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MONITORING OF RENAL TISSUE OXYGENATION IN YOUNG CHILDREN WITH CONGENITAL HEART DISEASE IN THE PERIOPERATIVE PERIOD

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Abstract. *Introduction.* Tissue oximetry is one of the most promising methods for assessing the efficiency of systemic perfusion in children in critical condition, which is especially true for newborns with heart defects, but it is not a routine method of diagnosing systemic hypoperfusion in neonatal intensive care units, which requires its wider implementation. The *aim of the study* is to demonstrate the possibilities of prolonged NIRS-monitoring of renal tissue oxygenation to determine further tactics of management of newborns with congenital heart disease. *Patients and methods.* Three clinical cases of prolonged noninvasive monitoring of renal oxygenation in infants with congenital heart disease accompanied by systemic hypoperfusion in the perioperative period are presented. *Results.* It was demonstrated that on the basis of renal tissue oxygenation indices it is possible to make an informed decision on the correction of intensive care measures and the need for emergency cardiac surgery. In some cases, NIRS-monitoring allows to avoid early intubation and invasive ventilation of lungs, which is reflected in the description of the third case. *Conclusion.* Noninvasive real-time bedside monitoring of tissue oxygenation is a highly effective method of diagnosing systemic hypoperfusion and should be more widely used in neonatal intensive care units, especially in neonates with CHD, in whom the risk of shock of various genesis is extremely high.

Key words: *tissue oximetry; neonate; critical congenital heart disease; systemic hypoperfusion.*

МОНИТОРИНГ ОКСИГЕНАЦИИ ТКАНЕЙ ПОЧЕК У ДЕТЕЙ РАННЕГО ВОЗРАСТА С ВРОЖДЕННЫМИ ПОРОКАМИ СЕРДЦА В ПЕРИОПЕРАЦИОННОМ ПЕРИОДЕ

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Резюме. *Введение.* Тканевая оксиметрия является одним из наиболее перспективных методов оценки эффективности перфузии у детей в критическом состоянии, что особенно справедливо для новорожденных с пороками развития сердца, однако она не является рутинным методом диагностики в неонатальных отделениях реанимации и интенсивной терапии, что требует ее более широкого внедрения. *Цель исследования* — демонстрация возможностей продленного NIRS-мониторинга оксигенации тканей почек с целью

определения дальнейшей тактики ведения новорожденных с врожденными пороками сердца. *Пациенты и методы.* Представлены три клинических случая применения продленного неинвазивного мониторинга почечной оксигенации у детей раннего возраста с врожденными пороками сердца, сопровождающимися системной гипоперфузией, в периоперационном периоде. *Результаты.* Продемонстрировано, что оценка показателей оксигенации тканей почек позволяет принять обоснованное решение о коррекции мероприятий интенсивной терапии и необходимости проведения экстренного кардиохирургического вмешательства. В ряде случаев NIRS-мониторинг позволяет избежать раннего перевода пациента на инвазивную вентиляцию легких, что отражено в описании третьего случая. *Заключение.* Неинвазивный прикроватный мониторинг тканевой оксигенации в режиме реального времени является высокоэффективным методом диагностики системной гипоперфузии и должен более широко использоваться в отделениях неонатальной реанимации и интенсивной терапии, особенно у новорожденных с врожденным пороком сердца, у которых риск развития шока различного генеза крайне высок.

Ключевые слова: *тканевая оксиметрия; новорожденные; критические врожденные пороки сердца; системная гипоперфузия.*

INTRODUCTION

The use of near-infrared spectroscopy to assess the adequacy of cerebral perfusion and oxygenation was first proposed by F.F. Jobsis in 1977 [1]. Subsequently, his idea was implemented by creating monitors to assess the saturation of brain tissue and other internal organs with oxygen.

