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Robotic Surgery in Children: Embracing the Future

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Abstract

Robotic surgery, defined as minimally invasive surgery (MIS) with the assistance of tele manipulators, was developed to increase the surgeon's skills, accuracy and high precision during complex surgery.
In a relatively short amount of time, robotic minimally invasive surgery has been rapidly adopted for a wide variety of surgical procedures in adult patients across a broad spectrum of surgical specialties, included pediatric surgery. The first case of robotic minimally invasive surgery in children was a Nissen fundoplication that was performed in July 2000 and since then, robotic techniques have been slowly adopted by select pediatric surgical specialists. The real innovation, especially for children, is that robotic surgery permits previously intangible minimal access surgical approaches for complex reconstructive procedures. But, unfortunately, there are some limitations, that slow down the spread of this technology in pediatric field such as the size and the higher costs, that needs to be overcome.
The use of robotic-assisted surgery is increasing even in younger children, infants, and neonates. However, more strong studies are needed in order to assess the scientific evidence of this approach versus the conventional open or laparoscopic techniques.

Key Words: Robotics, Robotic Surgery, Children

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Introduction

Surgical innovations focus on increasing patient safety and quality of life, that's why researcher try to discover the most effective treatments. The advent of minimally invasive surgery (MIS) is the main surgical innovation of the past three decades, combining multiple technological developments. High-definition cameras and smaller instruments, that require little incisions to enter in the human body, replace the eyes and hands of the surgeon. Reduced surgical trauma and incision-related complications, such as surgical-site infections (1,2), pain and hernias (3), reduced postoperative discomfort, morbidity and hospital stay, with faster recovery, earlier return to daily activities and improved cosmetic outcome, represent the main advantages of MIS over traditional open surgery.

The price to pay for the surgeon in order to increase the patient's quality of life is an intensive and continuous training that he has to do in order to manage this technical demanding technique. The two-dimensional (2D) monitor reduces in-depth perception and hand–eye coordination, instruments generate a reduced force feedback while manipulating tissues and usually the surgeon works without an ergonomic position. Difficulties are amplified when dealing with already complex surgical procedures. (4)

Robotic Surgery

Robotic surgery, defined as MIS with the assistance of tele manipulators, was developed to relieve these drawbacks, in order to increase the surgeon’s skills, accuracy and high precision during complex surgery.The US Food and Drug Administration approved 5 robotic systems during the last three decades: AESOP, Endoassist, Neuromate, Zeus, and da Vinci (5); however, the term ‘robotic surgery’ became synonymous with the da Vinci Surgical System (Intuitive Surgical) soon.The system includes 3 components: a surgeon console (the control), patient cart, and vision cart. Intuitive Surgical had patented EndoWrist Technology to the console, which provides 7° of freedom and 90° of articulation (6) per controller, mimicking the actual range of motion of the human wrist. The patient cart interacts with the patient, and the vision cart displays a real-time visualization of the procedure.(7) These 3 components work in unison to facilitate surgical procedures. Design features of robotic surgical platforms include motion scaling, greater optical magnification, stereoscopic vision, increased instrument tip dexterity, tremor filtration, instrument indexing, operator-controlled camera movement, and elimination of the fulcrum effect. (8-10) These robotic enhancements offer improvements to conventional minimal access surgery, permitting technical capabilities beyond existing threshold limits of human performance for surgery, even within the spatially constrained operative workspaces as in children. (8, 11-18) In a relatively short amount of time, robots have made its way into both general and subspecialty surgical fields. The da Vinci Surgical System has been around for over two decades now. The specialties that use the da Vinci system frequently are urological, gynecological, and gastrointestinal surgery. (19) In 2010, Intuitive Surgical Inc., the manufacturer of the da Vinci robot, reported that over 70% of robotic procedures were for both prostatectomy and hysterectomy combined. (19) Further, robotic technique is the preferred method of performing a radical prostatectomy as the definitive treatment for prostate cancer. (20) In gynecology, it is estimated that over 60% of minimally invasive hysterectomies performed in patients with endometrial cancer were done robotically. (21) There are several reasons why urologists and gynecologists perform more robotic procedures than their other surgical counterparts. These include balance of surgeon endoscopic skill level, meaning how often endoscopic or laparoscopic techniques are performed in their field; equipment limitations, especially when working with anatomically complex areas; and procedure complexity, taking into account which procedures are better performed open versus minimally invasive versus robotically, the latter having the greatest precision. (20) Robotic options do exist for surgical treatment in other specialties although it is used much less frequently. These include cardiothoracic surgery, for cases of coronary bypass and heart defects repairs; general surgical oncology, for esophageal tumors, gastric cancer, colon cancer, thymoma; and pediatrics, to resolve congenital heart diseases, gastroesophageal reflux disease, or ureteropelvic junction obstruction. (22)

Robotic minimally invasive surgery has been rapidly adopted for a wide variety of surgical procedures in adult patients across a broad spectrum of surgical specialties. This has occurred despite the high costs and uncertain benefits of surgical robots. Local competitive pressures may be driving the purchase of a robot: the adoption of this technology by a neighboring hospital increases the likelihood of nearby hospitals acquiring a surgical robot. (23)

Robotic surgery in pediatrics

Pediatric surgical disciplines have been much slower to embrace the surgical robot: many children's hospitals do not even possess a surgical robot, and many of those that do borrow them from the adult operating room within the same medical facility. (24)

The first case of robotic minimally invasive surgery in children was a Nissen fundoplication that was performed in July 2000 and reported in April 2001. (25) Since that time, robotic procedures have been slowly adopted by select pediatric surgical specialists. In the following decade, there were a total of 2393 procedures reported in 1840 patients in the published literature. (26)

