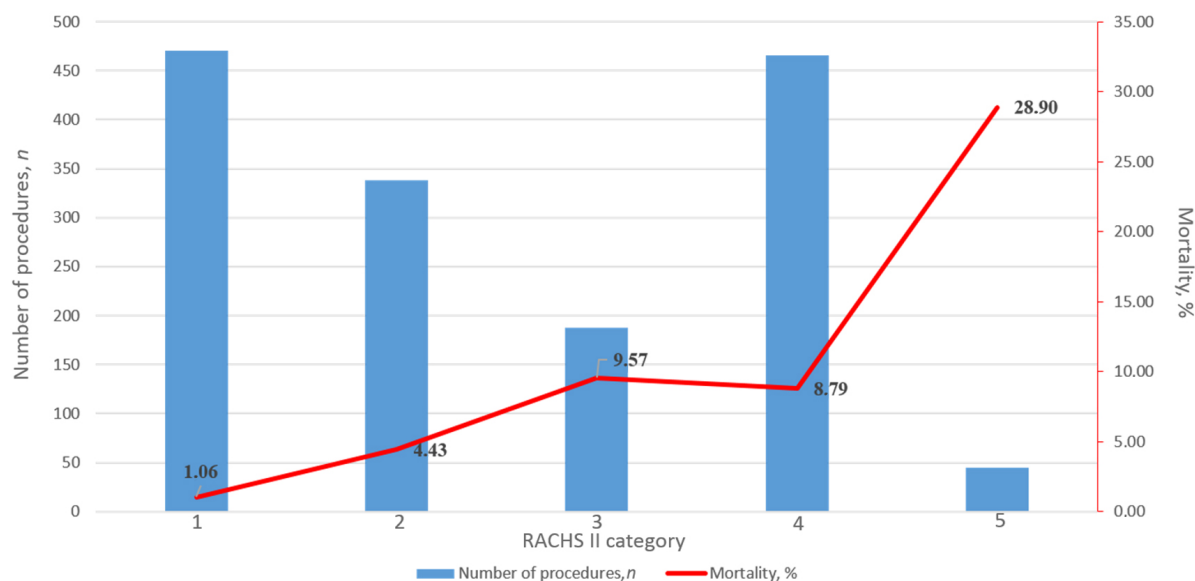


Fig. 3. RACHS II risk stratification for surgical repair in neonates

Note. Mortality percentages were calculated relative to the total number of procedures in each category.

in this group was 3.9%. All procedures in infants were assigned to RACHS II risk categories. The distribution of procedures in category 1 is presented in Table 17.

As shown in Table 17, a total of 1,828 category 1 procedures were performed, with a mortality rate of 0.65% (12 patients).

The distribution of procedures in RACHS II risk category 2 is presented in Table 18.

As shown in Table 18, a total of 837 category 2 procedures were performed, with a mortality rate of 2.98% (25 patients).

Table 15. RACHS II risk category 4 for surgical repair of congenital heart disease in neonates

Procedure	Number of procedures	Mortality, n (%)
Pulmonary artery banding	109	4 (3.6)
Resection of the narrowed aortic segment with main pulmonary artery banding	72	5 (6.9)
Complete repair of total anomalous pulmonary venous return	67	9 (13.4)
Systemic-to-pulmonary artery shunt	61	8 (13.1)
PDA stenting	53	1 (1.8)
Pulmonary artery branch banding with PDA stenting	38	7 (18.4)
Direct aortopulmonary anastomosis	22	5 (22.7)
RVOT stenting	14	1 (7.1)
Complete repair of common arterial trunk	12	1 (8.3)
Right ventricle-to-pulmonary artery shunt	8	0 (0)
Aortopulmonary window repair	5	0 (0)
Pulmonary artery debanding	2	0 (0)
Repair of common arterial trunk with interrupted aortic arch	2	0 (0)
Systemic-to-pulmonary artery shunt closure	1	0 (0)

Note. PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract.

Table 16. RACHS II risk category 5 for surgical repair of congenital heart disease in neonates

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Norwood procedure	39	12 (30.7)
Damus–Kaye–Stansel procedure	6	1 (16.7)

Table 17. RACHS II risk category 1 for surgical repair of congenital heart disease in infants

