Pediatr Surg Int (2017) 33:925–935
DOI 10.1007/s00383-017-4082-7

REVIEW ARTICLE

Robot-assisted laparoscopic pyeloplasty in the pediatric population: a review of technique, outcomes, complications, and special considerations in infants

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Accepted: 15 March 2017 / Published online: 1 April 2017

Abstract Ureteropelvic junction obstruction is a common condition encountered by the pediatric urologist, and treated with pyeloplasty when indicated. Recent technological advancements and a shift across all surgical fields to embrace minimally invasive surgery have led to increased utilization of minimally invasive pyeloplasty. Conventional laparoscopy is a reasonable choice, but its use is limited by the technical challenges of precise suturing in a confined space and the associated considerable learning curve. Robotic technology has simplified the minimally invasive approach to pyeloplasty, offering enhanced visualization and improved dexterity with a fairly short learning curve. As utilization of robotic pyeloplasty continues to increase, we sought to critically assess the literature on this approach. We begin with a review of the technical aspects of robot-assisted laparoscopic pyeloplasty including tips for surgical proficiency and patient safety. Outcomes and complications from the contemporary literature are reviewed, as well as special considerations in the pediatric population including infant pyeloplasty, cost concerns, training, and postoperative diversion/drainage.

Keywords Ureteropelvic junction obstruction · Pediatric urology · Minimally invasive surgery · Robotic surgery

The original version of this article was revised: Figure 5 has been incorrectly published. The corrected figure is updated in the article.

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Introduction

Ureteropelvic junction obstruction (UPJO) is a common congenital anomaly that is present in approximately 1:2000 live births. The majority of cases in the modern era are detected on routine antenatal ultrasound, though UPJO can less commonly present in older children and adults experiencing abdominal pain, nausea, and emesis [1]. The etiology of obstruction is most commonly intrinsic fibrosis and narrowing of the ureteropelvic junction, though an insertion anomaly of the ureter or an aberrant crossing vessel can also cause obstruction [2, 3]. While there is debate regarding the appropriate timing of surgical intervention, the indications to intervene include worsening split renal function, worsening hydronephrosis with thinning of renal parenchyma, urinary tract infections/pyelonephritis, pain, and nephrolithiasis [4].

The gold standard intervention for UPJO is the Anderson Hynes dismembered pyeloplasty, traditionally performed with an open flank approach. Endoscopic options including endopyelotomy and retrograde balloon dilation are less invasive, but not routinely used due to suboptimal outcomes relative to pyeloplasty [5]. Laparoscopic pyeloplasty was first described in 1995 [6] and subsequently shown to be a safe and effective minimally invasive treatment option for UPJO [7]. However, conventional laparoscopy has a significant learning curve relative to robot-assisted laparoscopy [8] and is technically challenging for many surgeons. Since its inception, conventional laparoscopic pyeloplasty (CLP) has only been performed by select experts and utilization has remained unchanged over time [9]. The robotic platform enhances the laparoscopic approach by providing the surgeon with high resolution three-dimensional visualization and enhanced dexterity with EndoWrist® instrumentation (Intuitive Surgical, Sunnyvale, CA). This technology has facilitated a shorter learning curve and acts as a bridge between the open and endoscopic approach. As such, utilization of robot-assisted laparoscopic pyeloplasty (RALP) has increased steadily since the initial case reports were published in 2005 [10–12]. With RALP rapidly becoming the new gold standard treatment for UPJO in children, we sought to provide an overview of the surgical technique, outcomes, complications, and benefits of the robotic approach to pyeloplasty in children.

Technique

Positioning

The patient is placed in the lateral decubitus position rotated approximately 30° from the vertical plane, and secured in position using a pediatric beanbag. Foley catheter is placed for bladder drainage. The contralateral arm is flexed and secured to a padded arm board, while the ipsilateral arm can be placed in an airplane position for older children or allowed to rest on the patient's side for smaller children and infants. The patient is then secured to the table using folded blue towels and silk tape across the chest and hips (Fig. 1). The child's positioning should be carefully inspected prior to preparing the surgical field, with great care taken to pad all pressure points and protect the child against iatrogenic injury from the robot or working arms. In our experience, there is no need for preoperative bowel preparation.

