OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

# Advancing Childhood Cancer Treatment: The Role of Artificial Intelligence in Robotic-Assisted Surgery

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**ABSTRACT**

This paper investigates the shift from regular robotic-assisted surgery (RAS) to AI-driven surgeries for childhood cancer and neonatal cancer, cancer that occurs in the first month of life. This paper examines patterns and trends in peer-reviewed sources to evaluate the differences in effectiveness between traditional treatment and robotic-assisted surgery to determine which yields the best, most efficient outcomes. Traditional treatments such as open surgery and chemotherapy present challenges that hinders its effectiveness and outcomes in cancer patients. While robotic-assisted surgery improves precision, recovery time, and many other factors, it is limited by high costs and primarily its lack of haptic feedback. This review analyzes the evaluation of how AI integration addresses these limitations through improved imaging and enhanced tactile feedback. Findings suggest that AI-assisted RAS overall outperforms regular RAS and traditional treatments, reducing complications and increasing surgical efficiency. Even though it presents promising outcomes, unequal access and ethical concerns remain a major setback. Ultimately, AI-enhanced robotic-assisted surgery represents an advancement toward a safer, more efficient form of treatment for pediatric cancer.

## 1 INTRODUCTION

While the term “cancer” remains a universal driving burden measured by its total fatalities, the gravity of neonatal cancer is uniquely devastating. Neonatal cancer, a subset of pediatric cancer involving children diagnosed with cancer in their first 28 days of living, is far more complex. Childhood cancer is extremely rare and is usually treated with standard treatment like chemotherapy and surgery. To put this into perspective, data from the National Cancer Institute’s Surveillance, Epidemiology, and End Results (SEER) report estimate that neonatal tumors and cancers occur at roughly 1 in 27,000 to 33,000 live births. For pediatric cancer, the incidence rate is roughly 1 in 285 children. Although neonatal cancer is much rarer, the idea of pediatric cancer is still a major concern. The extreme rarity of these cancer cases creates a “consistency gap” because surgeons rarely encounter these tumors, and the room for error is nonexistent. Lakshmi Shankar, a medical specialist in the Department of Stem Cell and Research in Martinique, claims diagnosing and treating neonatal cancer requires specialized knowledge and can be a “formidable task.” In this high-pressure environment, traditional “open” surgery methods may be too invasive for a neonate as risks rise due to the size of the patients, making them extremely vulnerable. Surgeons are face-to-face with both mechanical and physiological aspects of neonatal surgical procedures, primarily due to the neonate's size. (Mitul, Ashrarur Rahman, et al., 2017). Traditional treatments like chemotherapy are approached with caution due to the higher toxicity and mortality in a child because of the way the small body processes a drug. During traditional surgeries, surgeons rely on the physical sense of touch to know how much pressure to apply.

In light of this, the expansion of robotic-integrated innovations has reached healthcare, and its focus extends beyond encompassing intelligence without direct human involvement (Hirani, Rahim et al., 2024). Blending engineering and medicine creates robotic systems that support and improve the accuracy of human surgeons during medical procedures, known as robotic-assisted surgery (RAS). True to its name, high-tech robotic arms are utilized to help perform complex procedures. Surgical robots have highly intelligent learning systems built in that allow them to collaboratively assist surgical procedures. As robotic-assisted surgery becomes more common in high-risk pediatric cases, researchers are increasingly exploring the role of artificial intelligence as a means of enhancing precision and safety during operations. However, the reality of robotic arms performing life-threatening procedures presents a second obstacle: "Visual-Perceptual Mismatch In Robotic Surgery." Several limitations in pediatric robotic surgery include the cost of purchase and maintenance, as well as the difficulty in adapting to large robotic surgical instruments designed for adult patients (Saxena, Amulya L, et al., 2023).

