Asian Journal of Urology (2017) 4, 55–67

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journal homepage: www.elsevier.com/locate/ajur

Review

Robotic surgery in pediatric urology

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Received 22 June 2016; accepted 22 June 2016
Available online 6 September 2016

KEYWORDS
Robotic;
Robotic-assisted;
Pediatric;
Children;
Urology

Abstract While robotic surgery has shown clear utility and advantages in the adult population, its role in pediatrics remains controversial. Pediatric-sized robotic instruments and equipment are not readily available yet, so certain modifications can be made in order to make robotic surgery successful in children. While the cost of robotic surgery remains high compared to open procedures, patients experience greater satisfaction and quality of life with robotic surgery. Robotic pyeloplasty is a standard of care in older children, and has even been performed in infants and re-do surgery. Other robotic procedures performed in children include heminephroureterectomy, ureteroureterostomy, ureteral reimplantation, urachal cyst excision, bladder diverticulectomy, and bladder reconstructive procedures such as augmentation, appendicovesicostomy, antegrade continence enema, bladder neck reconstruction and sling, as well as other procedures. Robotic surgery has also been used in oncologic cases such as partial nephrectomy and retroperitoneal lymph node dissection. Future improvements in technology with production of pediatric-sized robotic instruments, along with increases in robotic-trained pediatric urologists and surgeon experience along each's learning curve, will help to further advance the field of robotic surgery in pediatric urology.

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Peer review under responsibility of Second Military Medical University.

http://dx.doi.org/10.1016/j.ajur.2016.06.002

1. Introduction

Minimally invasive surgery has become more widely accepted in pediatric urology. Laparoscopy was first employed in 1976 to identify an intraabdominal testes in an 18-year-old male [1]. The first infant laparoscopic nephrectomy was performed in 1992 by Koyle et al. [2] for a right multicystic dysplastic kidney identified *in utero*; the operative time was under 1 h and the patient recovered well. Robotic-assisted laparoscopic surgery was widely accepted in adult urology due to improved visualization (10—15 times magnification power and three-dimensional images), improved range of motion with 90° articulation of the robotic arms with seven degrees of freedom (compared to four in conventional laparoscopy) and motion scaling, along with elimination of hand tremor. This led to shorter hospital stays, decreased narcotic usage, decreased blood loss, with smaller scars and improved cosmesis. In children, the advent of better robotic instrumentation has led to its greater use for many common surgeries and its expansion in more complex procedures.

1.1. Troubleshooting robotic surgery for pediatric patients

In pediatric urology the benefits of robotics remains controversial. Many pediatric surgical facilities lack access to a robot, mainly due to cost but there is a lack of published high-level evidence of its benefits in children spurring critics to demand additional proof of its efficacy. Some of the challenges faced in performing robotics surgery in children is the loss of haptic feedback and limited instrumentation for and trocars suited for children [3]. Children have unique physiologic and anatomic differences compared to adults that increases the complexity of minimally invasive surgery. These limitations include more rapid gastric emptying times which leads to increased small bowel distention and subsequent compromise of access and visualization, the bladder is located in a more abdominal position, and the increased abdominal wall laxity creates higher risk for vascular or bowel injury during access. In order to overcome these challenges, various tricks can be employed such as using a "baby bump" (rolled up egg crate cushions) to position the smaller patient, marking the robotic ports after insufflation to adjust for the abdominal wall laxity, moving the robotic arm to a more linear and less triangulated position due to the smaller working space, using the open Hasson technique for peritoneal access, intussusception of the trocars during placement to avoid vascular or bowel injury, and anchoring the trocars to the skin with stitches to prevent dislodgement. Insufflation pressures are age-dependent: 0—2 years, 8—10 mmHg; 2—10 years, 10—12 mmHg; 10—18 years, 12—15 mmHg. Also, the use of the AirSeal® device is advantageous in keeping pneumoperitoneum when an assistant port is needed. Among a cohort of 858 patients, Clavien grade I, II, III, and IV complication rates of 6.9%, 8.2%, 4.8%, and 0.1%, respectively, were noted of which 1.6% required conversion to open or pure laparoscopic procedures, and 86% of these were due to mechanical malfunctions in the robot [4].

Despite size differences in children robotic surgery has been performed successfully in small infants. Ballouhey et al. [5] found that operative times, hospital stay, and postoperative outcomes were similar in children greater than or less than 15 kg, with only longer robotic set-up times for patients less than 15 kg, and Finkelstein et al. [6] found that at least a 13 cm distance between anterior superior iliac spines (for lower urinary tract procedures) and at least a 15 cm puboxyphoid (for upper urinary tract procedures) can aid in selecting infants for robotic surgery.

1.2. Robotic cost and patient satisfaction

The cost associated with robotic surgery is an often cited detractor of acceptance. Indirect costs (robot and console, annual service fees, operating room renovations and investments) seem to be the main contributor to total expense, while direct costs (operative room expenses, anesthesia, room and board, *etc*.) can be lower than the equivalent open procedure [7]. Mahida et al. [8] found the total cost of admission was higher following robotic procedures than non-robotic procedures for both pediatric urologic ($14 583 *vs*. $9388) and general surgery ($13 954 *vs*. $10 180) cases. Tedesco et al. [9] noted that 349 robotic cases needed to be performed annually at their institution to offset the added cost. Nevertheless, as the field of robotic surgery in pediatrics continues to grow and facilities purchase robotic equipment with increased usage, expenses should decrease and the robotic will become a more affordable treatment modality. Implementation of robotics into surgical training programs, along with formalized education, workshops, and robotic simulators all contribute to surgeon experience and efficiency of the learning curve with robotic surgery. Construction of robotic surgery programs in hospitals with dedicated robotic nursing staff, pediatric anesthesiologists familiar with the physiologic alterations associated with robotic-assisted laparoscopic surgery, and supportive administration will help to improve the robot's efficiency and thus its costs.

Patients have expressed improved satisfaction with robotic surgery. Parents of children who underwent robotic pyeloplasty reported significantly higher satisfaction with overall life, confidence, self-esteem, postoperative care, and scar size compared to open pyeloplasty in a validated survey [10]. As the size of the incision grows with the patient, the improved cosmesis that accompanies minimally-invasive surgery becomes arguably one of the most important factors in the pediatric population.

2. Surgeries

2.1. Pyeloplasty

Robotic pyeloplasty for treatment of ureteropelvic junction obstruction is the pioneer procedure of pediatric robotic surgery, and has been documented in literature since the turn of the millennium. The procedure is now a standard of care for older or larger children and data from some of the higher quality studies are shown in Table 1. Thorough description of the transperitoneal technique was documented by Peters [11]. For port placement, a