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Prospects For the Use of Robotic Surgical Technologies in Neonatal Practice

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ABSTRACT

In modern medicine, robotic surgical technologies continue to be actively developed and are being introduced into an increasingly wide range of clinical areas. Neonatal practice, which requires special precision and delicacy, is gradually opening up to the application of such innovative solutions.

The article reflects the results of a study aimed at analyzing the prospects of using robotic surgical systems in neonatal practice. Technical and clinical aspects including safety, efficacy and economic parameters are reviewed. Possible directions for the development and improvement of robotic equipment are discussed, and potential risks and limitations are analyzed.

The data obtained may contribute to the reasonable introduction of advanced robotic technologies in neonatological surgery in order to improve the quality and safety of treatment of newborn patients

Keyword: *Robotic surgery, neonatology, minimally invasive technologies, surgical robots, innovations in medicine, safety, efficiency, clinical practice, prospects of application*

1. INTRODUCTION

The modern development of medical science and technology has a significant impact on all aspects of healthcare. Particular attention is paid to minimally invasive and high-precision techniques that ensure not only treatment efficiency but also maximum patient safety. Robotic surgical technologies have already firmly entered the clinical practice of adults and older children, demonstrating a number of advantages over traditional methods. Increased accuracy of manipulation, reduced traumatic interventions and improved postoperative recovery rates all explain the growing interest in robotic systems.

The application of high-tech solutions in neonatal surgery can be considered particularly relevant, as patients in this category are characterised by limited physiological reserves and high vulnerability to external influences. Any surgical intervention requires filigree technique from the surgeon, as even a small error can lead to serious consequences. In this regard, robotic surgeons equipped with 3D visualization, instrument stabilisation and microsurgical precision appear to be a promising tool to improve the safety and efficiency of neonatal surgery.

In addition to the clinical benefits, the economic side of the issue becomes an important factor. The introduction of complex robotic systems requires substantial initial investments, as well as costs for staff training, maintenance and repair of the equipment. However, analysis of the experience of a number of large surgical centres shows that, if used systematically, such costs can be recouped in the long term by reducing the length of hospital stays and the risk of complications.

The aim of this study was to examine the experience of using robotic surgical technologies in newborns, as well as to analyze the factors affecting the effectiveness and safety of such interventions, including economic aspects and organizational issues of staff training.

The article presents the results of a comprehensive study combining retrospective evaluation of archival data, a survey of doctors and analysis of the dynamics of clinical indicators in institutions with experience in the use of robotic systems.

2. MATERIALS AND METHODS OF THE STUDY

The study was conducted on the basis of two leading medical centres specializing in neonatal surgery. It included newborn patients who underwent various types of robotic surgical interventions between January 2020 and December 2024. Patient data were collected and analyzed, including age at the time of intervention, diagnosis, type of surgical intervention, duration of surgery, presence and nature of postoperative complications, length of stay in the intensive care unit and hospital, and rehabilitation time. To clarify the economic parameters of the study, the cost of installation and amortization of equipment, personnel training and service costs were taken into account.

To form a representative sample, the case histories of neonates operated on not only using robotic systems but also using conventional methods were analyzed. This made it possible to compare the results of different surgical strategies. A total of 120 cases were included in the analysis, of which 60 were operated on using robotic systems and 60 by classical minimally invasive surgery. Exclusion criteria were intrauterine pathologies requiring special correction methods, as well as cases in which robotic intervention was initiated but ended with conversion to open surgery for technical reasons not directly related to the patient's clinical condition [8].

Formalized follow-up charts were used to evaluate the dynamics of the indicators, in which the details of each patient were recorded, as well as the protocols of the operating teams. Surgeons and operating nurses with experience of working with robotic systems were interviewed for a more in-depth analysis. The questionnaires included questions about subjective perceptions of ease of operation, difficulty in learning the technology, and stress levels during surgical procedures. In addition, the decision-making process of choosing patient management tactics and the role of the multidisciplinary team in assessing the appropriateness of robotic intervention in neonates was studied [6].

Statistical analysis was performed using a software package that allows calculation of mean and median values, standard deviations and 95% confidence intervals[4].

Non-parametric criteria were used to assess the reliability of differences, taking into account the small size of the groups and the peculiarities of data distribution. The level of $p < 0.05$ was considered significant.

Economic indicators were calculated based on the average cost of an operating hour, taking into account the cost of equipment amortization and medical staff remuneration.

3. RESULTS AND DISCUSSION

The study demonstrated marked differences in efficacy and safety between the groups. Newborns operated on with robotic systems had less blood loss, shorter length of stay in the intensive care unit, and faster recovery after the intervention [7]. However, the operation time was slightly longer in the group with robotic systems, partly due to the need for more thorough preparation and setup of the equipment.

To illustrate the findings, we have compiled a table summarizing the key clinical parameters.