Urologic procedures are the most common application of pediatric robotic surgery. (27) Procedures that have been performed using robotic assistance include pyeloplasty, ureteral reimplantation, complete and partial nephrectomies, bladder augmentation, Mitrofanoff appendicovesicostomy, bladder outlet procedures, and treatment of utricular cysts, among many others. (27) A 2018 publication categorized all reported robotic-assisted urologic procedures (total of 3688) in pediatrics from 2003 to 2016. By far, the most common were pyeloplasty (n 1923), ureteral reimplantation (n 1120), with heminephrectomy (n 136) and nephrectomy or nephroureterectomy (n 117). (28)

Robotic-assisted surgery in pediatric general and thoracic surgery have not yet reached the magnitude that it has in pediatric urology. Robotic procedures that have been reported in the pediatric literature include hepatectomy, excision of choledochal cysts, gastric fundoplication, colectomies, proctectomy with ilealpouch-anorectal anastomosis, mediastinal mass resections, lobectomies, diaphragmatic plications and repair of congenital diaphragmatic hernias. (27)

These procedures demonstrate the potential role of robotic surgery as an enabling innovation, permitting previously intangible minimal access surgical approaches for complex reconstructive procedures in children.

Doubts, concerns and perspectives

The general thought of the first pioneers of robotic technology was that its technical capabilities may be ideal for complex pediatric surgical cases that require intricate dissection. But, unfortunately, there are some limitations, that slow down the spread of this technology in pediatric field.

The first concern is about the size of the robot: it stands about 6 feet tall and weighs about 567 kg. This device was initially designed for adults. Standing next to the small infant, it is no wonder that many surgeons think this big device is too big for the small child; furthermore, its technical requirements can make it not feasible for smaller patients.

The manufacturer of the da Vinci surgical robot recommends an 8 cm distance between each port. This may be difficult to achieve in many neonatal cases. The size and length of the instruments can be an issue as well. Neonatal surgical procedures are often performed with 3-mm instruments and endoscopes, which are smaller than the smallest instruments and endoscopes available currently for robotic surgery. Currently, there are two endoscopes available for the da Vinci Surgical System: 12-mm 3D and 8.5-mm 3D scope. There was also a 5-mm 2D scope that was developed and later discontinued due to low usage. The 8.5-mm scope may be more versatile for smaller children, but it is still large for the intercostal space of a 5 kg child. (29) Instruments are available in two sizes: 8 and 5 mm. The 8-mm instruments articulate with a pitch-roll-yaw mechanism, whereas the 5-mm instruments articulate in a snake-like manner. (30) The difference in articulation results in the 5-mm instruments being longer than their 8-mm counterparts, losing workspace within a small body cavity. For infants and toddlers, 3-mm instruments are routinely used for many basic and advanced laparoscopic procedures. The lack of commercially available 3-mm instruments is a significant limitation of the current robotic surgical platforms and a disincentive for their use in small children. Finally, there are a limited number of instruments from which to choose and this may limit the use of the robots in infants and toddlers.

Despite this, Meehan et al. (29) found that, using careful preoperative planning, the da Vinci robot is well suited to children of all ages, including infants and neonates for numerous procedures: they reported 45 patients under 10 kg with an overall procedure completion rate of 89%. Obviously, careful planning of patient position, trocar location and depth are essential to optimize the full range of motion of the current da Vinci articulating instruments.

Ballouhey et al. (31) performed a multicentric study comparing the success of robotic-assisted surgery in patients who weighed less than 15.0 kg to patients heavier than 15.0 kg, in a total of 178 procedures. They found comparable the results between the two groups, supporting the feasibility of robotic-assisted surgery for small children, despite the lack of dedicated instruments.

The other concern is that robotic surgery has higher costs than open and laparoscopic procedures. This is due to the high costs of purchasing and maintaining a robot, increased operative time, and costs of disposable surgical supplies.

At a stand-alone pediatric hospital, a robotic platform is often not available, only a minority have robotic system, and this limits the number of procedures performed nationally. This is due to the costs of acquiring and maintaining a surgical robot coupled with the tendency for pediatric hospitals to have less income and fewer eligible patients to defray the fixed costs of the platform. A unique situation exists for pediatric surgeons in hospitals affiliated with adult care as robots may be available that are primarily used for adult subspecialties, most often urology. In this setup, the logistics may be difficult, and the pediatric team must be flexible and mobile to accommodate the robot. (24)

Various solutions have been suggested by financial controllers in order to reduce costs. The first is to increase the activity in order to decrease related fixed costs. A second solution is to reduce the average hospital stay versus conventional surgery, but this has not yet been fully proven to be a good option. (32)

Along with surgeon and patient demand, market competition will drive the next generation of surgical robotics to address these limitations and further enhance existing benefits of robotic technology such as image guidance, miniaturization, integrated sensing, and human–robot interaction, flexible robotic platforms designed for complex, spatially constrained operative. (33)

With the introduction of MIS in pediatric surgery many criticisms were raised because of difficult tissue manipulation in constricted spaces, difference between the size of the child and the instruments, and higher costs compared with traditional open surgery. RS is now experiencing the same skepticisms.

Clearly, realizing a robotic pediatric program is not easy, mostly because the advantages of this technology are still controversial. To date, the best available evidence for paediatric RAS is currently one study with Level 1b, relating to pyeloplasty. Main reported advantages of RAS were mainly reduced operative time for pyeloplasty, shorter hospital stay for fundoplication and less blood loss for splenectomy.There were no differences for complications, success rates, or short-term outcomes between paediatric RAS and LAPS in these procedures. (34) Others higher-quality studies for RAS procedures in children are required in order to improve the level of evidence of RAS in paediatric surgery and further technological improvements will probably help to overcome the faced difficulties and the high costs.

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