Newer robotic systems, such as the da Vinci IS 1200, are primarily designed for adult surgery, making it hard to adapt to neonatal cancer. In robotic surgery, the surgeon sits away from the patient on a platform, using joysticks. This is creating a "danger hazard" for children, especially neonates, who have tiny blood vessels and nerves that are extremely fragile, which can be crushed before the surgeon even sees them move on the console. As a result, surgeons are not able to feel the tension and have no warning that they are applying too much pressure. Ahmad, an academic researcher from the University of California, highlights the critical limitations of force-blind robotic platforms by identifying a "visual-perceptual mismatch" that degrades surgical performances (Abiri, Ahmad et al, 2016). To mitigate these issues, the integration of Artificial Intelligence (AI) with current RAS through visual haptic systems that combine sight with touch for surgeons to "replace" the need for direct physicality during invasive, complex procedures. The widespread impact of artificial intelligence is becoming increasingly prevalent in every industry. This response can effectively restore a surgeon's sense of touch and help close the safety gap in pediatric robotic surgery. This restoration of a surgeon's sense of touch through AI-integrated innovations has the possibility to outperform current treatment and can revolutionize the safety of healthcare outcomes.

## 2 COMPARATIVE ADVANTAGES OF RAS

In recent years, there has been a growing trend in the use of robotic innovations for neonatal and pediatric therapeutics. The first reported use of robotic-assisted surgery was in April 2001. Technological innovations have only improved since 2001 and have shown no signs of stopping. In fact, the evolution of

RAS promises a new era, where advanced robotization expands a surgeon's skill, enabling unparalleled control in complex procedures (Emil Radu Iacob et al, 2024). Dr. Thomas Cundy, a PhD in surgical robotics at Imperial College London, argues that RAS offers a wide range of technological solutions to challenges, particularly for procedures within spatially confined workspaces with children. He and his research colleagues note that "Robotic surgery is an expanding and diffusing innovation in pediatric surgery." Essentially, integrating the expertise of pediatric surgeons with modern robotics is a way to transform pediatric surgical procedures, with the aim of making a difference in the outcomes for neonates with cancer.

For starters, comparative data is assessed between robotic-assisted surgery, laparoscopic, and open surgery. Emil Radu Iacob, an associate Professor in the Department of Pediatric Surgery, portrays the evaluated criteria of the 3 forms of treatment and their individual assessment in each category. Table 1 shows an analysis where robotic-assisted surgery offers a more suitable approach as it offers higher-level clinical outcomes in terms of precision, visualization, and patient recovery time compared to both laparoscopic and traditional open methods. RAS minimizes physical trauma, pain, and scarring through smaller incisions and increased flexibility during operations. The data illustrate that RAS provides surgeons with a high operative flexibility, directly translating into clinical benefits such as postsurgical scarring and recovery time. By evaluating these elements between treatments, RAS establishes a new standard for surgical excellence through its advanced technological capabilities.

Table 1. Comparative data between robotic-assisted surgery and laparoscopic and open surgery

| Evaluated Criteria | Robotic-Assisted Surgery | Laparoscopic Surgery | Open Surgery |
|---|---|---|---|
| Incision size | Smaller incision | Small incision | Large incision |
| Precision/visualization | High precision and visualization | Good precision and visualization | Lower precision and visualization |
| Flexibility during operation | High flexibility | Limited flexibility | Standard flexibility |
| Learning curve | Moderate learning curve | Steeper learning curve | Standard learning curve |
| Postoperative pain | Reduced postoperative pain | Moderate pain | Higher pain |
| Recovery time | Faster recovery | Fast recovery | Slower recovery |
| Postsurgical scars | Minimal scarring | Small scars | Large scars |
| Risk of complications | Lower risk | Moderate risk | Higher risk |
| Cases applicability | Broad applicability | Applicable in many cases | Standard cases |
| Costs, accessibility | Higher initial cost, accessibility in developed settings | Moderate cost, accessible | Lower cost, accessible |

From Iacob, Emil Radu et al, 2024 https://pmc.ncbi.nlm.nih.gov/articles/PMC10968808/