Procedure	Number of procedures	Mortality, <i>n</i> (%)
VSD closure	860	7 (0.81)
ASD closure	208	0 (0)
Coarctation of the aorta repair	134	2 (1.5)
Vascular ring division	115	0 (0)
Balloon pulmonary valvuloplasty	104	0 (0)
Aortic valve repair	58	0 (0)
Occlusion of MAPCAs	55	0 (0)
Epicardial permanent pacemaker implantation	36	0 (0)
Pulmonary valvotomy	33	0 (0)
Main pulmonary artery reconstruction	29	1 (3.4)
Partial AVSD repair	28	1 (3.5)
Balloon aortic valvuloplasty	25	1 (4)
PAPVR repair	23	0 (0)
Supravalvar aortic stenosis repair	12	0 (0)
Veno-venous collateral occlusion	5	0 (0)
Cone reconstruction for Ebstein anomaly	5	0 (0)
Extended LVOT myectomy	4	0 (0)
Relief of LVOT obstruction	4	0 (0)
Radiofrequency ablation of accessory pathways	4	0 (0)
Resection of the narrowed aortic segment with aortic graft replacement	4	0 (0)
Repair of a left atrial membrane	4	0 (0)
Complete repair of PAPVR to the inferior vena cava	3	0 (0)
Aorto–left ventricular tunnel repair	3	0 (0)
Transvenous permanent pacemaker implantation	3	0 (0)
Resection of a fibromuscular membrane	2	0 (0)
Pulmonary valve replacement	2	0 (0)
Pericardiectomy	2	0 (0)
Transcatheter ASD closure with an occluder	1	0 (0)
Surgical repair of cardiac and great-vessel trauma	1	0 (0)
Transcatheter VSD closure with an occluder	1	0 (0)
Other procedures	60	0 (0)

Note. ASD, atrial septal defect; AVSD, atrioventricular septal defect; LVOT, left ventricular outflow tract; MAPCAs, major aortopulmonary collateral arteries; PAPVR, partial anomalous pulmonary venous return; VSD, ventricular septal defect.

The distribution of procedures in RACHS II risk category 3 is presented in Table 19.

As shown in Table 19, a total of 140 category 3 procedures were performed, with a mortality rate of 10% (14 patients).

The distribution of procedures in RACHS II risk category 4 is presented in Table 20.

As shown in Table 20, a total of 355 category 4 procedures were performed, with a mortality rate of 3.94% (14 patients).

The distribution of procedures in RACHS II risk category 5 is presented in Table 21.

As shown in Table 21, a total of 18 category 5 procedures were performed, with a mortality rate of 27.77% (5 patients).

The graphical representation of RACHS II risk stratification in infants is shown in Fig. 4.

RACHS II risk stratification in children older than 1 year (1–18 years of age)

A total of 10,949 procedures were performed in children older than 1 year, with an overall mortality rate of 0.37% (41 patients). Of these, 2,994 procedures (27.4% of the total) were performed with cardiopulmonary bypass (CPB); mortality in this group was 1.2%. All procedures in children older than 1 year were assigned to RACHS II risk categories. The distribution of procedures in category 1 is presented in Table 22.

As shown in Table 22, a total of 6,800 category 1 procedures were performed, with a mortality rate of 0.16% (11 patients).

Table 18. RACHS II risk category 2 for surgical repair of congenital heart disease in infants

Procedure	Number of procedures	Mortality, n (%)
Complete repair of TOF with a transannular patch	138	4 (2.9)
Complete AVSD repair	126	5 (3.9)
PDA ligation or clipping	118	0 (0)
Complete repair of TOF with preservation of the pulmonary valve annulus	88	0 (0)
Bidirectional cavopulmonary anastomosis	79	4 (5)
Relief of RVOT obstruction	61	3 (4.9)
Balloon angioplasty or stenting of the great vessels	50	0 (0)
Transcatheter PDA closure with an occluder or coil	38	0 (0)
Balloon angioplasty of the pulmonary artery branches	26	1 (3.8)
Repair of anomalous origin of a coronary artery from the pulmonary artery	23	1 (4.3)
Coarctation repair with VSD closure	19	1 (5.3)
Pulmonary artery branch stenting	16	2 (12.5)
Right ventricle-to-pulmonary artery conduit implantation	9	0 (0)
Resection of a supra-valvular mitral ring	9	0 (0)
Complete repair of TOF with pulmonary artery conduit implantation	6	1 (16.7)
Mitral valve repair	6	0 (0)
Removal of intracardiac foreign bodies	6	0 (0)
Hemi-Fontan procedure	5	1 (20)
Pulmonary artery branch reconstruction	5	0 (0)
Arterial switch operation	4	2 (50)
Systemic venous stenting	2	0 (0)
Repair of anomalous origin of a pulmonary artery from the aorta	1	0 (0)
Senning procedure	1	0 (0)
Mustard procedure	1	0 (0)

Note. AVSD, atrioventricular septal defect; PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

Table 19. RACHS II risk category 3 for surgical repair of congenital heart disease in infants

Procedure	Number of procedures	Mortality, n (%)
Complete repair of pulmonary atresia with VSD	27	4 (14.8)
Construction of a left ventricle-to-aorta tunnel	20	0 (0)
Complete repair of transposition of the great arteries with VSD and LVOT obstruction	14	1 (7.1)
Rashkind procedure	12	1 (8.3)
Arterial switch operation with VSD closure	11	3 (27.3)
Resection of cardiac tumors	8	0 (0)
Ross procedure	8	2 (25)
Aortic arch reconstruction for interrupted aortic arch	8	0 (0)
Mitral valve replacement	6	1 (16.7)
Aortic root replacement	5	1 (20)
Unifocalization of the pulmonary arteries	5	1 (20)
ASD stenting	5	0 (0)
Rastelli procedure	4	0 (0)
One-and-a-half ventricular repair	4	0 (0)
Redo pulmonary valve replacement	1	0 (0)
Systemic AV valve replacement in ccTGA	1	0 (0)
Yamagishi procedure	1	0 (0)

Note. ASD, atrial septal defect; AV, atrioventricular; ccTGA, congenitally corrected transposition of the great arteries; LVOT, left ventricular outflow tract; VSD, ventricular septal defect.