The principle of the NIRS method is based on the ability of tissues to transmit light in the range close to the infrared spectrum (740–3000 nm), this ability is maximum in the range of 600–1000 nm. As a light beam passes through the tissues of internal organs, pigment compounds known as chromophores absorb light. Human tissues contain many components for which absorption spectra of light with a wavelength close to the infrared range have been well studied, the concentration of which varies depending on tissue oxygenation and the level of oxyhemoglobin, deoxyhemoglobin and cytochrome a-a3. In addition to oxyhemoglobin and deoxyhemoglobin, other hemoglobin compounds, in particular carboxyhemoglobin, are also capable of absorbing a light beam in a spectrum close to infrared radiation, but under physiological conditions the overall error in the absence of taking into account the optical properties of these compounds does not exceed 1% [2, 3]. The venous component accounts for approximately 75–85% of the blood flow volume, and since monitoring using NIRS technology is not dependent on the presence of a pulse wave, the data obtained during the study reflects the weighted average (75–85% venous) oxyhemoglobin concentration of the studied area [4]. Numerous factors can influence NIRS values, but the two main ones are tissue perfusion and tissue oxygen utilization. Thus, NIRS indirectly reflects the balance between oxygen delivery and oxygen consumption. Since the tissue oximeter signal propagates according to the Beer–Lambert Law, which states that a parallel monochromatic beam of light attenuates as it propagates through an absorbing medium and reflects information about vessels with a diameter of less than 1 mm, the monitoring is a convenient tool for assessing visceral perfusion, which is beneficial distinguishes it from Doppler ultrasound, which allows one to evaluate the efficiency of blood flow in larger blood vessels at a limited point in time [5].

First of all, this monitoring method became widespread in neurosurgery; later, the cerebral NIRS monitoring began to be used in various branches of medicine [6]. In particular, in cardiac surgery it is used as the only option for neuromonitoring or as part of combined neuromonitoring during cardiac surgery. It has been established that the use of parainfrared spectroscopy during cardiac surgery with cardiopulmonary bypass makes it possible to detect episodes of cerebral ischemia with a higher frequency than previously thought, which, in turn, can significantly reduce the frequency of cerebral-vascular intraoperative complications in cardiac surgery [7–9].

Since 1980, studies have appeared on the effectiveness of using NIRS to monitor cerebral, tissue and organ perfusion in newborns and young children [10, 11]. A radiation close to the infrared spectrum is absorbed mainly in the dermis, but about 30% of the light flux penetrates to a depth of 30 mm, reaching the subcutaneous fat layer and the organs located underneath it [12]. This penetrating ability of para-infrared radiation, on the one hand, and the insignificant thickness of the integumentary tissues in newborns, on the

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other, make it possible to evaluate the effectiveness of oxygenation and perfusion of the kidneys, intestines, liver, muscles and brain [13, 14].

Currently, there are many studies on the use of cerebral oximetry in young children with congenital heart defects (CHDs) during cardiac surgery with cardiopulmonary bypass. Special protocols have been developed that take into account cerebral oximetry indicators to determine clinical tactics during cardiac surgery in order to improve long-term neurological prognosis [15–19].

There are studies of organ perfusion in premature newborns for the purpose of early diagnosis of necrotizing enterocolitis, one of which demonstrated that regional oximetry indices of the abdominal region correlate with volume-velocity characteristics in the superior mesenteric artery obtained by Doppler study [20]. Several studies have noted that preterm infants with clinical necrotizing enterocolitis (NEC) had lower abdominal oxygenation values and less variability from baseline compared to controls [21, 22]. The effectiveness of the use of parainfrared spectroscopy in children with congenital heart disease has been proven as a predictor of the development of NEC in the postoperative period [23]. A.G. DeWitt et al. demonstrated the possibility of prolonged monitoring of organ perfusion using parainfrared spectroscopy to assess the risks of developing necrotizing enterocolitis in newborns with congenital heart disease, including those with a functionally single ventricle [24]. The study included 64 newborns who underwent biventricular correction of congenital heart disease or palliative interventions. In the postoperative period, organ blood flow was monitored before and during the initiation of enteral feeding to determine whether changes in the obtained parameters are associated with the risk of developing necrotizing enterocolitis. The proven necrotizing enterocolitis or suspicion of it was noted in 32% of patients with a functionally single ventricle, while it was absent in children with biventricular correction, which was statistically significant ($p = 0{,}001$). Compared with patients with or without suspected NEC, children with proven NEC had lower rates of splanchnic rSO_2 (32.6% vs. 47%; $p = 0{,}05$).

The advantage of the method is non-invasiveness and safety for patients, no restrictions on the duration of use, the ability to assess tissue oxygenation in real time, which allows you to monitor changes during therapeutic measures that affect vascular resistance, the balance of pulmonary and systemic blood flow. At the same time, it should be noted that, according to some experts, there are difficulties in determining the critical values of organ perfusion indicators and eliminating artifacts that arise when the patient moves, which limits the use of NIRS for monitoring splanchnic blood flow [25].

Despite the potential of NIRS monitoring in cardiac anesthesiology, including in newborns with congenital heart disease, this technique has not been widely used in the practice of intensive care units to assess the effectiveness of organ perfusion [26, 27].

It should be noted that newborns with CHDs who are at high risk of severe impairment of systemic perfusion, which makes continuous monitoring of renal oxygenation the most promising method for assessing changes in regional blood flow even before irreversible organ damage occurs.

