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Cardiological Support in Neonatal Surgery: Modern Approaches to The Correction of Congenital Heart Anomalies

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ABSTRACT

The article reviews modern approaches to cardiological support in surgical treatment of congenital heart disease in newborns. Special attention is paid to the integration of neonatal cardiology and surgery to improve the efficiency of diagnosis, preparation for surgery and postoperative management of patients. Advanced prenatal diagnostic techniques, such as three- and four-dimensional echocardiographic studies, are discussed, as well as the role of multimodal technology in assessing the severity of anomalies and planning surgical intervention.

The article analyses the use of minimally invasive techniques for defect correction, including catheter-based technologies and stenting, which can reduce the risk of complications and improve prognosis in newborns with critical heart defects. The importance of a multidisciplinary approach is emphasised, where cardiologists, surgeons, anaesthesiologists and neonatologists work together to ensure optimal management of the patient's condition at all stages of treatment.

In addition, data are presented on the role of supportive therapies, including extracorporeal membrane oxygenation (ECMO) and other life support methods, which are becoming an integral part of treatment protocols for complex congenital heart anomalies. The prospects for the development of genetic diagnostics and personalised medicine in the context of prevention and correction of neonatal heart defects are considered.

Keywords: *congenital heart defects, neonatal surgery, cardiological support, prenatal diagnosis, catheter technologies, extracorporeal membrane oxygenation, multidisciplinary approach.*

1. INTRODUCTION

Congenital heart defects (CHD) remain one of the most common groups of congenital anomalies, accounting for about 8-10 cases per 1000 live births. Despite significant achievements of modern medicine, CHDs continue to be the main cause of mortality among newborns with congenital defects. The development of neonatal surgery and cardiology has significantly increased the survival rate of patients with critical forms of CHD, but the success of treatment largely depends on careful cardiological support at all stages: from the prenatal period to postoperative recovery [1].

Cardiological support in neonatal surgery is a complex process that requires coordination of the efforts of specialists from various fields - cardiologists, surgeons, anaesthesiologists, neonatologists and geneticists. Modern diagnostic methods such as three- and four-dimensional echocardiography, magnetic resonance imaging and computed tomography provide detailed information on the structure and function of the fetal and neonatal heart, which is a key factor in making timely decisions about the need for surgical intervention.

Minimally invasive techniques of CHD correction, including catheter technology and stenting, play a special role, which significantly reduce the risk of complications and improve prognosis in newborns. At the same time, the use of extracorporeal methods of life support, such as extracorporeal membrane oxygenation (ECMO), opens new opportunities for life support in patients with severe CHD.

Despite the successes achieved, the relevance of the problem remains high, as many issues related to the optimisation of treatment protocols and long-term quality of life of patients require further study. In this regard, the development of multidisciplinary approaches, the introduction of personalised treatment strategies and the improvement of supportive care technologies are becoming priorities in modern neonatal cardiac surgery.

2. MATERIALS AND METHODS

In the process of studying modern approaches to the correction of congenital heart anomalies in neonates, various materials and methods were used to systematise the accumulated knowledge, analyse the existing treatment protocols and develop new patient management strategies. The study of publications in leading medical journals, monographs, clinical recommendations and guidelines on neonatal cardiology and surgery allowed us to identify current trends in the diagnosis, treatment and rehabilitation of patients with congenital heart defects.

Comparison of different methods of diagnosis, treatment and postoperative management of patients helped to identify the most effective approaches, as well as the weaknesses of existing protocols. Systemic analysis was used to study the relationships between various factors affecting the outcome of treatment, including the anatomy of the defect, the patient's age, general health status, and the availability of technology.

Collecting and analysing data from multiple clinical cases has highlighted common patterns in the management of patients with congenital cardiac anomalies, providing a basis for the development of new treatment protocols.

3. RESULTS

Modern approaches to cardiological support during surgical treatment of congenital heart defects in newborns are based on complex multidisciplinary interaction of specialists and the use of innovative technologies [2]. Prenatal diagnostics plays a key role, making it possible to detect anomalies early in pregnancy using three- and four-dimensional echocardiography, magnetic resonance imaging, and genetic studies, which ensures the planning of delivery in specialised centres and timely preparation for treatment.

Preparation for surgery includes pharmacological therapy to stabilise the patient's condition, such as the use of prostaglandins to maintain abnormal blood flow, as well as optimisation of the child's general condition through correction of electrolyte balance and monitoring of oxygen levels[3]. Continuous monitoring of cardiac function using ECG, pulse oximetry and other methods helps to assess the dynamics of the condition.