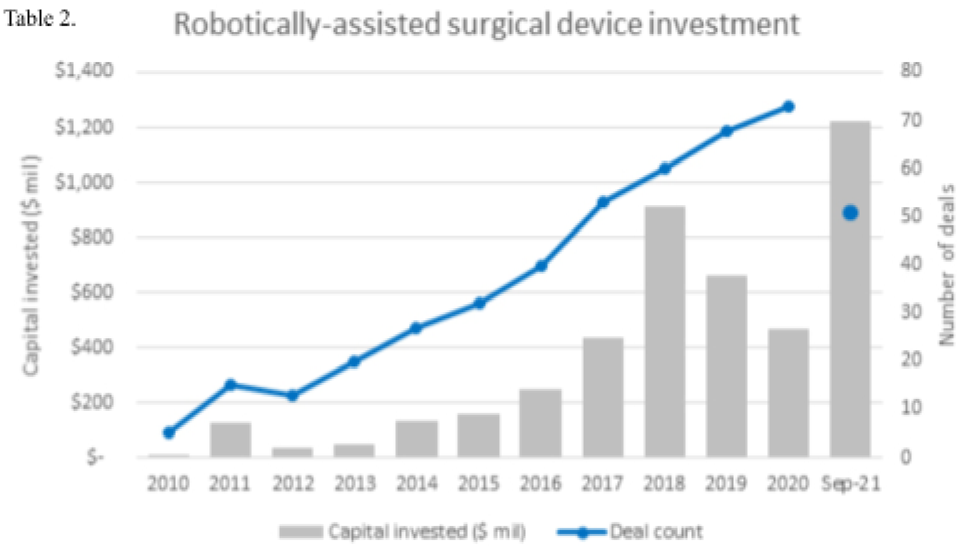
Building on this, robotic-assisted surgery has many engineering factors that traditional open surgery does not include, such as enhanced ergonomics, articulated instruments, the removal of hand tremors, and three-dimensional vision (Handa, Alisha et al, 2024). These advancements allow surgeons to operate from a seated console, reducing physical limitations and ensuring focus. This robotic instrument outperforms human-held tools in open surgeries, granting more "flexibility." The system's three-dimensional vision, an imaging technology, helps eliminate hand tremors and enables "high precision," which is imperative when operating on children and newborns, since their anatomy is extremely small. Having even the slightest increase in accuracy and precision can prevent lethal outcomes in high-pressure procedures.

Newer systems of RAS have enabled real-time data on tissue stiffness and thickness, where "off-the-jaw" sensors deliver objective tactical feedback measuring force (Friebe, Michael, 2025). This mechanism helps avoid the need to place delicate sensors in the patient, bypassing sterilization issues. In fact, some surgical platforms integrate both force and tactile feedback, achieving up to 95% accuracy in force, essentially improving surgical control. Again, this enhances precision and the safety of children in minimally invasive procedures, building the stance that robotic-assisted surgery is a pivotal tool in response to pediatric and neonatal cancer.

Pediatric cancer causes detrimental effects to children, inflicting pain that not only stems from the cancer itself but also from the medical treatments and procedures. The pain and discomfort that is linked with traditional treatment, like chemotherapy or surgery, can heavily affect a child's quality of life. Patients who undergo open operations may encounter elevated levels of postoperative anxiety as a result of the larger incisions and the invasive nature of the procedures. In cases of pediatric cancer, over 50% of pediatric cancer patients experience untreated pain that affects a patient's psychological, emotional, and social well-being (Le-Short, Christina et al, 2022). Children who are receiving active cancer therapies and even cancer survivors are experiencing increased impairments in behavioral domains. When children experience these pains, it creates a cycle of suffering that is especially bad at a young age. It leads to social isolation, depression, and low self-worth. In addition, it often disrupts normal developmental milestones and increases long-term mental health risks.

On the other hand, research has indicated that patients, especially "youngsters," who have gone through robotic treatment have experienced a decrease in postoperative tension and anxiety (Emil Radu Iacob et al, 2024). In view of the data in Table 1, the reduced invasiveness, smaller incisions, and postoperative pain highlight a more favorable experience psychologically. The heightened accuracy in robotic devices provides caregivers with a direct visual representation, boosting confidence and reducing unpleasant feelings about potential dangers. In brief, it is essential to evaluate and understand the full scale factors in a patient's quality of life in order to provide patient-centered treatment.

Table 2.




From Stuart, David, et al 2021 www.meddeviceonline.com/doc/robotically-assisted-surgical-devices-ripe-for-innovation-0001

Table 2, which was produced by RSM U.S, a leading provider of tax and consulting services, shows how investment and deal activity in robotically-assisted surgical devices changed from 2010 to Sep-2021. Both the capital investment and the number of deal counts generally rise each year, showing growing interest from investors in robotic assisted technology. Investment spikes primarily after 2016 depict rapid growth in the field. Despite the sudden drop in deals towards 2019 and 2020, the number of deals continues to increase suggesting that more companies are entering the market and receiving funds.  This trend suggests that interest in robotic assisted surgical devices will likely continue to grow in the modern world. Considering these findings, the integration of robotic platforms in pediatric and neonatal cancer represents a shift toward a more optimal surgical standard, offering various benefits of surgical structure and improved postoperative feedback.