Role of retrograde studies

Retrograde studies of the ureter and collecting system can be avoided in most cases, helping to reduce overall costs and radiation exposure to the patient. Renal ultrasound performed and interpreted by an experienced radiologist, complimented by diuretic renal scan with proper interpretation, is typically adequate for operative planning. We reserve cystoscopy and retrograde pyelogram for redo cases and children with renal anomalies like horseshoe kidney.

Port placement

Due to its inherent safety, an open Hasson technique is the senior author's preferred method to gain access to the peritoneal cavity and place a 12 mm balloon port for the robotic camera (an 8 mm port can be used with the Xi system). Pnuemoperitoneum is then established, and all additional ports are placed under direct vision. The insufflation pressure can be transiently increased to facilitate port placement given the laxity of the pediatric abdominal wall. The abdominal wall can also be buttressed with a laparoscopic instrument or percutaneous suture to provide counter traction, though in infants and small children we recommend the "port in port" technique in which the 8 or 5 mm trocar is directed into the 12 mm camera port when entering the peritoneal cavity to minimize rise of iatrogenic injury [13].

Though the precise location of robotic and assistant ports should be left to the surgeon's discretion, some general guidelines can facilitate efficiency and minimize collisions between robotic arms. For children and adolescents, the one robotic trocar is placed cranial to the camera port in the midline and a second is placed equidistant from the camera port in a caudal position 30° off the midline (Fig. 2). For infants, the robotic trocars are both placed in the midline equidistant from the camera port due to the limited working space (Fig. 3). An additional 5 mm assistant port can be placed as needed, to allow for efficient passing of suture material and assistance with retraction or suction. For right-sided procedures, an additional 5 mm port can be used to pass a liver retractor if needed. There is an option

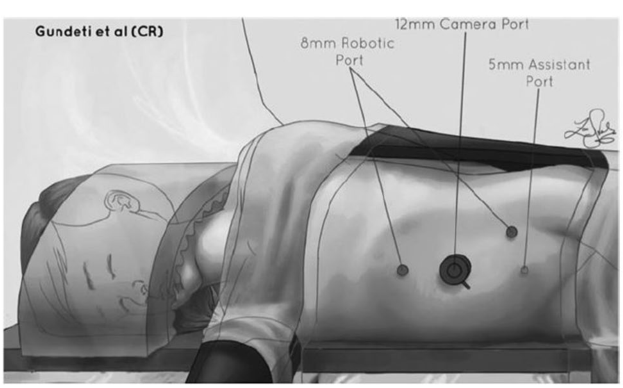

Fig. 1 Positioning for RALP; note the foam padding protecting the face and extremities (reproduced with permission from Chang et al. [13])

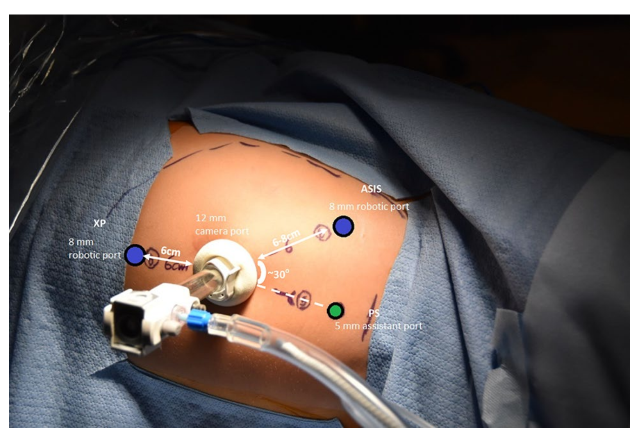

Fig. 2 Port placement for left sided pediatric RALP; *PS* pubic symphysis, *XP* xyphoid process, *ASIS* anterior superior iliac spine

