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Robotic Urologic Surgery in the Infant: a Review

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Abstract

Purpose of Review The goal of this article is to review the current role of robotic urologic surgery in the infant population across a spectrum of diseases and procedures.

Recent Findings Robotic urological surgery has been performed in the infant population across a variety of conditions including ureteropelvic junction obstruction, vesicoureteral reflux, and duplicated and nonfunctional renal moieties. However, most of the durable evidence showing safety and success remains in the repair of the obstructed ureteropelvic junction. Included in this review are also strategies to address the limitations imposed by the unique physiology and anatomy of the infant.

Summary Robotic urologic surgery remains an alternative to other surgical approaches in the properly selected infant in the hands of experienced surgeons. As additional larger studies are performed, the utility of the robotic platform in this population will be clearer.

Keywords Pediatric urology · Robotic urologic surgery · Obstructed ureteropelvic junction

Introduction

Robotic surgery entered the mainstream practice of urology in the 1990s. The robot introduced a degree of dexterity not easily reproduced in pure laparoscopy, resulting in the greater utilization of minimally invasive procedures in our field. Since then, it has been increasingly adopted by the pediatric urology community for more diverse conditions within an expanding range of age groups. This review will focus on the use of robotic urologic surgery in the infant population which we have defined in this paper as less than 12 months.

Perioperative Considerations

Successful application of robotic surgery in infants follows the principles of laparoscopic surgery. It requires attention to

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patient selection, optimal positioning of the patient, appreciation of the physiologic impact of CO_2 insufflation, and knowledge of the limitations imposed by the infant peritoneal cavity.

Patient selection must include consideration of comorbidities which make insufflation hazardous. Insufflation increases vagal activity with resultant bradycardia and decreases ventricular preload which can compromise infants with immature or insufficient cardiac systems. Furthermore, insufflation increases airway pressures and decreases respiratory compliance. Insufflated CO_2 can cause hypercapnia and acidosis which requires attentive anesthetic care [1]. Infants are known to be more vulnerable to the respiratory effects of pneumoperitoneum than adults. Otherwise, healthy infants should tolerate these intraoperative stresses, but those with known cardiac or respiratory issues should have a preoperative consultation considered [2].

Beyond cardiopulmonary conditions which intensify the effect of intraperitoneal insufflation, infants less than 6 months old require special attention to the utilized pressures. One prospective and randomized study in laparoscopic renal surgery in infants less than 10 kg found that hemodynamic and pulmonary parameters were more greatly affected by pressures 9 mmHg and above. Furthermore, infants with insufflation pressures above 9 mmHg required more analgesia, experienced more pain, and took longer to resume feeding. There was no difference in the ability to complete the laparoscopic surgery or time to completion [3].

Laparoscopic entry in the infant population has additional hazards beyond typical concerns with peritoneal access like bowel or visceral injury. A younger infant will be more likely to have an immature cardiovascular system. Air emboli can be caused by an injury to a patent umbilical vein or ductus venosus. Afterward, air emboli may even enter the arterial system due to patent foramen ovale or ductus arteriosus. Excellent communication must be ongoing between the operative and anesthetic teams, especially during insufflation. Additionally, purging the length of insufflation tubing with CO_2 can help address this risk, especially because some infants may require less than 100 cc of insufflation for adequate distention [4]. Furthermore, the abdominal wall is thinner and innately pliable which compounds the decreased force required for entry. These factors make laparoscopic access challenging in this age group [5].

Temperature regulation is an issue during minimally invasive pediatric surgery. During these procedures, children are vulnerable to hypothermia particularly when insufflation gases cause evaporative cooling [6]. Due to a greater ratio of surface area to body mass, temperature monitoring and warming devices should be used intraoperatively [7]. Additionally, due to their small size, increased metabolic activity, and fetal hemoglobin concentrations, awareness of surgical blood loss in infants is particularly important [8]. Robotic-assisted surgery has been credited with decreasing blood loss in surgeries due to the magnified and three-dimensional vision along with improved dexterity of instruments [9].