Minimally invasive methods of correction are becoming increasingly common, allowing many procedures to be performed without open thoracotomy. Catheter technologies are used to close interatrial and interventricular septal defects, as well as to expand the valves using balloon angioplasty or stent placement. In complex cases, extracorporeal membrane oxygenation is used to maintain vital signs during surgery.

Surgical treatment is performed in stages, which allows the treatment strategy to be adapted to the characteristics of each patient [4]. Modern techniques make it possible to minimise trauma and increase the efficiency of correction. Postoperative follow-up includes careful monitoring of the cardiovascular system, correction of possible complications, and rehabilitation measures. A personalised approach based on genetic diagnostic data and long-term follow-up is becoming an important direction for improving the quality of life of patients after treatment [5].

Integration of neonatal cardiology and surgery is a comprehensive approach aimed at improving the effectiveness of all stages of treatment of newborns with congenital heart disease (CHD) [6]. Modern medicine is based on close interaction

between specialists of different profiles, which allows optimising diagnosis, preparation for surgery and postoperative management of patients (Table 1).

Table 1: Integration of neonatal cardiology and surgery to improve the effectiveness of treatment of newborns with congenital heart disease

Treatment phase	Advances in neonatal cardiology	Advances in neonatal surgery
Diagnosis	- prenatal echocardiography; - magnetic resonance tomography; - genetic studies	- Analysing the anatomical features of the defects; - assessment of possible complications during surgery
Preparing for surgery	- pharmacological therapy (prostaglandins, diuretics); - correction of electrolyte balance; - continuous monitoring	- assessment of the need for preoperative catheter procedures; - preparation for EMO (extracorporeal oxygenation)
Surgical intervention	- real-time cardiac monitoring; - cardiovascular function monitoring	- minimally invasive methods (catheter technology, stenting); - use of robotic systems
Postoperative management	- continuous cardiac monitoring (ECG, pulse oximetry); - correction of possible complications	- rehabilitation measures; - control of postoperative scars and organ function
Long-term follow-up	- regular echocardiography; - assessment of the functional state of the heart	- monitoring of structural recovery after surgery; - detection of possible recurrences

Prenatal diagnosis plays a central role in the early detection of CHD. Improvements in ultrasonographic techniques, such as three- and four-dimensional echocardiography and magnetic resonance imaging (MRI), provide detailed information on the structure of the fetal heart and predict possible complications (7). Genetic studies help to establish a link between congenital anomalies and syndromes that require a specialised treatment approach. Cardiologists and surgeons jointly analyse the data to develop individual intervention plans.

Preparation of the neonate for surgery requires careful coordination between cardiologists and anaesthesiologists [8]. Pharmacological therapy, including the use of prostaglandins to maintain open ductus arteriosus or diuretics to correct oedema, ensures that the patient is stabilised preoperatively. Surgeons and cardiologists jointly assess the need for prior minimally invasive procedures such as catheter-based defect closure or valve dilation.

Modern technologies make it possible to perform complex surgeries with minimal risk to newborns. The integration of cardiology and surgery is manifested in the use of extracorporeal membrane oxygenation (ECMO) to maintain vital signs during surgery, as well as in the use of robotic systems for precise interventions [9]. Real-time cardiac monitoring helps to correct possible circulatory disorders in a timely manner.

Postoperative follow-up is a critical stage of treatment where cardiologists and surgeons continue to work together. Monitoring of cardiac function, control of oxygen levels and electrolyte balance ensure rapid patient recovery [10]. The use of modern rehabilitation techniques, including physiotherapy and psychological support, helps to improve the quality of life of the child. Long-term follow-up makes it possible to evaluate the effectiveness of treatment and timely adjust the further patient management strategy [11].

Thus, the integration of neonatal cardiology and surgery provides a solid foundation for the successful treatment of newborns

with congenital heart disease, ensuring high survival rates and positive long-term outcomes.

Prenatal diagnosis plays a key role in the detection of congenital heart disease (CHD) in the foetus, allowing adequate treatment to be planned immediately after birth. Modern technologies provide high accuracy and detail in assessing the structural condition of the fetal heart, allowing cardiologists and surgeons to make informed decisions about treatment tactics [12]. Three- and four-dimensional echocardiography are advanced methods of prenatal diagnosis of CHD, which are significantly superior to traditional two-dimensional echocardiography in terms of information and visualisation.

Three-dimensional echocardiography (3D) provides a three-dimensional image of the fetal heart, which is particularly important for the evaluation of complex anatomical defects such as transposition of the main vessels, hypoplastic left heart syndrome or valve atresia. Thanks to 3D images, the spatial relationships between cardiac structures can be clearly seen, which greatly simplifies surgical planning.