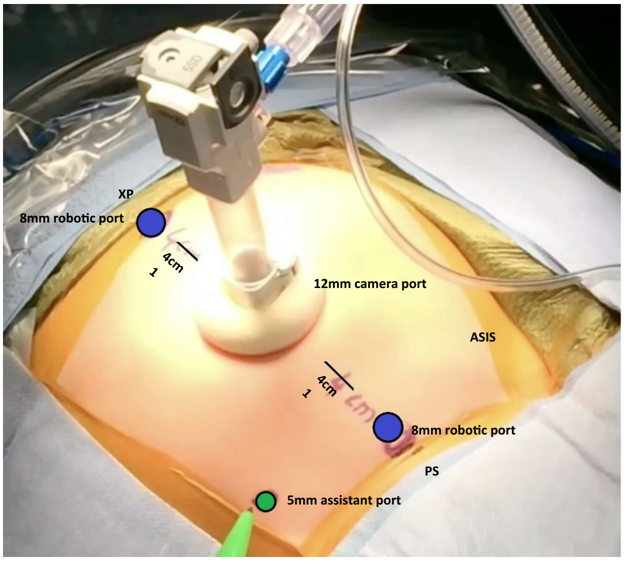

Fig. 3 Port placement for left sided infant RALP; *PS* pubic symphysis, *XP* xyphoid process, *ASIS* anterior superior iliac spine

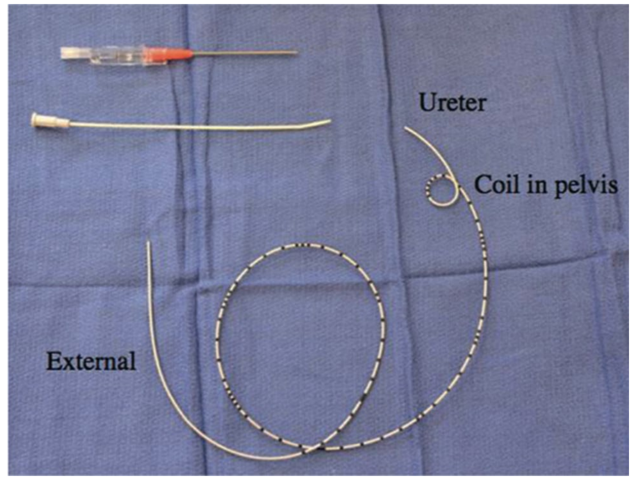

Fig. 4 Cutaneous pyeloureteral stent used for infant pyeloplasty (modification of Salle stent); note coil to be placed in renal pelvis and short distal segment placed in proximal ureter (reproduced with permission from Dangle et al. [14])

of 8 mm camera and 5 mm robotic ports, but in our experience these pose limitations that are discussed further in the future directions section.

Operative technique

Following port placement, the procedure begins with identifying the dilated renal pelvis. During dissection, the senior author uses a bipolar grasping forceps in the left hand and monopolar scissor in the right. For left sided cases, a transmesenteric approach is most convenient if the renal pelvis can be visualized through the colonic mesentery. Alternatively, the colon is mobilized by incising the peritoneum along the white line and reflecting the colon medially. Next, the proximal ureter and renal pelvis are carefully dissected while taking care to preserve the ureteral blood supply. A percutaneous hitch stich (20 Vicryl suture) can be useful to stabilize the dilated renal pelvis and facilitate the anastomosis. The renal pelvis is then transected and healthy ureter is identified distally. The ureter is partially transected at this point, leaving the hypoplastic or strictured segment partially attached to serve as a handle. The distal ureter is spatulated and then anastomosis is performed using a running 6-0 PDS-II (Ethicon Inc, Somerville NJ USA) of the posterior wall of the ureter and renal pelvis. Placement of a double-J ureteral stent or cutaneous pyeloureteral (CPU) stent is left to the surgeon's discretion.