## 3 IDENTIFYING GAPS IN STANDARD RAS

As the application of robotic-assisted surgery in response to childhood cancer serves as an advancement within healthcare, its efficacy is challenged by certain limitations. As mentioned earlier, the price tag associated with robotic systems may limit access and exacerbate existing disparities in healthcare (Sadat, Anoush Sardesai et al., 2025). Many families are always looking for the best treatment for their children and are even willing to face financial burdens. This creates a systemic privilege for wealthy families who can afford this highly advanced treatment. In fact, high-income countries are at the forefront of technological advancements, yet these ideas are limited to low-income nations due to a lack of "financial infrastructure" (Handa, Alisha et al, 2024). In addition, health facilities have infrastructure issues that make it difficult to integrate technologies smoothly, and enhancing robotic surgery could result in extra funds and time. Along with families, the high cost of initial investment, maintenance expenses, and instrument cost also raises concerns for healthcare institutions and hospitals. This challenge can potentially limit widespread access and utilization of robotic-assisted surgery in pediatric surgery.

The major drawback of the long training is the lack of palpation and haptic feedback. As mentioned before, surgeons rely solely on visual cues from a very narrow field-of-view camera, and the lack of tactile feedback hinders tissue characterization, risking inadvertent damage (Friebe, Michael, 2025). Not having the ability to "feel" tissue texture and the force they are applying is extremely dangerous for pediatric patients, as it can cause tissue damage from excessive force. Unlike traditional laparoscopy, which provides some kinesthetic feedback through the instrument itself, most robotic systems lack kinesthetic and tactile feedback. In recent years of research, numerous forms of haptic feedback systems (HFS) have been introduced with the aim to address this limitation. Even in current systems like the da Vinci Surgical Systems, which often lack localized sensations like texture and pressure, it is hard to perform procedures involving children with small bodies. In addition, the size and design of robotic specialized instruments pose challenges in pediatric surgeries. The instruments that are designed for adult procedures are not optimal for the smaller anatomies of pediatric patients, especially neonates. This raises concerns regarding the precision and adaptability of the system in certain procedures. Operating these instruments in confined, delicate pediatric tissues underscores the need for specialized pediatric adaptations.

Due to learning curve and size challenges, ethical viewpoints on robotic-assisted surgery and limited public understanding of RAS arise, where families are unsure and hesitant, discouraging potential patients from choosing robotic procedures for their children. Reasons include fears of technical malfunctions and worries about the surgeon's level of experience with advanced technology (Brar, Gurneet et al, 2024). This problem arises as there is a complex learning curve, creating barriers to robotic surgery programs due to the extensive training required for human operators. Finding fully trained surgeons is difficult as there are not enough and few are concentrated in area-specific hospitals. Pediatric surgeons who use robotic systems require dedicated education and hands-on experience, leading to prolonged surgical durations and increased operative times during their learning process (Emil Radu Iacob et al, 2024). This reaches beyond the surgeon to include specialized care requiring a large number of resources and staff, which hospitals struggle to maintain (Catchpole, Ken et al, 2018). This major setback underlines the importance of carefully maneuvering robotic tools during pediatric surgery because one simple mistake can potentially cost a patient's life.

As these ethical, economic, and educational challenges persist, the integration of RAS in pediatric oncology care remains uncertain. It highlights a critical trade-off between the advantages and potential of robotic-assisted surgery and its practical disadvantages, especially the lack of palpation and haptic feedback. It has not fully replicated the "human touch" in open surgery. Furthermore, these long-standing issues revolving around RAS suggest that until these challenges are addressed, RAS remains a sub-optimal system.