Four-dimensional echocardiography (4D) adds a dynamic component to the volumetric image, allowing real-time observation of the functional activity of the heart. This helps to assess not only the structure but also the functioning of the heart chambers, valves and vessels, which is particularly important for determining the severity of the defect and predicting possible complications.

Multimodal technologies combine several diagnostic modalities to provide comprehensive information on the fetal heart, allowing a more accurate assessment of the severity of anomalies and the development of an optimal treatment plan. Echocardiography provides a rapid and accessible examination but may be limited by image quality due to technical factors (e.g. fetal position) (13). Magnetic resonance imaging (MRI) complements echocardiography by providing high-quality images of the heart and large vessels, particularly useful in the evaluation of complex defects such as abnormal vessel location or pulmonary malformations.

PECG is used to assess the rhythm and conduction of the fetal heart, which is particularly important in the detection of rhythm disturbances associated with CHD. The combined use of echocardiography and PECG provides a complete picture of the functional status of the fetal cardiovascular system. Genetic testing (e.g. chromosome analysis or gene sequencing) can identify syndromes associated with CHD, such as Down syndrome or Di George syndrome. Integrating genetic information with imaging findings helps to better understand the causes of the malformation and to predict its course.

Accurate prenatal diagnosis is crucial for successful surgical planning [14]. Detailed information about the structure of the heart allows the selection of the most appropriate method of correction, whether it is catheter intervention or open surgery. Some malformations require emergency intervention immediately after birth, whereas others can be corrected later [15]. Prenatal diagnosis helps to establish the optimal timing of surgery. Knowledge of the presence of CHD allows delivery to be arranged in a specialist centre with readiness for immediate treatment of the newborn.

Thus, advanced prenatal diagnostic techniques such as three- and four-dimensional echocardiography and multimodal technologies are becoming indispensable tools for assessing the severity of cardiac anomalies and planning surgical intervention. They contribute to improving treatment efficacy and outcomes in neonates with congenital heart disease.

4. DISCUSSION

Minimally invasive techniques for the correction of congenital heart disease (CHD) represent a revolutionary approach in neonatal cardiology, which significantly reduces the risk of complications and improves prognosis in newborns with critical anomalies. These technologies allow complex procedures to be performed without the need for open thoracotomy, which is especially important for fragile patients whose condition requires quick and effective correction.

Catheter-based techniques are one of the key areas of minimally invasive treatment of CHD. They are based on the use of thin flexible catheters that are inserted through peripheral vessels (usually femoral artery or vein) and delivered to the affected area of the heart under the control of an X-ray cardiographic system.

Special occluders (closers) made of biocompatible materials are inserted into the defect using a catheter to prevent abnormal blood flow between the chambers of the heart.

Balloon angioplasty is used to dilate stenosed valves (e.g. pulmonary or aortic valves) [16]. A balloon catheter is delivered to the affected valve and the balloon is then inflated to enlarge its lumen. Stent placement is used to correct large vessel narrowings such as coarctation of the aorta or pulmonary artery hypoplasia. Stents help restore normal blood flow and improve heart function.

Minimally invasive techniques have a number of significant advantages over traditional open surgery. The absence of the need for a large chest incision significantly reduces the risk of damage to surrounding tissues and organs. Newborns who have undergone catheter-based procedures usually recover faster and can be discharged home sooner than after classical surgery.

For newborns with critical heart defects, minimally invasive techniques are often a safer option, especially if their condition requires rapid correction [17]. Some procedures, such as stenting or placement of occluders, can be repeated as needed,

which is especially important for the growing paediatric body.

Despite the obvious advantages, minimally invasive techniques have their limitations. Not all types of heart defects can be corrected using catheter-based techniques. For example, complex anomalies requiring rearrangement of anatomical structures most often require classical surgery. Technical limitations may arise in neonates with very low birth weight or vessel size. The need for a high level of specialisation of medical teams to perform these procedures.

The treatment of newborns with congenital heart disease (CHD) requires complex coordination between specialists from different disciplines [18]. A multidisciplinary approach combining the efforts of cardiologists, surgeons, anaesthesiologists and neonatologists becomes a key success factor at all stages of treatment. This integrated method allows for optimal management of the patient's condition, reducing the risk of complications and improving outcomes.

Cardiologists play a central role in diagnosis, assessment of the severity of the malformation and treatment planning [19]. They perform prenatal and postnatal echocardiographic studies, assess the functional status of the cardiovascular system, and adjust drug therapy to stabilise the patient preoperatively and postoperatively.