Following stent placement, the anastomosis is completed with a second running 6-0 PDS II suture. We do not routinely place a drain. If a transmesenteric approach was used, the defect in the mesentery is left open. Leaving the camera port in place after removing the remaining ports allows the fascia of each port to be closed under direct vision, thereby minimizing the risk of damage to bowel or postoperative hernia.

Diversion and drainage after pyeloplasty

It is the senior author's practice to routinely place an indwelling stent in adolescents and patients with an intrarenal pelvis and a CPU stent in infants and toddlers, as blood clots or edema can cause obstruction at the newly reconstructed UPJ leading to minor urine leak and delay in recovery. The CPU stent is created by modifying a Salle pyeloplasty stent (Cook Medical, Bloomington IN USA), as shown in Fig. 4. The stent is passed percutaneously into the peritoneal space and through the renal pelvis, with a coil in the renal pelvis and short segment in the proximal ureter crossing the anastomosis (Fig. 5). This can be removed in the office without need for a second operating room procedure [14]. The advantage of bringing this stent through the pelvis is reduced bleeding compared to the conventional placement through the renal cortex. While this is the practice at our institution, there remains debate over the role of internal stenting, percutaneous stenting, and stentless pyeloplasty [15, 16].

Postoperative plan and follow up care

The child is monitored overnight in the hospital. Clear liquid diet is initiated as tolerated immediately after the operation, and advanced to regular as tolerated. Analgesia is achieved with intravenous ketorolac and oral acetaminophen, with narcotics used only for breakthrough pain.

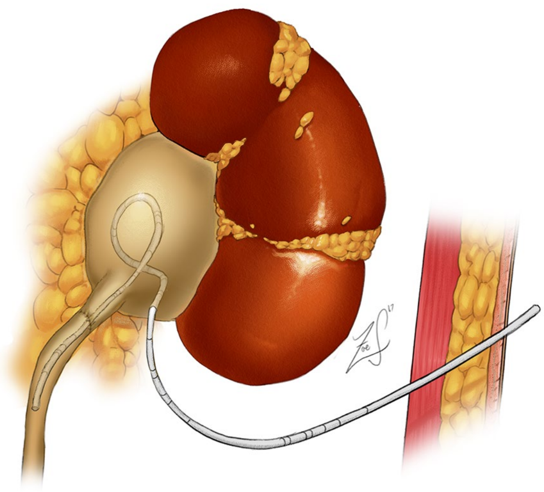

Fig. 5 Illustration of positioning of cutaneous pyeloureteral stent used for infant pyeloplasty

Foley catheter is removed on the morning of postoperative day (POD) 1 and the child is encouraged to ambulate if appropriate. Indwelling stents are removed via cystoscopy after 4 weeks. CPU stents are clamped on POD1, and parents are instructed to unclamp the stent and drain to gravity if there is excessive leakage around the stent or the infant has fevers, inconsolable crying, or refusal to feed. The CPU stent is then removed after 1 week in the clinic. Postoperative renal ultrasound (RUS) is obtained at 1, 6, and 12 months postoperatively. Nuclear medicine scan to assess the function and drainage is obtained around 6–12 months postoperatively based on parental preference, or if there is concern for increased hydronephrosis on RUS. Only those with concerning hydronephrosis are followed beyond this point, with the remainder discharged back to the care of their pediatrician.

Outcomes and complications

A successful pyeloplasty should result in improved hydronephrosis on renal ultrasound and improved drainage on diuretic renogram. The largest single institution study assessed 155 pediatric patients undergoing RALP and found a success rate of 96%, with only 3% of patients requiring reoperation for recurrent obstruction [17]. A metaanalysis of comparative studies found no difference in success rate between RALP, CLP, and OP [18]. This metaanalysis included 12 observational studies on pyeloplasty in children, with a total of 384 RALPs, 131 CLPs, and 164 OPs. The cumulative success rate among studies comparing RALP and CLP was 99.3% for RALP and 96.9% for CLP, with no significant difference detected. The reoperation rates were low overall (2.8% for RALP and 4.8% for OP) and not statistically significant between the groups. RALP is associated with excellent outcomes on par with reported values for open series.