Finally, while identifying the ideal candidates for pediatric urological surgery is beyond the scope of this review, infants are unique due to their rate of growth and maturation. A challenging surgery in an infant may be more technically favorable if a procedure can be safely delayed into later childhood. Large medical organizations have placed guidelines to avoid overdiagnosis of historically "operative" problems which may be transient in nature [10]. Furthermore, most pediatric urological surgeries are for benign conditions which only in certain cases may cause functional or physiologic injury. For example, a database which captured patient information from dozens of tertiary care pediatric hospitals found that the median age of pyeloplasty increased from 2 to 4 months in the 1990s to 12–14 months around 2010. The authors attribute this change to a gradual acceptance of the literature which questioned the belief that all hydronephrosis represents clinically significant obstruction [11].

Patient Positioning and Port Placement

Positioning for robotic procedures in infants is similar to that in older children, except that infants may exhibit more pliability in their bodies and thus one must be careful to avoid hyperextension/flexion that could result in unforeseen neuropraxia. Although exact positioning is dependent on the specific procedure, the main goals are providing adequate padding, securing the patient to table appropriately, and lastly, making sure that skin is protected. Access to the renal pelvis and renal unit is typically performed in a lateral decubitus position. Pelvis procedures can be performed in low lithotomy or a supine position (with legs spread). Limbs must likewise be positioned to prevent nerve or pressure injuries. Diligence with padding is important in young infants due to their thin and fragile skin. At our institution, we are especially mindful to pad any IV tubing or anesthesia equipment such as monitors and wires during this positioning process as well. Finally, due to the small frame of the patient, a foam ring is placed around the face to protect it and the airway from clashes from the robotic elbows. It is routine practice to have bladder and gastric decompression during these surgeries prior to incision/insufflation.

At present, there are two camera port sizes: 8.5 mm and 10 mm; and two sizes for robotic trocars: 8 mm and 5 mm. In our institution, the use of a 4th arm or an assistant port are typically restricted in this population due to the reconstructive nature of the procedures and limited abdominal surface area. Five-millimeter ports are available but because of longer wrist lengths in a smaller working space and limited instrument selection, they are not universally utilized in this age group [12]. Interestingly, Baek et al. recently published their experience using an 8.5-mm camera and 5-mm working ports in their series of 65 robotic-assisted laparoscopic pyeloplasties in 65 children, which included 16 infants. The use of smaller trocars allowed surgery to be performed without any significant differences in total operative time and surgical success [13•]. The authors mentioned occasionally increasing insufflation rates to address camera fogging. At our institution, we routinely use one vented robotic instrument trocar to decrease the fogging associated with an 8.5-mm lens.

Intraperitoneal access can be performed in a variety of ways. In series which contain infant patients, the Veress approach, Hassan, and transumbilical cord access have all been shown to be adequate methods for entry [14, 15]. In a survey to pediatrics urologists who performed procedures on infants, the use of a Veress needle was associated with a higher rate of complications from laparoscopic entry compared to open access. However, in this study, the laparoscopic experience was a stronger predictor of complication rate [16].

Insufflation volumes in a 10-kg child are less than 1 L which decreases the working space considerably [17]. It will also decrease the distance between trocar entry sites and major organs and vasculature. Furthermore, the infant has a disproportionately larger spleen and liver which limits the working space further. One method to address these concerns during laparoscopic access is to direct the entry of the working trocar into the camera port while engaging the fascia perpendicularly. Working space can be functionally increased by either

carefully "burping" the robotic arms out or placing the remote center (delineated by the thick black line on the trocar) external to the abdominal wall [18]. Both of these maneuvers can increase abdominal wall tension and stress and should be used judiciously.

The small peritoneal volume will also lead to trocar dislodgement due to rapid desufflation when exchanging instruments. Thus, some groups will anchor their trocars with adhesives or epidermal or fascial sutures. The limited intraperitoneal working space and small surface area of the abdomen adds additional complexity by limiting trocar spacing which, in turns, leads to instrument collisions. Encouragingly, in a retrospective study of robotic-assisted pyeloplasty, there was no difference in operative time and success rates between infants and older children [19]. Finkelstein et al. described how to optimize patient selection for the robotic platform in infants for upper or lower urinary tract surgery. This group found that a distance of 13 cm or less between the anterior superior iliac spines or a pubo-xiphoid distance of 15 cm or less are associated with a high risk of instrument collisions. Increased instrument collisions were strongly associated with increased operative time [20•].