We believe that the currently available data, despite some limitations, make it possible to use the assessment of tissue oxygenation and perfusion as a useful tool for improving the effectiveness of intensive care measures in children with CHDs and hemodynamics of the functionally single ventricle [24].

AIM OF THE STUDY

To demonstrate the possibilities of extended NIRS monitoring of kidney tissue oxygenation in order to determine further tactics for the management of newborns with congenital heart disease.

PATIENTS AND METHODS

Three clinical cases of the use of prolonged non-invasive monitoring of renal oxygenation in young children with congenital heart defects accompanied by systemic hypoperfusion in the perioperative period are presented.

The sensor for assessing regional renal oxygenation was placed according to the recommendations of M.W. Harer et al. (2020): below the costal arch and above the iliac crest, with the tip of the sensor located lateral to the spine and the reading end of the sensor wrapped around the lateral surface (Fig. 1) [27].

Clinical case № 1

Newborn boy, 1 month of life. Diagnosis: congenital heart disease, critical aortic valve stenosis. Atrial septal defect. Patent ductus arteriosus. Ductus-dependent systemic circulation. The

mother's medical history is unremarkable. 2nd term birth at 41 weeks and 1 day. The diagnosis was confirmed by echocardiography (EchoCG) and multislice computed tomography (MSCT). On the 7th day of life, open aortic commissurotomy and planar resection of the leaflets were performed under artificial circulation. In the postoperative period, there was a dependence on high positive end-expiratory pressure (PEEP) in the range of 7–8 mm H2O. When trying to reduce parameters — clinical and radiological picture of pulmonary edema, inotropic support, intolerance to enteral nutrition due to the persistent clinical picture of intestinal paresis, the need for constant stimulation of diuresis with high doses of loop diuretics, and the development of chyloperitoneum were observed. An chocardiography revealed mitral valve insufficiency of grade II–III. Despite conservative therapy, these manifestations persisted. According to the assessment of organ blood flow using Doppler ultrasonography against the background of analgosedation, minimal reverse was noted in the renal arteries and vertebrobasilar arteries (VBA), which did not correspond to the existing clinical picture. In order to assess the significance of mitral regurgitation and the accompanying hypoperfusion of the abdominal organs and kidneys over the time, continuous extended NIRS monitoring of renal blood flow was initiated.

According to the monitoring results, significant hypoperfusion was revealed — average saturation values according to monitoring data were 53–55% lower than transcutaneous pulse oximetry values, average values were 43–47%, with regular episodes of desaturation up to 25–28% upon awakening and activation of the patient. Based on the totality of clinical and instrumental data, a decision was made to perform a repeat surgical intervention. At the age of 1.5 months of life, the mitral valve replacement was performed with a mechanical prosthesis "Carbomedix" with a diameter of 16 mm, revision of the aortic valve, planar resection of the aortic valve leaflets under conditions of cardiopulmonary bypass (CPB) and cardioplegia (CP). The early postoperative period was unremarkable. The ionotropic support was stopped on the 2nd day after surgery. On the 10th day of the perioperative period, the patient was extubated, transferred to non-invasive artificial ventilation, and against the background of regression of intestinal paresis, enteral nutrition was started with a gradual expansion to the full age requirement within three weeks. On the 20th day, the respiratory support was stopped. The chyloperitoneum regressed on the 5th day after surgery. In the demonstrated case, the NIRS monitoring made it possible to confirm the presence of hypoperfusion in real time and make a decision on the need for repeated surgery.