Table 1. Comparison of clinical parameters between groups

Parameter	Robotic surgeries (n=60)	Traditional minimally invasive surgeries (n=60)
Average duration of the operation (min)	130	110
Average blood loss (ml)	20	40
Average length of stay in the ICU (days)	1,5	2,3
Frequency of complications (%)	5	10

The analysis shows that robotic surgical interventions in neonates are associated with lower blood loss and shorter ICU stays, despite increased operative time. This correlation confirms the high precision of robotic systems to minimize tissue trauma.

The positive impact on patient rehabilitation is particularly important in neonatal practice, where each day of hospitalization carries additional risks of infections and stress for the immature organism [3].

An additional indicator reflecting the effectiveness of the interventions was the analysis of the timing of the start of independent enteral feeding and the total period of hospitalization. In the group with robotic surgery, patients returned to natural feeding faster on average and in most cases were discharged from the hospital two days earlier. This fact may indicate less pain syndrome, better postoperative condition and fewer postoperative complications [5].

To illustrate the dynamics more clearly, we constructed graphs showing the changes in key parameters during the first 24 hours after surgery.

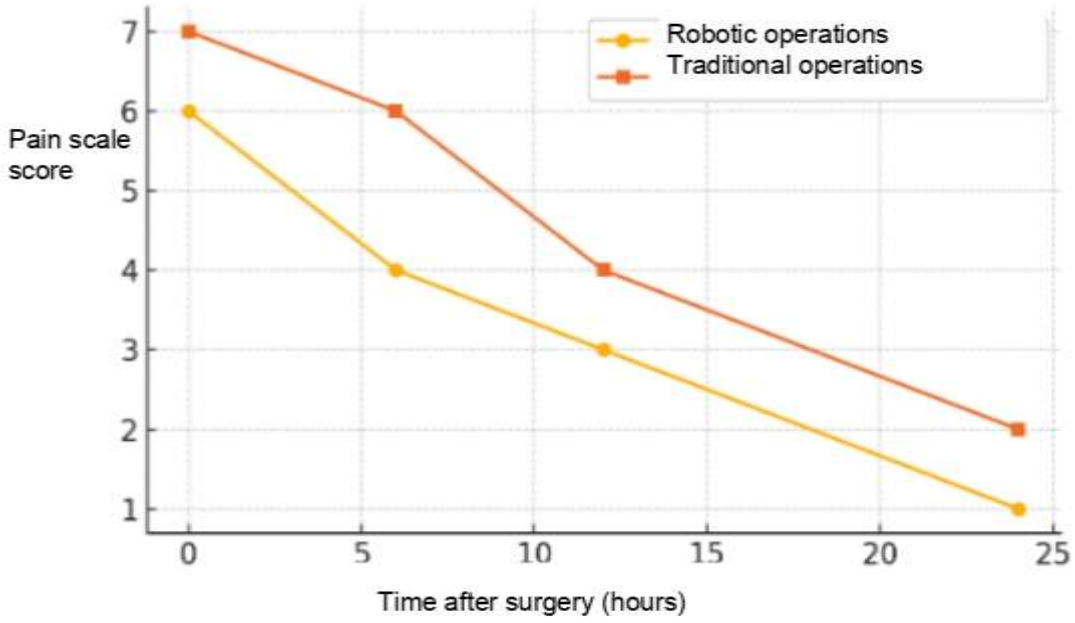

Figure 1 - Pain syndrome level as a function of time

Figure 1 demonstrates the change in the level of pain syndrome in scores on the pain response assessment scale for newborns. The initial value in the group with robotic surgery was slightly lower, and by the end of the first day after the intervention, this index decreased almost to the initial values[1]. In the group with traditional surgeries, a more pronounced pain syndrome was observed in the first hours after coming out of anaesthesia and persisted statistically significantly longer.