Table 20. RACHS II risk category 4 for surgical repair of congenital heart disease in infants

Procedure	Number of procedures	Mortality, n (%)
Pulmonary artery banding	204	6 (2.9)
Systemic-to-pulmonary artery shunt	39	2 (5.1)
Complete repair of total anomalous pulmonary venous return	30	1 (3.3)
Resection of the narrowed aortic segment with main pulmonary artery banding	12	0 (0)
Complete repair of common arterial trunk	12	2 (16.7)
Direct aortopulmonary anastomosis	10	1 (10)
Pulmonary vein stenosis repair	9	2 (22.2)
Pulmonary artery debanding	9	0 (0)
PDA stenting	8	0 (0)
Aortopulmonary window repair	8	0 (0)
RVOT stenting	8	0 (0)
Pulmonary artery branch banding with PDA stenting	3	0 (0)
Repair of systemic venous return anomalies	2	0 (0)
Repair of common arterial trunk with interrupted aortic arch	1	0 (0)

Note. PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract.

Table 21. RACHS II risk category 5 for surgical repair of congenital heart disease in infants

Procedure	Number of procedures	Mortality, n (%)
Norwood procedure	12	3 (25)
Damus–Kaye–Stansel procedure	4	2 (50)
Yasui procedure	2	0 (0)

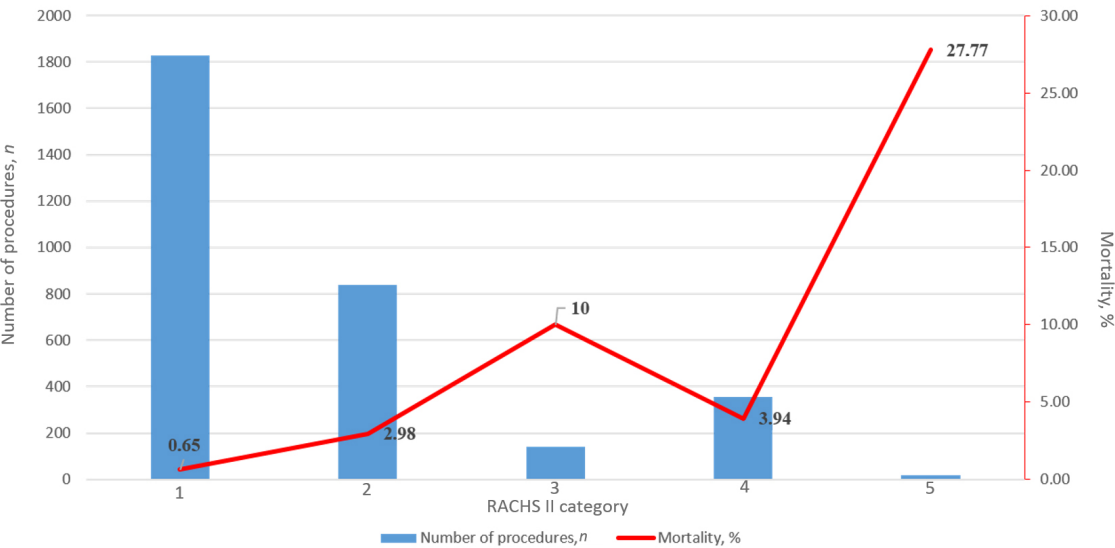


Fig. 4. RACHS II risk stratification for surgical treatment in infants

Note. Mortality percentages were calculated relative to the total number of procedures in each category.

The distribution of procedures in RACHS II risk category 2 is presented in Table 23.

As shown in Table 23, a total of 3,712 category 2 procedures were performed, with a mortality rate of 0.30% (11 patients).

The distribution of procedures in RACHS II risk category 3 is presented in Table 24.

As shown in Table 24, a total of 352 category 3 procedures were performed, with a mortality rate of 4.87% (17 patients).

The distribution of procedures in RACHS II risk category 4 is presented in Table 25.

As shown in Table 25, a total of 82 category 4 procedures were performed, with a mortality rate of 3.43% (2 patients).

The distribution of procedures in RACHS II risk category 5 is presented in Table 26.

As shown in Table 26, a total of 4 category 5 procedures were performed, with no deaths.