## 4 INTEGRATING AI AS A TRANSFORMATIVE SOLUTION

The implementation of robotic-assisted surgery laid the groundwork for technological advances in healthcare. However, the main issue regarding RAS, like the da Vinci system, was the safety measures related to haptic feedback, as it required surgeons to rely too heavily on visual cues, endangering pediatric patients. Given this, health experts aim to fix this issue by integrating "artificial" sensors on the surgical instruments that relay force data back to the surgeon's console. Artificial intelligence is the development and study of algorithms that give machines the ability to perform cognitive functions ranging from finance use to agriculture, manufacturing, and even education (Knudsen, J Everett et al, 2024). Artificial intelligence is already revolutionizing nearly every aspect of modern life. Everett Knudset, an innovative healthcare professional, argues that AI is the most "impactful" when crossed over into the medical field as it is used to help medical experts make more precise decisions and predict patient outcomes with a higher degree of certainty. AI has the potential to do numerous tasks, including clinical documentation, patient outreach, patient monitoring, and medical device automation, like robotic-assisted surgery (Bohr, Adam et al, 2020). Regular robotic surgeries have already outperformed regular treatments in almost every category, and this raises the question: "How can AI further expand the performance scale of RAS in childhood cancer?"

As technology continues to evolve each year, advancements in robotics paired with artificial intelligence and haptic feedback systems make surgical practices more efficient (Emil Radu Iacob et al, 2024). AI promises benefits for healthcare optimization and patient safety. Cohort studies and systematic reviews were conducted to evaluate outcomes compared to manual surgical procedures. Research indicates AI-assisted robotic surgeries have outperformed manual methods in operative time by a 25% reduction. Both forms of procedures have unforeseen injuries occurring between skin incision and closure, but AI-assisted robotic surgeries demonstrated a 30% decrease in intraoperative complications compared to traditional procedures. These advantages translate to a 20% increase in surgeon workflow efficiency paired with an additional 10% reduction in healthcare costs over conventional procedures (Wah, Jack Ng Kok, 2025). When considering all of these benefits, it directly translates to a safer, more effective environment for pediatric patients for several reasons. Every minute that is saved and every complication that is avoided has an impact on the patient's long-term health. Children respond differently to the physiological stress of surgery and anesthesia as their bodies are developing. Again, pediatric cancer puts a huge strain on families, so the increase in workflow efficiency and reduction in healthcare costs reduces the "out-of-pocket" burden, allowing parents to worry less about the medical bills. AI-enhanced robotic surgery is simply increasing the proficiency gap between traditional methods like chemotherapy and radiation, supporting the widespread clinical adoption of new technological procedures.

Beyond the immediate surgical advantages, the major game-changer of AI-enhanced robotic surgery is its haptic feedback system. The palpation and haptic feedback are essential for overall safety and outcomes for children. The current RAS platforms are heavily reliant on visual inputs, limiting functionality and impairing the accuracy of distinguishing between healthy and diseased tissue (Friebe, Michael, 2025). The margin for error is microscopic in pediatric patients, where organs are smaller, and tissues are more fragile, so the inability to feel tissue increases the risk of vascular injury and tears. Therefore, improved haptic feedback helps provide a more realistic sense of touch, equipping surgeons with better navigation in delicate tissues (Emil Radu Iacob et al, 2024). Integrating sensors enhances tissue characterization by identifying stiffness, compliance, and elasticity. For instance, autonomous systems that are equipped with force sensors can gauge the depth of tumours within soft tissue effectively simulating human palpation. Identifying stiffness and elasticity allows surgeons to categorize dense tumors from soft, healthy organs with efficacy. AI-enhanced robotic systems have drastically decreased surgical trauma rates and inadvertent damage to tissues (Wah, Jack Ng Kok, 2025). Up to 43% lower applied force in recent haptic-enabled robotic systems, demonstrating significant reductions in tissue loading (Friebe, Micheal, 2026). Additionally, integrated force sensors can achieve roughly 95% measurement accuracy for surgical tool loads. Artificial intelligence can provide optimal force levels and act based on feedback patterns and motion tracking instruments, allowing surgeons to predict tissue stiffness and force. This ensures the lowered risk of accidental trauma to delicate pediatric nerves and vessels. These systems act as a substitute for a surgeon's touch, ensuring the actions necessary for a child's long-term recovery and health.

The integration of AI is a way for surgeons to perform surgeries in a simpler and safer way, a medical evolution researched by Dr. Omar Usmani and a group of colleagues at Era's Lucknow Medical College and Hospital. The da Vinci System is able to deliver precise surgery decisions with AI by "scaling movements, lowering tremors, and displaying everything in 3D"(Usmani, Omar et al., 2025). AI algorithms have enhanced the quality of surgical imaging, creating a clearer, more precise visual of anatomical structures. By leveraging advanced imaging techniques from AI tools, surgeons can plan out the patient's anatomy in 3D, allowing for the best and safest incision. AI-driven 3D images help surgeons navigate through a child's and even a neonate's small-scale structure with utmost precision, lowering the risk of complications. Complex anatomies and developmental factors require the need for a patient-specific intervention utilizing three-dimensional surgical imaging. Artificial Intelligence has the ability to outline a child's anatomy and highlight risk factors (Harrison, Lucas M et al., 2025). Moreover, the ongoing improvements with AI in pediatric oncology play a pivotal role in aiding surgeons to carry out informed decisions, ultimately contributing to better surgical outcomes (Morris, Miranda X et al., 2024).