Infants may be at higher risk for port site hernias. In a retrospective study of their pediatric laparoscopic cases, Cost et al. examined variables related to hernia development which occurred in 3.2% of their population. The only statistically significant factor related to hernia development was that only younger patients (8 months–3 years) developed trocar-related hernias. Fascial closure status, port location, and port size were all unrelated statistically to development of an incisional hernia. The authors posited this to the much smaller diameter of abdominal contents [21]. However, the technique of fascial closure and closure of all port sites may certainly have a role in hernia development. Tapscott et al. found herniation rates of less than 1% in their cohort of pediatric patients (average age 3.2 years, as young as 5 months old) who underwent robotic surgery. Herniation rates were not noted to be associated with patient age [22].

Pyeloplasty

Repair of an obstructed renal pelvis is by far the most common use of urologic robotic surgery in infants. The robot-assisted laparoscopic dismembered pyeloplasty is considered standard of care for older children and adults, and its technique has been explored in the infant population.

One of the largest studies examining robotic pyeloplasty in infants was from a retrospective multi-centered group which recruited a total of 60 patients (mean age 7.2 months, mean operative time 232 mins). This group had variable techniques and follow-up but found comparable success and complication rates compared to other studies which examined other

approaches to pyeloplasty. Specifically, 91% demonstrated either improved hydronephrosis on postoperative ultrasounds or improved drainage times on MAG3. Complications occurred in 11%, which included herniation at a port site, urine leak, retained stent, renal calculus, and prolonged ileus. Two cases required repeated interventions for postoperative renal obstruction which resolved with either endoscopic balloon dilation or repeat pyeloplasty [23•]. This group recommended several techniques to avoid problems in the infant robotic pyeloplasty associated with the robotic platform. Specifically, in patients, less than 10 kg, midline placement of all ports allows less instrument collisions. Furthermore, trocars can be stitched in at the fascial or skin level to prevent dislodgement during instrument exchanges or manipulation.

An earlier and smaller study published in 2006 demonstrated that in their younger patients (5.6 months) operative time was shorter at 122 mins. A possible reason posited by the authors was that the tissues in this age group tended to have a translucent mesentery which allowed an easier view of the pelvis and UPJ. The senior author in this paper also had significant experience in laparoscopy which likely contributed to the faster operative time [24].

In a retrospective study, which described similar success rates between an open infant pyeloplasty and robotic infant pyeloplasty, there was also a nonsignificant cost difference of $4410 in the open group and $4979 in the robotic group. A significant difference between the two groups was total operative time, with 122 mins in the open group compared to 160 mins in the robotic group [12].

In an effort to identify surgeon proficiency and the learning curve associated with robotic-assisted pyeloplasty, Kassite et al. performed a retrospective review of prospectively collected data of infant and pediatric robotic-assisted pyeloplasties. The analysis factored operative time, complication rates, and success rates of the operation to generate a composite score which acted as a marker of proficiency of attending surgeons who had previous experience in laparoscopy. The authors found that there was a steep learning curve which continued until the 19th case. Afterward, acquiring proficiency continued until the 33rd case, followed by further refinement which continued until the 39th case [25].

Partial Nephrectomy/Nephrectomy

Partial nephrectomies are typically performed in the pediatric population for benign diseases such as the excision of a poorly functioning renal moiety. These can be performed in an open fashion or with conventional laparoscopy. The robotic system has been used in older and larger children (mean age 7.2 years) but has also been performed in patients as young as 11 months [26]. This group used an assistant port in addition to two robotic working trocars to assist with exposure, control of

vessels, and hemostasis. Additionally, they report adhering to a pubo-xiphoid distance of 14 cm to perform this procedure.

Similarly, nephrectomies can be performed for a poorly functioning and often dysplastic unit. Typically, conventional laparoscopy is sufficient for a minimally invasive approach, though the robotic platform has been used to perform nephrectomies with contralateral ureteral surgery. This may reduce the total hospitalization time when compared to staging two separate procedures. Lee et al. described their series which included infants where robotic nephrectomies were performed in conjunction with extravesical ureteral reimplantation. This group's results showed an average of 16-mL blood loss, average operative time of 291 mins, and good results on postoperative imaging [27].