The graphical representation of RACHS II risk stratification in children older than 1 year is shown in Fig. 5.

Discussion

Data from the 2025 National Multicenter Database on Congenital Heart Disease and Cardiac Arrhythmias demonstrate the continued development of the system of specialized care for children with cardiovascular disease in the Russian Federation. Compared with 2024, the total number of interventions increased from 14,640 to 15,634, an absolute increase of 994 procedures, corresponding to a 6.35% rise [3]. At the same time, overall in-hospital mortality decreased from 1.42% to 1.30%. The combination of increased procedural activity and improved outcomes indicates greater efficiency of the healthcare delivery system, advances in perioperative management, and the accumulation of clinical experience at centers participating in the National Multicenter Database. In this regard, the 2025 data are particularly valuable because they make it possible to view the structured digital database not only as a tool for the initial assessment of the state of the service, but also as a platform for evaluating the consistency of the observed trends.

Table 22. RACHS II risk category 1 for surgical repair of congenital heart disease in children older than 1 year

Procedure	Number of procedures	Mortality, n (%)
ASD closure	1,660	1 (0.06)
Radiofrequency ablation of accessory pathways	1,637	0 (0)
Transcatheter ASD closure with an occluder	924	0 (0)
VSD closure	417	3 (0.7)
Occlusion of MAPCAs	379	0 (0)
PAPVR repair	189	0 (0)
Balloon pulmonary valvuloplasty	173	0 (0)
Epicardial permanent pacemaker implantation	166	0 (0)
Aortic valve replacement	110	2 (1.8)
Transvenous permanent pacemaker implantation	109	0 (0)
Coarctation of the aorta repair	101	1 (1)
Partial AVSD repair	95	0 (0)
Pulmonary valve replacement	94	0 (0)
Aortic valve repair	86	1 (1.1)
Vascular ring division	81	0 (0)
Transcatheter VSD closure with an occluder	69	0 (0)
Tricuspid valve repair	54	0 (0)
Resection of a fibromuscular membrane	53	0 (0)
Veno-venous collateral occlusion	53	0 (0)
Cone reconstruction for Ebstein anomaly	47	1 (2.1)
Extended LVOT myectomy	38	2 (5.2)
Supravalvular aortic stenosis repair	36	0 (0)
Relief of LVOT obstruction	33	0 (0)
Implantable cardioverter-defibrillator implantation	26	0 (0)
Resection of the narrowed aortic segment with aortic graft replacement	23	0 (0)
Pulmonary valvotomy	22	0 (0)
Repair of a left atrial membrane	20	0 (0)
Main pulmonary artery reconstruction	19	0 (0)
Ozaki procedure	18	0 (0)
Implantable loop recorder implantation	15	0 (0)
Balloon aortic valvuloplasty	8	0 (0)
Complete repair of PAPVR to the inferior vena cava	8	0 (0)
Aorto-left ventricular tunnel repair	4	0 (0)
Closure of previously created fenestrations	4	0 (0)
VSD closure in ccTGA	3	0 (0)
Surgical repair of cardiac and great-vessel trauma	2	0 (0)
Pericardiectomy	1	0 (0)
Other procedures	23	0 (0)

Note. ASD, atrial septal defect; AVSD, atrioventricular septal defect; ccTGA, congenitally corrected transposition of the great arteries; LVOT, left ventricular outflow tract; MAPCAs, major aortopulmonary collateral arteries; PAPVR, partial anomalous pulmonary venous return; VSD, ventricular septal defect.

Table 23. RACHS II risk category 2 for surgical repair of congenital heart disease in children older than 1 year

Procedure	Number of procedures	Mortality, n (%)
Transcatheter PDA closure with an occluder or coil	1,926	0 (0)
PDA ligation or clipping	710	0 (0)
Balloon angioplasty of the pulmonary artery branches	247	0 (0)
Balloon angioplasty or stenting of the great vessels	237	0 (0)
Right ventricle-to-pulmonary artery conduit implantation	187	4 (2.13)
Fontan procedure	60	1 (1.6)
Mitral valve repair	53	1 (1.9)
Pulmonary artery branch stenting	37	1 (2.7)
Bidirectional cavopulmonary anastomosis	31	0 (0)
Relief of RVOT obstruction	30	1 (3.3)
Pulmonary artery branch reconstruction	28	1 (3.6)
Complete AVSD repair	27	0 (0)
Complete repair of TOF with a transannular patch	25	2 (8)
Complete repair of TOF with preservation of the pulmonary valve annulus	19	0 (0)
Complete repair of TOF with pulmonary artery conduit implantation	17	0 (0)
Resection of a supraaortic mitral ring	16	0 (0)
Repair of anomalous origin of a coronary artery from the pulmonary artery	13	0 (0)
Removal of intracardiac foreign bodies	12	0 (0)
Systemic venous stenting	12	0 (0)
Coronary fistula closure	6	0 (0)
Left ventricular aneurysm resection	3	0 (0)
RVOT aneurysm resection	3	0 (0)
Coarctation repair with VSD closure	3	0 (0)
Thrombectomy from the cardiac chambers	3	0 (0)
Kawashima procedure	2	0 (0)
Arterial switch operation	2	0 (0)
Coronary artery bypass grafting	2	0 (0)
Repair of anomalous origin of a pulmonary artery from the aorta	1	0 (0)

Note. AVSD, atrioventricular septal defect; PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract; TOF, tetralogy of Fallot; VSD, ventricular septal defect.

