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Pediatric Robotic Oncology Surgery: Is there a Reduction in Post-Surgical Complications?

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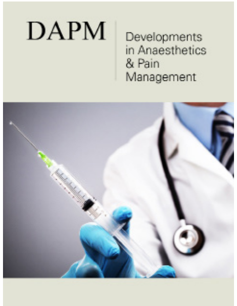

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Abstract

Robotic-assisted surgery has become an established tool in adult oncology, offering enhanced visualization, dexterity and surgeon ergonomics. However, its application in pediatric oncology remains limited, largely due to the rarity of childhood cancers, unique physiological constraints and the distinct biology of embryonal tumors. The review synthesizes current evidence on the safety, complication rates and broader implications of robotic utilization in pediatric oncologic surgery. Data from pediatric urology and other surgical subspecialities demonstrate potential advantages-including shorter hospitalization and comparable success rates to open or laparoscopic approaches-yet complication rates in select series appear higher with robotic platforms, particularly in smaller cohorts or among less experienced operators. Importantly, robot-specific malfunctions are exceedingly rare (<0.5%) and many observed complications stem from modifiable factors such as case selection, patient positioning and training. Beyond outcomes, this review highlights critical considerations in pediatric robotics; challenges in surgical education due to low oncologic case volumes, disproportionate financial burden in comparison to adults, ethical complexities in parental informed consent and physiologic vulnerabilities inherent to pediatric patients. Future directions include refinements of pediatric-specific instrumentation, multicenter prospective trials to ensure oncologic safety and optimize long term outcomes.

Keywords: Pediatric oncology; Robotic assisted surgery; Minimally invasive surgery; Surgical outcomes; Embryonal tumors; Surgical education; Postoperative complications; Cost-effectiveness

Introduction

The incidence of global childhood cancer is estimated at 400,000 cases per year [1], with 15,780 new cases per year in the United States according to the American Cancer Society [2]. While robotics has become commonplace in adult oncology, it remains rare in pediatric oncology due to the rarity of childhood cancers. Pediatric cancers also differ from adult cancer in that they are mainly embryological tumors with high-speed growth and huge volume at diagnosis. Treatment usually associates neo-adjuvant chemotherapy, surgery and radiotherapy as required. As a result of advances in treatment, the mean overall survival is about 80% [3], whatever the tumor type. The advantages of robotic-assisted surgery in addition to laparoscopic surgery are their three-dimensional (3D) vision, seven degrees of freedom, tremor filtration and precise camera control [4]. Robotic surgery for pediatric tumors is a safe option in highly selected cases. Indications should be discussed in the framework of certified tumor boards with medical oncologists, pathologists and radiologists, to avoid widespread and uncontrolled application. This article will explore the issue of post-surgical complications, broad implications of robotic oncology surgery.

Discussion

The utilization of pediatric robotic surgery has been integrating into surgical practice for over two decades. The first robotic surgical procedure in a child was in April 2001. Since 2001 to 2012 there has been an increasingly steady rise in robotic surgeries in children, with 2393 procedures performed [5] with the majority of robotic surgeries taking place in the field of urology. With this increase, it is important to assess the efficacy, outcomes, cost and complication rates of robotic surgeries versus traditional surgical procedures. Although there is a rise of robotic surgeries in children, the utilization of robotic tumor surgery in children is still low. However, examination of current uses of robotic surgeries in other pediatric surgical fields, may give insight into the future uses in pediatric oncologic surgeries as well as the potential complications. Current research has examined the potential advantages and benefits of robotic surgery in comparison to traditional procedures, such as the ability for 7 degrees of freedom, visualization of 10x in magnification, as well as better ergonomic conditions for the operating surgeon [6]. With these potential advantages, there is an indication that this could aid in better postsurgical outcomes. Several meta-analyses regarding robot-assisted laparoscopic pyeloplasty in children revealed shorter operative time and decreased hospitalization [6]. This study also showed that these same surgeries had similar success rates to either open or laparoscopic procedures. This provides promising results for the field of pediatric robotic surgeries, however a significant area where differences were noted between surgery groups was in the complication rate. In systematic review of 108 robotic vs 1494 open ureteral reimplantation surgeries those who underwent an extravesical robotic ureteral reimplantation the complication rate was 13.0% vs 4.5% [6]. The robotic surgical group had a complication rate almost triple the open surgical group, however there are potential confounding factors to make note of. The robotic group has a smaller sample size and potential operator error when using new technology. Both of these likely influenced the complication rates seen in the study indicating that a larger cohort study would be needed to assess and validate the complication rate comparisons between groups. Another systematic review was completed oriented around the postoperative complications of pediatric robotic surgeries. When evaluating the morbidity in robotic surgery a few key factors were discussed that are unique to children. These factors were the small size of children and oncologic conditions as a confounding variable [7]. The latter condition being critical to not only postoperative complications, but additionally patient selection initially. Since robotic surgery is still minimally used in pediatric oncology, patients must be thoroughly screened prior to being qualified for a robotic surgery. One of these variables is the type of cancer, location of tumor, staging of cancer, prognosis and likelihood for success. If these factors are properly screened and accounted for, then robotic surgery in children can be a safe and viable option. Current complications of robotic surgery are mainly related to patient positioning and robot malfunctions, with the latter occurring in 0-0.5% of surgeries. In current large pediatric cohort studies, robot-specific complications are extremely rare [7]. This was an important outcome that was discussed in this study since these surgeries are still rarely performed, however if current complications are related to more controllable factors such as patient positioning this could be promising for future surgeries. Additionally, the mention of robotic malfunction rates being below 0.5% in this systematic review highlights another critical issue that could be possible in the field of robotic surgery versus open surgical procedures. Utilization of a robotic assisted device inherently adds in another variable that could impact success rates and outcomes, as well as the potential risk associated with these procedures. Evaluating current success rates, in comparison to their complication rates will be fundamental in determining the future application of robotic surgeries in the pediatric field [8].