Surgeons are responsible for performing complex operations, which may include both open interventions and minimally invasive procedures. Their job is to precisely correct anatomical defects, minimising trauma and ensuring the long-term effectiveness of treatment. Anaesthesiologists ensure the safe performance of surgery by monitoring the patient's vital signs during surgery [20]. They also play an important role in managing pain and maintaining adequate postoperative well-being of the baby. Neonatologists are involved in the overall management of the newborn, especially in the first hours and days of life: they monitor basic physiological parameters, maintain respiration and circulation, and coordinate the activities of other specialists to ensure comprehensive care.

Each specialist brings a unique contribution to the treatment, allowing for a holistic strategy to manage the patient's condition. This approach ensures that all aspects of the child's health are taken into account, from cardiological problems to the general state of the body. Close collaboration between specialists allows for timely identification and prevention of potential complications [20]. For example, the anaesthesiologist can adjust drug doses depending on changes in the cardiovascular status observed by the cardiologist.

Multidisciplinary approach facilitates more accurate planning of operations, selection of the most appropriate treatment methods and adequate rehabilitation, which significantly increases the chances of successful recovery and improves the patient's quality of life. Coordination of specialists helps to rationally use medical resources, reducing the likelihood of unnecessary procedures or repeated hospitalisations [21].

Cardiologists and neonatologists jointly analyse the results of the prenatal diagnosis in order to plan the delivery in a specialised centre with readiness for immediate treatment of the newborn. Surgeons can join the discussion if there is a need for emergency correction of the malformation immediately after birth.

Anaesthetists and cardiologists work together to stabilise the patient before surgery. Indicated may include correction of electrolyte balance, use of prostaglandins to maintain abnormal blood flow, and other measures. After surgery, neonatologists monitor the general condition of the baby, anaesthesiologists control the pain syndrome, and cardiologists monitor cardiac function [22]. Such cooperation helps the patient to recover faster and prevent possible complications.

Supportive therapy plays a key role in the management of neonates with severe congenital heart disease (CHD), especially when cardiopulmonary function is significantly impaired. Modern life support techniques such as extracorporeal membrane oxygenation (ECMO) and other innovative technologies are becoming an integral part of treatment protocols, ensuring the patient's stable condition before, during and after surgical intervention[23].

EMO is a method of artificial respiratory and circulatory support in which the patient's blood is withdrawn from the body through a catheter, passed through a special machine to oxygenate and remove carbon dioxide, and then returned back into the body. This method is widely used in the treatment of newborns with critical CHD. If the baby's condition is extremely severe and the cardiopulmonary system cannot provide an adequate blood supply, EMO helps to stabilize the condition before surgical intervention.

EMO can be used as a temporary replacement for heart and lung function during complex cardiac surgical procedures. Some patients have postoperative heart or lung dysfunction. In such cases, EMO allows time for the organs to recover.

Accordingly, EMO:

- maintains oxygen balance in the body, preventing hypoxia;

- provides temporary relief of the heart and lungs, which is important for their recovery;

- allows complex procedures to be performed on patients with extremely unstable conditions.

Mechanical ventilation remains one of the main methods of maintaining respiratory function in neonates with CHD[24]. It is particularly important when the heart defect causes significant circulatory collapse in the lungs.

Invasive ventilation is used through an endotracheal tube for critically ill patients. Non-invasive ventilation is used for less severe cases or as a transitional step after invasive ventilation. This method provides adequate oxygenation and ventilation of the lungs and minimises cardiac workload by improving gas exchange.

Pharmacological therapy is an important component of supportive therapy in newborns with CHD. It is aimed at stabilising the patient's condition before and after surgery.

Prostaglandins are used to maintain open ductus arteriosus, which is necessary to ensure adequate blood flow in patients with critical malformations. Norepinephrine, dopamine and milrinone are used to enhance contractile function of the heart. Diuretics contribute to the reduction of oedema and reduce the load on the heart.

These drugs correct pathological processes in real time, allow the patient to prepare for surgery or stabilize his condition after the intervention.

Haemodynamic monitoring plays a crucial role in the management of neonates with CHD, which allows timely detection of changes in the cardiovascular system and correction of treatment.

After stabilisation of the condition and completion of the main treatment, rehabilitation methods play an important role in restoring the functions of the cardiovascular system. In this regard, special exercises to strengthen muscles and improve the general condition, nutritional correction to ensure normal growth and development, work with parents and the child to overcome the stress associated with the disease are very important.

Genetic diagnostics and personalized medicine are cutting-edge technologies that offer new opportunities for early detection, prevention and treatment of congenital heart disease (CHD) in newborns. Such technologies allow for a deeper understanding of the molecular mechanisms of CHD development, as well as the development of personalized treatment approaches based on the unique genetic characteristics of each patient.