The most pronounced favorable trend was observed in interventions for cardiac arrhythmias. Their number increased from 1,342 procedures in 2024 to 2,100 in 2025, representing an absolute increase of 758 interventions, or 56.5%. This trend reflects not only the expanding availability of interventional electrophysiology, but also clinicians' growing confidence in the safety, reproducibility, and clinical effectiveness of these technologies [8]. From a practical perspective, this indicates that care for children with cardiac arrhythmias is gradually evolving

from a narrowly focused, highly specialized field into a systematically organized component of specialized healthcare services [9].

The overall procedural profile confirms the continuing transformation of contemporary pediatric cardiac surgery toward the broader use of minimally invasive and interventional technologies [10; 11]. The substantial proportion of catheter-based interventions, coupled with their extremely low mortality, indicates a high level of technological maturity in this field and a shift in clinical

Table 24. RACHS II risk category 3 for surgical repair of congenital heart disease in children older than 1 year

Procedure	Number of procedures	Mortality, n (%)
Redo pulmonary valve replacement	65	0 (0)
Ross procedure	47	1 (2.1)
Aortic root replacement	45	3 (6.6)
Mitral valve replacement	36	1 (2.8)
Heart transplantation	23	3 (13)
Complete repair of pulmonary atresia with VSD	20	5 (25)
Redo mitral valve replacement	14	0 (0)
Redo tricuspid valve replacement	14	0 (0)
Left ventricular assist device implantation	12	2 (16.7)
Unifocalization of the pulmonary arteries	10	0 (0)
Resection of cardiac tumors	9	0 (0)
Rastelli procedure	8	0 (0)
Double-switch procedure	6	0 (0)
Tricuspid valve replacement	5	0 (0)
Complete repair of transposition of the great arteries with VSD and LVOT obstruction	5	0 (0)
Aortic arch reconstruction for interrupted aortic arch	5	0 (0)
Construction of a left ventricle-to-aorta tunnel	5	0 (0)
Nikaidoh procedure	4	2 (50.0)
Rashkind procedure	4	0 (0)
Redo aortic valve replacement	4	0 (0)
Systemic AV valve replacement in ccTGA	3	0 (0)
ASD stenting	3	0 (0)
Multiple redo valve replacement	2	0 (0)
Tricuspid valve replacement with a valved homograft	1	0 (0)
Mitral valve replacement with a valved homograft	1	0 (0)
Arterial switch operation with VSD closure	1	0 (0)

Note. ASD, atrial septal defect; AV, atrioventricular; ccTGA, congenitally corrected transposition of the great arteries; LVOT, left ventricular outflow tract; VSD, ventricular septal defect.

strategy toward less invasive options when justified by the anatomical and hemodynamic characteristics of the defect [12–14]. The absence of mortality in interventional electrophysiology further underscores the high degree of standardization and safety achieved in this area of care.

Nevertheless, open cardiac surgery continues to account for the major part of the clinical workload and remains the mainstay of treatment for complex and critical forms of congenital heart disease (CHD). In 2025, as in previous years, open procedures were associated with

Table 25. RACHS II risk category 4 for surgical repair of congenital heart disease in children older than 1 year

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Systemic-to-pulmonary artery shunt	18	1 (5.5)
Pulmonary vein stenosis repair	14	0 (0)
PDA stenting	10	0 (0)
Pulmonary artery debanding	8	0 (0)
Pulmonary artery banding	7	0 (0)
Direct aortopulmonary anastomosis	6	0 (0)
Repair of systemic venous return anomalies	5	0 (0)
RVOT stenting	4	0 (0)
Aortopulmonary window repair	3	0 (0)
Fontan takedown	2	0 (0)
Complete repair of total anomalous pulmonary venous return	2	1 (50)
Right ventricle-to-pulmonary artery shunt	1	0 (0)
Complete repair of common arterial trunk	1	0 (0)
Systemic-to-pulmonary artery shunt closure	1	0 (0)

Note. PDA, patent ductus arteriosus; RVOT, right ventricular outflow tract.