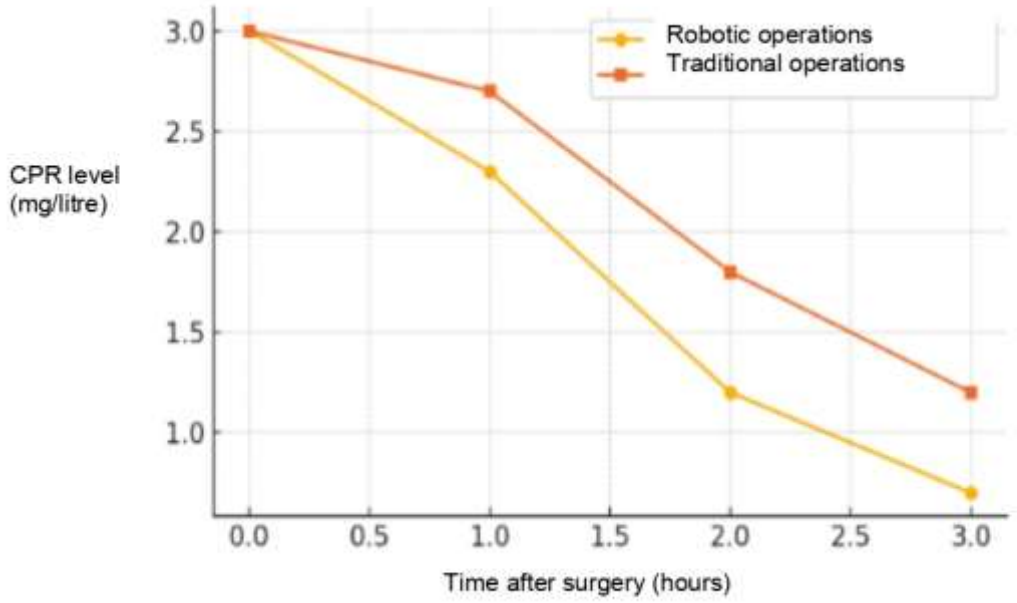

Figure 2 - Change in CRP levels during the first days after surgery

Figure 2 shows the rate of decrease in inflammatory markers (C-reactive protein) during the first three days after surgery. The group with robotic technology showed a faster decrease in CRP concentration, indirectly reflecting less traumatic impact on the patient's body. In the group with conventional technique, it took longer time to achieve similar values[10].

The study also addressed economic aspects, the key one being a comparative analysis of the total costs of surgery and postoperative management. The cost per case in the robotic surgery group was initially higher due to the substantial costs of equipment amortization, service and staff training. However, a detailed analysis of the costs of complications and prolonged hospital stay showed that with systematic use of robotic technologies, the total costs may decrease in the long term.

Table 2 summarizes the economic indicators.

Indicator	Robotic surgeries (n=60)	Traditional minimally invasive surgeries (n=60)
Average cost per operating hour (USD)	5000	2000
Additional expenses on personnel training (USD)	120 000 (one-off)	0
Average length of stay in hospital (days)	5	7
Average costs per patient (including rehabilitation) (USD)	25 000	22 000

Analysis of the table shows that robotic surgeries have higher economic costs compared to traditional minimally invasive surgeries. The average cost per operating hour with the robotic approach is 5000 USD, which is 2.5 times higher than the same indicator (2000 USD) for traditional methods. Additionally, a one-time investment of 120,000 USD is required for staff training, which is not available for traditional surgeries.

However, robotic surgeries reduce the average hospitalization time of patients from 7 to 5 days, which indirectly indicates their advantage in speeding up recovery and freeing up bed space. Despite this, the average cost per patient, including rehabilitation, remains higher with the robotic approach (25,000 USD versus 22,000 USD for traditional surgeries)[11].

Thus, despite shortening the length of hospital stay, robotic surgeries require significant initial and ongoing financial costs that are higher than those of traditional surgical techniques.

Despite the high cost per operating hour and the necessary investment in staff training, robotic technologies may be

economically feasible when calculating the total cost of treatment (taking into account re-hospitalisations, the risk of infectious complications and the need for resuscitation support) [9].

The key prerequisite remains a sufficient number of operations per year to 'spread' the initial costs.

This is why the most successful examples of robotic systems are found in large perinatal centres with high surgical activity.

The results of the questionnaire survey of medical staff demonstrated a general positive attitude to new technologies, but psychological stress related to the fear of possible technical failures and the high cost of error in case of equipment malfunction was noted.

The need for systematic improvement of surgeons' skills was also identified: constant practice on simulators and collaboration within multidisciplinary teams including neonatologists, anesthetists, engineers and medical robotics specialists became an important element.

The discussion of the results obtained during the study allows us to state that robotic surgical systems in neonatal practice can provide a number of advantages related to the accuracy and sparing nature of surgical interventions.

Today, existing systems have sufficient functionality to perform a range of minimally invasive procedures in neonates, but their widespread use is hampered by high costs and the need for significant resources at the initial implementation stage. At the same time, the dynamics of technology development, as well as accumulating experience and specialized training programmes, indicate a significant potential for scaling up robotic technology in neonatal surgery.

4. CONCLUSIONS

The study confirmed the clinical and economic prospectively of using robotic surgical technologies in neonatal practice. As a result of the analysis of retrospective data and current statistics, it was established that robotic interventions in neonatal patients contribute to the reduction of blood loss, accelerated recovery and potential reduction of complication risks compared to traditional minimally invasive methods.

The positive effect of robotic surgery is particularly noticeable in the reduction of postoperative pain syndrome and faster normalization of inflammatory indices, which is important in the early period of a patient's life. The economic aspect also points to the possibility of reducing total costs if robotic systems are used regularly in clinics with a high patient flow.

Nevertheless, the main obstacle to the widespread integration of such technologies remains their high cost, which includes the purchase of robotic equipment, the cost of training surgical teams and maintenance. An additional factor affecting outcomes is the need for careful patient selection and the availability of appropriate infrastructure, including a modern operating theatre with specialized equipment and neonatal anaesthetic support.

The way forward is to improve the technical characteristics of robotic systems, reducing their size, increasing the maneuverability of instruments and introducing adaptive artificial intelligence systems to assist the surgeon in decision-making. Continued research and accumulation of data on long-term outcomes, safety and cost-effectiveness will allow robotic technology to be more reasonably recommended in most neonatal surgery centres in the future.

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