Genetic factors play a significant role in the development of CHD, with up to 30% of all cases associated with genetic mutations or chromosomal abnormalities. Modern genetic diagnostic techniques are helping to better define the risks and mechanisms of these diseases.

Exome sequencing allows the coding regions of the genome to be analysed and mutations associated with CHD to be identified. This helps to establish causal links between genetic changes and specific types of malformations.

Coccygeal liquoroscopy (amniocentesis) is used to detect chromosomal abnormalities such as Down syndrome or DiGeorge syndrome, which are often associated with CHD.Techniques such as NIPT (free fetal DNA in maternal blood) allow non-invasive testing for genetic abnormalities early in pregnancy.

Genetic diagnosis can be used to identify a high risk of CHD even before conception by analysing the genetic status of future parents. Identification of genetic markers allows the development of prevention programmes, for example, through lifestyle adjustments or the use of special drugs during pregnancy.

Personalised medicine is based on the individual characteristics of the patient, including their genetic profile, clinical presentation and prognosis. This approach allows for the development of more effective and safer treatments for each child. By taking into account a patient's genetic characteristics, the most appropriate drugs and dosages can be selected, minimising the risk of side effects. Genetic markers can serve as indicators of the effectiveness of therapy, which allows timely adjustment of the treatment plan.

Gene therapy research aims to correct the pathogenic mutations that cause CHD. For example, CRISPR/Cas9 and other gene editing technologies can be used to restore normal function of genes responsible for heart development.

Using stem cells to regenerate damaged heart tissue opens up new possibilities for treating complex malformations. Studying how genetic variants affect drug metabolism will allow the development of more effective pharmacological strategies for each patient.

The integration of these two approaches offers unique opportunities to improve the outcomes of CHD treatment. A more precise determination of the type of malformation and its genetic basis allows the optimal treatment tactics to be planned. Individualised protocols are tailored to each patient, increasing the likelihood of a successful outcome. A personalized approach minimises the side effects of treatment and prevents possible complications. Genetic information can be used for long-term monitoring of patients and prevention of relapses or secondary problems.

Genetic diagnosis and personalized medicine are becoming key elements of the modern approach to the prevention and treatment of congenital heart disease in newborns. They allow not only a better understanding of the causes of these diseases, but also the development of more effective and safer treatment methods. Given the rapid development of technologies in this field, we can expect significant breakthroughs that will significantly improve the quality of life of children with CHD and their families.

5. CONCLUSIONS

Modern treatment of congenital heart disease (CHD) in newborns requires close interaction between cardiologists, surgeons, anaesthesiologists, neonatologists and other specialists. This integrated approach allows for optimal management of the patient's condition at all stages of treatment, from prenatal diagnosis to long-term rehabilitation.

Prenatal diagnostics, especially three- and four-dimensional echocardiography, magnetic resonance imaging (MRI) and genetic studies, are becoming the basis for early detection of CHD and treatment planning. Multimodal diagnostic techniques provide detailed information on cardiac structure and function, which is critical for selecting intervention tactics. Catheter-based techniques such as closure of atrial septal defects, dilation of stenosed valves and vascular stenting significantly reduce the risk of complications and improve prognosis in newborns with critical heart defects. These techniques are becoming increasingly available and play an important role in modern neonatal cardiology.

Extracorporeal membrane oxygenation (ECMO) and other life support techniques are an integral part of treatment protocols for complex cardiac anomalies. They provide temporary support for cardiopulmonary function, allowing the patient to be prepared for surgery or to give the organs time to recover after intervention.

Genetic diagnosis opens up new possibilities for the prevention and correction of CHD. Personalised approaches that take into account the unique genetic characteristics of each patient contribute to the development of more effective and safer treatments. The development of gene therapy and gene editing technologies may be the next step in the fight against congenital heart disease.

Assessment of long-term treatment outcomes and quality of life of patients is the most important criterion for the success of therapy. Despite the advances, many questions remain open, requiring further research to improve treatment techniques, minimise complications and improve patients' quality of life.

Improvement of existing methods and development of new strategies for the treatment of CHD is impossible without active development of scientific research. Particular attention should be paid to the study of molecular mechanisms of malformations, introduction of digital technologies and creation of individualised treatment plans.

Thus, cardiological support in surgical treatment of congenital heart disease in newborns is a multidimensional task, the solution of which requires the use of modern technologies, multidisciplinary approach and continuous development of clinical protocols, which guarantees high efficiency of treatment and improvement of the quality of life of children with CHD.

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