Table 26. RACHS II risk category 5 for surgical repair of congenital heart disease in children older than 1 year

Procedure	Number of procedures	Mortality, <i>n</i> (%)
Damus–Kaye–Stansel procedure	3	0 (0)
Norwood procedure	1	0 (0)

higher mortality, which predictably reflects their greater surgical trauma, the frequent use of cardiopulmonary bypass, and the high proportion of patients with severe anatomical variants of CHD [15–18]. Differences in outcomes between open surgery and interventional procedures should therefore not be interpreted as evidence of the general superiority of one technology over another, but rather as a reflection of objective differences in the severity of the clinical scenarios and the baseline characteristics of the patients undergoing treatment.

The outcomes in the most vulnerable age groups warrant particular attention. In neonatal cardiac surgery, the number of interventions decreased slightly in 2025 compared with 2024, from 1,542 to 1,507 procedures, while mortality declined from 6.60% to 6.47%. Although these changes were modest, the trend itself appears clinically meaningful because it concerns the most severely ill and resource-intensive patient population. The reduction in mortality alongside a decrease in procedural volume may indirectly reflect more careful patient selection, changes in management favoring staged, hybrid, and palliative approaches, and improvements in

the perioperative care of neonates with critical CHD [12–16; 19; 20].

A similar trend was observed among procedures performed with cardiopulmonary bypass. The decline in mortality accompanied by a reduction in the number of procedures in this category suggests improvements in patient referral, preoperative stabilization, and selection for definitive repair. This is particularly important for neonates and infants during the first months of life, in whom early outcomes depend not only on the technical performance of the operation, but also on timely diagnosis, the quality of transportation, the patient’s condition at admission to the surgical center, and the availability and capabilities of postoperative intensive care [21].

Analysis of the age distribution of interventions confirms that the most favorable outcomes are achieved in children older than 1 year, whereas neonates and infants remain at substantially higher risk of adverse outcomes. This is consistent with the generally accepted understanding that treatment outcomes depend on the anatomical complexity of the defect, the severity of hemodynamic compromise, and the physiological

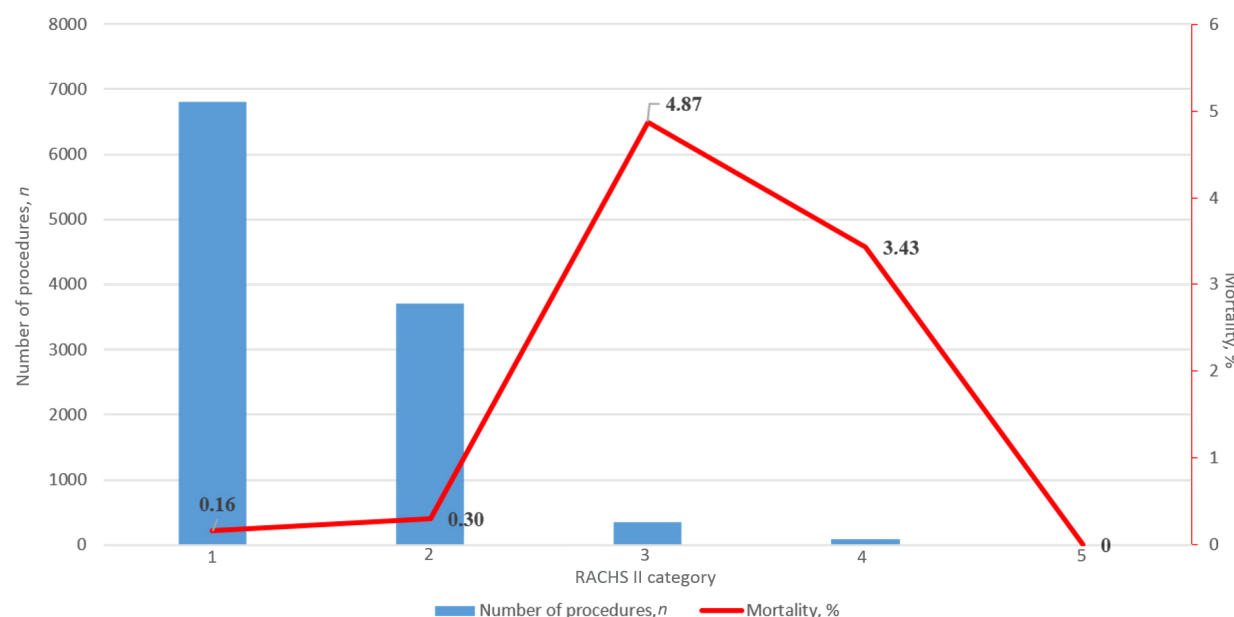


Fig. 5. RACHS II risk stratification for surgical treatment in children older than 1 year

Note. Mortality percentages were calculated relative to the total number of procedures in each category.

vulnerability of younger age groups [22; 23]. At the same time, the substantial number of procedures performed in neonates, including those with low body weight, indicates a high level of specialized care and the readiness of participating centers to manage the most severely ill patient groups.