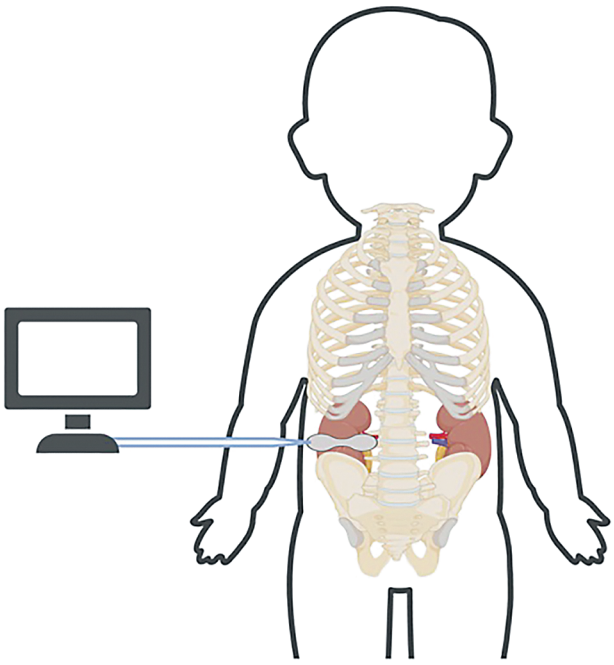

Fig. 1. Neonatal renal NIRS sensor location

Рис. 1. Расположение неонатального почечного датчика NIRS

Clinical case № 2

Boy B., 7 months old. Basic diagnosis: Congenital heart disease: hypoplastic left heart syndrome (mitral valve atresia, left ventricular hypoplasia, aortic valve atresia, aortic arch hypoplasia). The defect was diagnosed prenatally. On the 6th day of life, a modified Norwood operation (right ventricle — pulmonary artery) with a valve-containing bicuspidal alloconduit, atroiseptostomy under conditions of artificial circulation, antegrade cerebral perfusion and cardioplegia was performed. The course of the postoperative period was smooth and corresponded to the nature, volume and timing of the surgical intervention performed. At 1.5 months he was discharged home, the next stage of cardiac surgery was planned. At 5.5 months, a thrombosis of the alloconduit developed with severe myocardial ischemia, acute decompensation of chronic heart failure, a thrombolytic therapy was carried out with a positive effect. At 6 months, the Glenn's surgery was performed. In the early postoperative period, sinus

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tachycardia up to 160–170 beats per minute and a persistent increase in pressure in the cavapulmonary anastomosis (15–18 mm Hg) were noteworthy. An EchoCG revealed signs of dilatation of the right atrium against the background of regurgitation on the tricuspid valve of II–III degree. Despite the full conservative therapy, the child had a progressive clinical picture of retrograde pulmonary edema against the background of regurgitation on the tricuspid (systemic) valve and hypoperfusion of the abdominal organs, which was manifested by intolerance to enteral nutrition, severe dependence on high doses of loop diuretics to maintain an adequate pace diuresis. In order to assess the significance of regurgitation on the systemic valve and the accompanying hypoperfusion of the abdominal organs and kidneys over time, continuous extended NIRS monitoring of renal blood flow was initiated. Based on the monitoring results, the significant hypoperfusion was identified — average saturation values according to monitoring data were 43–45% lower than those according to transcutaneous pulse oximetry, average values were 33–37%, with regular episodes of desaturation up to 23–26% upon awakening and activation of the patient. Based on the totality of clinical and instrumental data, a decision was made to perform endovascular surgical intervention: a probing of the heart chambers, cardiac ventriculography, angiography of the great vessels. According to the results of the study, return angiopulmonograms show contrasting of the left atrium, contrasting of the pulmonary veins that flow into the left atrium is noted; the ventriculogram reveals regurgitation on the tricuspid valve of II–III degree, dilatation of the right atrium; Qp/Qs — 0.57/1. Based on the data obtained, a decision was made to replace the system valve. In this situation, in addition to the clinical picture and echocardiography data, confirmation of organ hypoperfusion using extended NIRS monitoring made it possible to make a decision to conduct an invasive study to determine further surgical tactics.

Clinical case № 3

Newborn boy, two days of life. Main diagnosis: Q23.4 Hypoplastic left heart syndrome (mitral valve hypoplasia, left ventricular hypoplasia, aortic valve hypoplasia, aortic arch hypoplasia). Fibroelastosis of the left ventricle. Coarctation of the aorta. Patent ductus arteriosus. Atrial septal defect. Ductus-dependent coronary and systemic circulation.

The pregnancy proceeded against the background of mild anemia, gestosis in the first half of pregnancy with hospitalization at 10/11 weeks. According to an ultrasound examination at 23/24 weeks of gestation, the congenital heart disease was detected: hypoplastic left heart syndrome. Micromelia? 1st urgent birth by emergency cesarean section due to severe preeclampsia at 39 weeks of gestation.