Ureteroureterostomy

Ureterostomies may be performed in duplicated renal systems where one ureter inserts appropriately into the bladder while the other ureter causes clinical problems with incontinence, infection, obstruction, or reflux. Bansal et al. reviewed their series of robotic surgery in infants less than 1 year which included 2 ureteroureterostomies as young as 4 months old and found that robotic surgery is technically feasible in this age group. This series included ureteroureterostomies in both a duplicated and single systems. Furthermore, of the ureteroureterostomies, there were no intraoperative complications, and both had improved hydronephrosis of their obstructed systems [28].

A larger study of ureteroureterostomies by Biles et al. included 12 children, 4 of whom were less than 1 year old. This study is one of the largest for this surgical procedure in this age group and consisted of patients with duplicated systems with ureteral ectopia and associated hydronephrosis. The authors found no intraoperative complications, with universal improvement in upper tract dilation and resolution of associated incontinence if it were present preoperatively. Notably, this group utilized open-ended ureteral catheters which stented the lower pole ureter which was intentionally removed on the first postoperative day. No urine leaks occurred postoperatively in this group [29].

Lee et al. compared robotic versus open approaches for ureteroureterostomies in the pediatric population. This group found improved hospitalization times as well as improvement in hydronephrosis in the robotic group compared to the open group. This study included an open ureteroureterostomy in a 6 months old who sustained an intimal flap during ureteral stent placement which was temporized with a percutaneous nephrostomy tube [30].

We perform robotic-assisted ureteroureterostomies in selected infants in our institution. After perioperative antibiotics are given, we place a ureteral stent transurethrally in the recipient ureter. An 8.5-mm camera is placed at a subumbilical incision and two 8-mm working ports are placed, one subxiphoid and the other four fingerbreadths below the umbilicus and off midline towards the affected side. The DeBakey and monopolar scissors are used to reflect the colon medially, exposing the retroperitoneum. After isolating the intersection of both ureters, the recipient ureter is easily identified with its indwelling ureteral stent. The vertical ureterostomy on the recipient ureter should equal the diameter of the donor ureter. The anastomosis is performed with running 6–0 Vicryl at an end to side fashion, typically performing the anterior side first. If the donor ureter is obstructing, its distal end may be left in situ. However, if it is refluxing, we will ligate it as distally as possible, taking care to preserve the shared blood supply of the ureteral sheath. All port sites are closed at the fascial and skin level with absorbable sutures. The catheter and the ureteral stent are removed on a postoperative day 1 and postoperative week 6 respectively.

Ureteral Reimplantation

Ureteral reimplantation is typically performed for vesicoureteral reflux, but can also be applied to obstructed or ectopic ureters. Minimally invasive approaches initially comprised of strict laparoscopic (either transperitoneal or transvesical), but have come to include the robotic platform. Some groups have written about the utility of the robotic platform in performing robotic-assisted laparoscopic ureteral reimplantation, though these authors preferred applying robotic surgery to older children and not specifically to the infant population [31]. Furthermore, due to a clearer understanding of the natural history of vesicoureteral reflux as well as national guidelines on the evaluation of febrile urinary tract infections, surgical correction in general is being performed less frequently [32].

Published information on robotic-assisted ureteral reimplantation in infants is sparse, but a multi-institutional review which included children as young as 7 months found that while the procedure was technically possible, a clear improvement over other approaches was not obvious. Specifically, the authors note more than 20% of children had radiographic failure and more than 10% sustained additional surgery for persistent reflux or a surgical complication. Additional reoperations included ureteral stent placement or balloon dilation, subureteral Deflux injection, and open ureteral reimplantation. These outcomes are lower than reported in open approaches to ureteral reimplantation [33]. At our institution, we limit robotic-assisted ureteral reimplantation to select and older patients due to the excellent outcomes of the open procedure.

Conclusions

Robotic surgery has been performed across a broad range of ages among urological patients. Successful application of the platform has been achieved for numerous upper and lower urinary tract procedures in the infant population.

In general, the immaturity of pediatric tissues and organs requires a modification of traditional techniques applied to typical pediatric urological surgeries. Careful attention to the infant's anatomic and physiologic attributes will help avoid suboptimal outcomes. More importantly, precise indications to delay or avoid surgeries altogether will help provide good outcomes for this population.

Compliance with Ethical Standards

Conflict of Interest   Jeffrey Villanueva, Mary Killian, and Rajeev Chaudhry each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent   This article does not contain any studies with human or animal subjects performed by any of the authors.

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