One of the key issues arising from analysis of the multicenter database is the relationship between procedural volume and quality of outcomes. International experience, particularly in Europe and North America, indicates that an effective system of care for children with CHD should combine the centralization of the most complex surgical procedures with the regional availability of emergency and basic specialized care [24]. A model in which one center providing care for patients with CHD serves a population of approximately 3.5 million and performs up to 500 operations per year is considered organizationally appropriate [24; 25]. This approach maintains the clinical volume required to preserve professional expertise while ensuring access to care for critically ill patients and for children whose families may not always be able to reach a federal center promptly.

However, the mere existence of a regional cardiac surgery center does not in itself guarantee acceptable outcomes. Low surgical volume may be regarded as an independent risk factor, particularly in neonatal cardiac surgery and the treatment of critical CHD. If a center performs fewer than 100 operations per year, limited clinical experience, reduced access to a multidisciplinary

team, constrained intensive care capabilities, and infrequent exposure to complex clinical scenarios may be associated with increased mortality [26]. Further development of a two-tier model of care therefore appears justified: straightforward and emergency interventions should be performed as close as possible to the patient's place of residence, whereas the most complex reconstructive operations, particularly those in the higher RACHS II risk categories, should be concentrated in high-volume centers with documented outcomes [27].

An important feature of 2025 was the changing profile of severe congenital heart defects among operated patients. The functionally univentricular heart provides a notable example. In 2025, this condition was recorded in 2.1% of patients with CHD, placing it among the ten most common diagnostic categories. Although the proportion of these patients was comparable in 2024, the change in the defect's position within the overall registry profile suggests an increase in the relative clinical importance of this group [3]. This means that the specialized care system is increasingly managing patients who require multistage surgical treatment, long-term follow-up, and particularly careful interstage surveillance [28].

In this context, the outcomes of patients with a functionally univentricular heart and hypoplastic left heart syndrome are of particular concern. Based on approximate annual birth estimates of 219 children with a functionally univentricular heart and 53 patients with hypoplastic left heart syndrome, the number of patients

who actually complete all stages of palliative surgery appears insufficient. Available estimates suggest that approximately 110 patient's progress from the first to the second stage and approximately 60 reach the third stage. Even allowing for the anatomical heterogeneity of this population, possible differences in treatment strategies, and potential movement of patients between institutions, these figures may indicate substantial losses during interstage follow-up [28].

The causes of this situation are likely multifactorial and may include the absence of comprehensive centralized monitoring after discharge, insufficient standardization of outpatient follow-up, premature transfer of critically ill children to local facilities for continued care without an adequate monitoring system, limited awareness among primary care physicians and regional hospitals regarding the management of patients after staged procedures, and the erroneous perception that previously operated children are not candidates for subsequent surgical stages [28–30]. A systematic solution to this problem is possible only through the establishment of a mechanism for active patient surveillance throughout the entire care pathway [28–30].

In this context, a government pilot project for the digital monitoring of patients with CHD through the Gosuslugi public services portal or another unified digital framework appears promising. Such a system could be used not only to record in-hospital mortality, but also to capture long-term outcomes, repeat hospitalizations, treatment stages, causes of interstage mortality, and overall quality of specialized care. For patients with a functionally univentricular heart and hypoplastic left heart syndrome, this approach could have not only statistical value but also direct clinical relevance.

Analysis of the procedural profile for so-called simple congenital heart defects also raises several issues requiring professional discussion. For example, the number of atrial septal defect (ASD) operations in infants decreased from 238 in 2024 to 208 in 2025 [3]. This trend may be regarded as favorable because, in most cases, an isolated secundum ASD does not require surgical closure at this age in the absence of significant hemodynamic indications. Thus, the reduction in the number of such interventions may indicate closer adherence to clinical guidelines and a lower frequency of unjustifiably early repair [31].

At the same time, the number of patients who underwent transcatheter ASD closure with an occluder decreased from 1,007 procedures in 2024 to 925 in 2025. This decline cannot be interpreted unequivocally and should be assessed in light of the patients' age distribution, the anatomical characteristics of the defects, center-specific logistical factors, and resource availability.

However, because transcatheter closure is the treatment of choice for secundum ASD in patients with suitable anatomy, this trend warrants further analysis [31; 32]. It is necessary to determine whether it is related to a change in the patient profile, variation in approaches across centers, workforce-related factors, or constraints on the availability of consumables and devices.

Another important issue is the persistently high number of interventions for patent ductus arteriosus (PDA) in children older than 1 year: 1,033 operations in 2024 and 710 in 2025. Despite the decrease in absolute numbers, this figure remains high. Under current practice, transcatheter closure of the ductus is considered the preferred approach for most such patients with suitable anatomy [33]. The substantial volume of open surgical procedures may therefore reflect heterogeneous clinical indications, differences in the technical preparedness of endovascular services, referral patterns, or persistent institutional inertia whereby some relatively straightforward interventions continue to be performed predominantly by surgical means. This issue calls not for criticism of individual institutions, but for the development of uniform criteria for multidisciplinary patient selection and referral.