Broader Implications of Robotic Utilization in Surgery

Beyond outcomes and complication rates, robotic surgery carries broader implications that must be considered. One of the key dimensions of the integration of robotic surgery is surgical training and education. In adult surgical practice, case exposure toward robotic procedures is increasingly competing with traditional open approach surgeries8. This raises the question whether new generations of surgeons will continue to maintain adequate proficiency in open surgery, which remains essential for emergencies or when robotic platforms are unavailable or inaccessible. As well as the opposite of this scenario, will all surgeons have enough opportunity and exposure to robotic surgeries to become competent and skilled. In pediatrics, these concerns are magnified: oncologic case volumes are low, meaning opportunities for residents and fellows to gain adequate exposure and training in both robotic and open surgery are limited [9]. As robotic systems become more integrated into pediatric surgery, residency and fellowship programs will need to balance exposure across modalities to ensure surgical versatility. This adds in another layer of complexity for residencies regarding proper surgical training and facilities to train residents and fellows properly in regards to robotic surgery. Another important consideration is cost effectiveness. Robotic platforms require high upfront investment, ongoing maintenance and expensive instrumentation. Studies in pediatric fundoplication and urologic procedures have found robotic assisted cases to be consistently more expensive than laparoscopic or open surgery, sometimes without a clear advantage [10]. Multiple large-scale analyses studies demonstrate that robotic assisted operations incur higher direct hospital costs, high supply costs and fixed costs associated with maintenance of robotic systems [11]. When looking at adult oncology, cost-effectiveness analyses suggest that higher expenditures are not always offset by improved outcomes. The financial burden becomes even more relevant in pediatrics where case volumes are relatively low in comparison to adult oncology. There may be difficulties for smaller or more rural surgical centers to justify the added expense of robotic surgery, raising the question of access and equity in pediatric oncology care.

Unique Considerations in Pediatrics

In pediatrics there are unique considerations that do not apply the same as in adults. Informed consent in particular is salient. In adults, currently informed consent practices regarding disclosure of robotic assistance are inconsistent; not all patients are explicitly informed beforehand [12]. In pediatrics, parents and guardians bear the responsibility of making complex health decisions on behalf of their child. This raises an ethical obligation to provide clear, comprehensive information about the role of robotic assistance, the risks, benefits and uncertainties that still remain due to limited pediatric data [13]. The current guidelines recommended a process that explicitly discusses the higher costs that are implicated with robotic surgery and the increased risk of safety and effect on feasibility that is associated with pediatric robotic surgery. Another dimension of pediatric care is the unique physiologic and oncologic challenges compared to adults. Children have smaller anatomy, which complicates trocar placement, instrument maneuverability and patient positioning [6]. The fixed diameter of robotic instruments can be disproportionately large for neonates and infants (typically 8mm). Although smaller instruments (5mm) have been developed, they have limited range of motion compared to their 8mm counterparts, potentially reducing the technical benefits of robotic assistance [14]. In comparison to adult tumors, pediatric tumors are often large embryological masses that are rapidly growing. Bulky tumors such as a Wilms tumor can fill the abdomen, leaving minimal space for robotic manipulation.

Furthermore, docking and instrument collision are more frequent in pediatrics compared to adults, and there is an absence of haptic feedback [15]. Haptic feedback is essential for surgeons to assess tissue planes, tension and force application. This can increase the risk of inadvertent tissue injury, which may be increased in children due to the more delicate nature of their physiology. Additionally, in comparison to the adult population, pediatric physiology differs from adults in multiple areas; one significant mention being the reduced cardiopulmonary reserve pediatric patients have. The insufflation pressures required for robotic surgery can impair venous return, increase systemic vascular resistance and reduce lung compliance. Newborns and infants are at increased risk for hemodynamic instability due to the effects of pneumoperitoneum, positioning and prolonged operating times associated with robotic surgery [16]. This raises the question how widely applicable robotic surgery would be in pediatrics currently since even modest insufflation pressures needed for robotic visualization can cause complications.

Conclusion

Robotic-assisted surgery represents a rapidly evolving adjunct in pediatric oncology. The current literature demonstrates that robotic platforms can be applied safely in highly selected cases, offering advantages in visualization, precision and surgeon ergonomics. However, their widespread adoption remains constrained by unique challenges intrinsic to the pediatric population, including small body, physiologic vulnerability and the distinct oncologic biology of large embryonal tumors. As discussed in the present review, complication rates remain an important and sometimes underappreciated factor. While robotic surgery offers reduced hospital stay and recovery benefits in certain procedures, systemic reviews indicate complication rates can exceed those of open approaches in pediatric cohorts-particularly when sample sizes are small and surgeons are early in their learning curve and robotic training. Importantly, many complications appear related not to the robotic platform itself but to modifiable factors such as patient position, case selection and operator experience.

Currently large pediatric series suggest that robot-specific malfunctions are exceedingly rare (<0.5%), yet the integration of this technology into oncology must remain cautious, given the oncologic imperative to avoid tumor rupture and ensure margin-negative resections. Taken together, the evidence suggests that robotic surgery should not be viewed as a replacement for conventional open or laparoscopic approaches in pediatric oncology but rather as a complementary tool reserved for centers with appropriate expertise and infrastructure. Future progress will require multicenter prospective studies, refinements of pediatric-specific instruments, incorporation of simulation-based training into surgical education and systematic evaluation of long-term oncologic and functional outcomes. Until such data is available, robotic-assisted surgery in pediatric oncology should be employed judiciously-guided by rigorous oncological standards, ethical transparency and a multidisciplinary framework.

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