The child's condition at birth is satisfactory. Upon admission, the umbilical cord vein was catheterized and alprostan infusion was started. Noteworthy, there was moderate anemia, hemoglobin (145 g/l), probably caused by fetoplacental transfusion. At the end of the first day of life, a persistent high SpO2 was noted for this variant of the hemodynamics of the defect, which was in the range of 96–97%. According to the acid-base state, there was an increase in metabolic acidosis: BE = –9.5 mmol/l, HCO3 = 17.8 mmol/l, a decrease in the rate of diuresis to 0.8 ml/kg per hour was clinically noted. Clinical and laboratory data could indicate an imbalance of systemic and pulmonary blood flow, which is typical for patients with hypoplastic left heart syndrome, however, as a rule, its clinical manifestations occur on the 3rd–4th day of life, which is due to a decrease in pressure in the pulmonary circulation . To assess the adequacy of organ perfusion, the bedside NIRS monitoring of renal blood flow was initiated. According to the monitoring results, the absence of hypoperfusion was revealed — saturation according to monitoring data was 3–5% lower than the values according to transcutaneous pulse oximetry, average values were 87–90%, without episodes of significant desaturation. Based on the monitoring data, it was concluded that there was no imbalance in the pulmonary and systemic blood flow, hypoperfusion of the abdominal organs and kidneys, which was later confirmed by Doppler study. Taking into account the child's age and clinical and laboratory data, the red blood cell transfusion was performed according to individual selection. Against the background of correction of anemia, normalization of acid-base status indicators and a decrease in lactate levels to normal values were noted. Thanks to NIRS monitoring data, it was possible to refrain from early transfer to mechanical ventilation and sedation in order to limit pulmonary blood flow.

DISCUSSION

Adequate renal perfusion and oxygenation are critical to the outcome of critically ill neonates. At

the same time, in the routine practice of neonatal intensive care units, there are not enough diagnostic tools to assess the effectiveness of tissue oxygenation and blood flow, which, in turn, does not allow for the earliest and most reasonable therapeutic interventions aimed at preventing or reducing the degree of tissue damage.

In the presented clinical cases, the indicators of extended NIRS monitoring of organ blood flow correlated with the results of other instrumental studies. However, it should be noted that although the NIRS is a promising technology for monitoring organ blood flow in newborns and young children with congenital heart disease in the Intensive Care Unit, currently the number of multicenter randomized studies to determine the normative data of splanchnic oxygenation in young children, including in patients with hemodynamics of the same ventricle, very little.

G. Greisen et al. summarized the challenges of using tissue oximetry in an article discussing the prospect of introducing cerebral oximetry: "On the one hand, cerebral oximetry has the potential to become inexpensive because it is based on technology that can be mass-produced. Convincing evidence of benefit to patients will create a large market. On the other hand, what happens if the clinical application of cerebral oximetry is not developed in a rational, evidence-based format? This could then become another expensive technology applied randomly. Cerebral oximetry will be supported by anecdotal evidence, expert opinion, and aggressive branding and marketing. Consequences include unnecessary disruption and risks to a very vulnerable patient population and a drain on health care resources" [28].

One of the factors facilitating the widespread introduction of renal blood flow assessment by NIRS into clinical practice and the interpretation of the data obtained is the theoretical model of normal oxygenation of renal tissue in premature newborns during the first month of life (Fig. 2), proposed by M.W. Harer et al. (2020) based on publications by other authors, which reflects indicators of oxygen saturation of kidney tissue in the absence of pathology [29, 30].

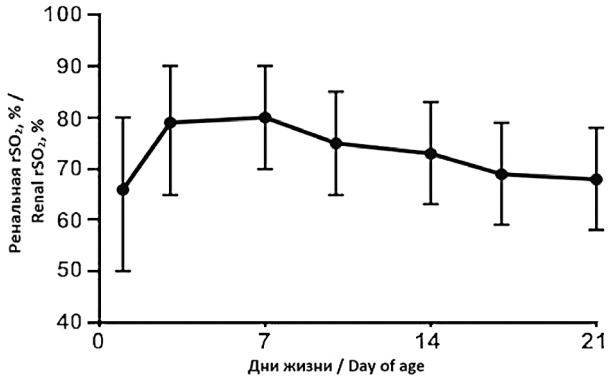

Fig. 2. Normal renal tissue oxygenation of premature newborns in the first month of life

Рис. 2. Показатели нормальной оксигенации тканей почек у недоношенных новорожденных в первый месяц жизни

CONCLUSION

The non-invasive real-time bedside monitoring of tissue oxygenation is a highly effective method for diagnosing disorders of organ perfusion and oxygenation and should be more widely used in neonatal intensive care units, especially in newborns with congenital heart disease.

ADDITIONAL INFORMATION

Author contribution. Concept and design of the study: Solovyova E.A., Trizna E.V.; collection and processing of primary material: Solovyova E.A., Romanova E.P.; writing the text of the article: Solovyova E.A., Pshenisnov K.V.; editing: Aleksandrovich Yu.S., Pshenisnov K.V., Trizna E.V. All authors read and approved the final version before publication.

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Consent for publication. Written consent was obtained from the legal representatives of patients for publication of relevant medical information within the manuscript.

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