Definitive procedures recorded during the neonatal period for defects that are generally repaired at 3–6 months of age or later also warrant separate discussion [34]. These interventions included definitive ventricular septal defect (VSD) repair, VSD closure in congenitally corrected transposition of the great arteries, repair of partial anomalous pulmonary venous return, complete atrioventricular septal defect repair, the Yamagishi procedure, complete repair of transposition of the great arteries with VSD and left ventricular outflow tract obstruction, and the Nikaidoh procedure [34]. The fact that such interventions were performed in neonates requires particularly cautious interpretation.

In selected cases, definitive repair during the neonatal period may undoubtedly be dictated by the exceptional severity of the patient's condition, specific hemodynamic features, or the absence of a safe palliative alternative. However, for a substantial proportion of the procedures listed above, surgical repair is more commonly undertaken at a later age, after clinical stabilization, weight gain, and detailed preoperative assessment of the cardiac anatomy. The recorded data may therefore represent either genuinely rare clinical scenarios or possible data-entry errors, including an incorrectly recorded age at the time of surgery, inaccuracies in coding the stage of treatment, or technical deficiencies in database completion.

The extremely high mortality rates associated with certain rare and technically complex procedures require

particular attention. Mortality was 37.5% after complete repair of transposition of the great arteries with VSD and left ventricular outflow tract obstruction and 75% after the Nikaidoh procedure. These figures cannot be interpreted outside the context of the small number of observations; nevertheless, even with these statistical limitations, they require in-depth review. If these procedures were indeed performed during the neonatal period, the findings may reflect both the extreme severity of the patients' baseline condition and the exceptional complexity of the surgical strategy. If, however, some of these cases are attributable to registration errors, this further underscores the need to strengthen both internal and external quality control of the database.

From a practical perspective, this set of observations highlights the need not only for clinical discussion of the optimal timing of definitive repair in rare and complex congenital heart defects, but also for further improvement of the registry methodology. For these diagnostic categories, mandatory additional verification of the patient's age, the type and stage of the intervention, and its conformity with current clinical guidelines should be considered. This would make it possible to distinguish genuinely unique clinical scenarios from potential data-entry errors and improve the reliability of subsequent analyses.

It should also be emphasized that the high degree of data consolidation and comparability was achieved through the coordinating role of the Interregional Public Organization of Pediatric Cardiac Surgeons, the Society of Specialists in Congenital Heart Disease. The organization facilitated professional collaboration among cardiac surgery centers, harmonized approaches to data collection, and coordinated the analytical processing of the accumulated data. Given the country's vast geographical area and the organizational heterogeneity of its institutions, such consolidation is of fundamental importance and provides the foundation for a national system for monitoring the quality of care delivered to children with congenital heart disease.

Study limitations

Despite the considerable practical value of the findings presented, this study has several limitations. The retrospective nature of the analysis; the dependence of the final measures on the completeness and accuracy of data entered into the database; the absence, in some cases, of complete information regarding whether an intervention was primary or repeat, the surgical strategy, and individual clinical parameters; and the fact that the

analysis was largely limited to in-hospital outcomes all constrain the depth with which some measures can be interpreted. An additional limitation of this report is the absence of data from the Republican Cardiac Surgery Center in Ufa, which performs approximately 350–400 surgical procedures annually in pediatric patients with congenital heart disease. The outcomes of this institution may affect the completeness of the nationwide assessment of specialized care volumes, and their absence may limit the representativeness of the data presented to some extent. Future development of multicenter analyses should focus on expanding the set of mandatory data fields, improving data verification, incorporating information on long-term treatment outcomes, repeat hospitalizations, reinterventions, and patient quality of life, and ensuring the fullest possible participation of all specialist centers in a unified system for data collection and analysis.

Conclusion

The 2025 National Database on Congenital Heart Disease and Cardiac Arrhythmias demonstrated its considerable value as a tool for assessing the state of specialized care for children with cardiovascular disease in the Russian Federation. The data presented reflect a substantial volume of surgical activity, a low overall in-hospital mortality rate, and the widespread adoption of contemporary open surgical, catheter-based, and electrophysiological technologies.

The findings confirm that the key priorities for further development are improving care for neonates and infants, optimizing referral pathways for patients with severe and critical forms of congenital heart disease, and developing a system of interstage surveillance. This can be achieved only through comprehensive, individualized analysis. It is critically important to assess the quality of care by taking into account the patient's clinical status at discharge to the place of residence and to analyze survival in relation to the number of patients rather than the number of procedures performed.

Further improvement in the completeness and quality of registry data, expansion of analyses to include long-term outcomes, and consolidation of a unified national approach to evaluating the effectiveness of pediatric cardiac surgical care are of substantial importance. Such evaluation should be based on an individualized approach that determines the complexity and effectiveness of all interventions performed for each patient throughout the patient's lifetime.

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