When pairing the "brain" of AI powered systems with the "body" of regular robotic-assisted surgeries, it demonstrates clear advantages. The rise of artificial intelligence is continuing to grow and playing a crucial role when it comes to enhancing robotic-assisted pediatric surgeries. Whether it is aiding surgeons in real-time decision making, planning procedures, or improving overall efficiency, the integration of AI-driven surgical systems is expanding the scope of robotic interventions in pediatrics and redefining the gap between traditional open surgeries and AI-driven RAS. AI-powered tools are revolutionizing cancer diagnosis and predicting treatment outcomes, overall improving survival rates in pediatric cancer patients (Hashem, Hasan et al., 2025). Despite solving the haptic feedback obstacle in regular RAS, AI-driven platforms find themselves in a loophole with the ethical perspective and accessibility in certain parts of the world. These AI-medical machines contain a complex, ethical challenge making it hard to tell who is at fault in the case of when something goes wrong. In a traditional operating setting, the legal accountability falls primarily under the operating surgeon but because of this intricate system, it requires the need for a “robust regulatory framework” to outline responsibilities in the event of complications (Goedeke, Jan et al., 2025).

## 5 DISCUSSION

This review has consistently supported the argument that integrating artificial intelligence into robotic-assisted surgery offers a tremendous step to a safer and more effective approach for treating both neonatal and pediatric cancer than traditional methods. Studies and trends comparing robotic-assisted surgery with traditional open procedures demonstrate improved precision, reduced pain, faster recovery, and overall better patient outcomes.

The integration of artificial intelligence into robotic-assisted surgery has presented a groundbreaking form in the treatment of childhood and neonatal cancer, potentially establishing a “new standard for paediatric surgery” (Alex Joseph, A. Franklin, et al., 2025 . While traditional treatments remain foundational, they are limited due to invasiveness, toxicity, and long-term health implications in children. Normal robotic-assisted surgery has outperformed traditional treatment but is constrained by its limitations, particularly the lack of haptic feedback, high costs, and steep learning curves, hindering its ability to maximize patient outcomes. However, AI-driven robotic-assisted systems directly address these shortcomings by not only restoring sensory feedback but also enhancing surgical outcomes through imaging and decision making. It can also track recovery trajectories, predict the likelihood of secondary interventions, reduce the risk of long-term morbidity through post-surgical imaging and patient data (Harrison, Lucas M et al., 2025).

Despite the promising advancements, the challenges related to ethical viewpoints, accessibility, and global disparities still persist and must be carefully addressed to ensure optimal treatment. For children’s cancer, there is very little use of AI treatment systems and is required for equitable outcomes just like adult cancer (Mubashir Hassan, et al., 2025). Ongoing research by researchers, technologists, and clinicians is essential to overcome current issues and unlock AI’s full potential in advancing treatments for children with cancer (Hashem, Hasan et al., 2025). Future research should be focused on improving affordability, expanding training programs for surgeons, and robotic systems designed specifically for pediatric patients. Overall, the literature supports the conclusion that AI integration is a major step toward improving surgical outcomes for children with cancer.

## 6 CONCLUSION

AI-driven robotic-assisted surgeries have shown promising results in improving the overall treatment of childhood cancer, but it is difficult to understand their full reach. It has helped restore aspects of tactile sensation but still falls short of fully replicating the full grasp of human touch in open surgeries (Friebe, Michael, 2025). Therefore, ongoing research must continue to carefully evaluate the implementation to ensure safety and efficacy. In short, artificial intelligence has shown great potential in the fields of healthcare and medicine so far and will offer a more solid alternative in the treatment of pediatric cancers in the future (Saxena, Amulya L, et al, 2023). As childhood cancer continues to affect children around the world, treatment methods should only improve and evolve to prioritize patient safety and outcomes.

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