A recent multicenter study included 407 pediatric patients treated with RALP and found an overall complication rate of 13.8% [19]. The majority of these compilations were low grade. Clavien grade I or II complications occurred in 8.8% of cases and Clavien grade III complications occurred in 4.9%. There were no Clavien grade IV or V complications. Several studies have compared complication rates of RALP and OP and found no difference [20–22], with overall complication rate of 1.7–26% for RALP and 4.3–15% for OP. Furthermore, a metaanalysis of comparative studies found no difference in complication rate between RALP, CLP, and OP [18]. In this metaanalysis, the cumulative complication rate for RALP was 8.3% compared to 4.8% in OP and there was also no difference in the grade of complications between groups.

A summary of studies assessing RALP outcomes and complications [11, 12, 17, 18, 20–30] is provided in Table 1.

Benefits of robotic approach

The proposed benefits of minimally invasive surgery primarily relate to the decreased pain and length of stay associated with the smaller incisions needed for laparoscopic trocars. Single center comparisons of open pyeloplasty (OP) to RALP have demonstrated mixed results with respect to these benefits. Lee et al. compared 33 children undergoing RALP to 33 undergoing RALP, and found that the RALP cohort had a shorter length of stay (LOS, 2.3 vs 3.5 days) and decreased postoperative narcotic requirement [11]. Two subsequent studies comparing OP to RALP failed to show a difference in postoperative LOS or narcotic requirement [20, 22]. However, a metaanalysis comparing minimally invasive pyeloplasty to OP demonstrated a significantly shorter LOS and a trend toward decreased narcotic requirement [28].

There are additional benefits to minimally invasive surgery that are perhaps unique to the pediatric population, including cosmetic outcomes and impact on the parents or caregivers. Parental satisfaction rates on a validated questionnaire were higher following RALP compared to OP with respect to the size of incision scar, burden of postoperative follow up, and "overall life" [31]. Parents also benefit from the associated decreased length of stay following RALP by experiencing fewer lost wages [32]. Regarding cosmetic outcomes, Barbosa et al. showed that for pyeloplasty the scar size was important or very important to 83% of parents and that the majority would prefer RALP

Table 1 Summary of outcomes and overall complications

Study	Year	Study type	Patients	RALP success	Complication rate (definition)	Pertinent findings
Atug et al.	2005	Case series	7 RALP	100%[a]	Not reported	Among the earliest feasibility reports
Lee et al.	2006	Comparative	33 RALP 33 OP	97%	3% (need for redo-pyeloplasty)	No difference in success or complication rates between RALP and OP
Yee et al.	2006	Comparative	8 RALP 8 OP	100%	12.5% (overall complications)	No difference in success rates between RALP and OP; complication rates not compared
Olsen et al.	2007	Case series	67 RALP	94%	13.8% (overall complications)	Retroperitoneoscopic approach possible
Franco et al.	2007	Comparative	15 RALP 12 CLP	100%	Not reported	No difference in success rates between RALP and CLP
Minnillo et al	2011	Case series	155 RALP	96%	11% (overall complications)	Significant decrease in OT with cohesive staff
Sorensen et al.	2011	Comparative	33 RALP 33 OP	97%	15% (overall complications)	Operative time learning curve could be surmounted in 20 cases; no difference in success or complication rates between RALP and OP
Subotic et al.	2011	Comparative	19 RALP 20 CLP	100%	28.0% (overall complications)	No difference in success or complications rates between RALP and CLP
Barbosa et al.	2012	Comparative	58 RALP 104 OP	74%[b]	1.7% (need for redo-preloplasty)	RALP delivers faster anatomic improvement and resolution of hydronephrosis than OP
Riachy et al.	2012	Comparative	46 RALP 18 CLP	100%	4% (overall complications)	No difference in success or complications rates between RALP and CLP
Murthy et al.	2014	Comparative	52RALP 40 OP	94%	13% (grade 3 complications)	No difference in success or complication rates between RALP and OP
Autorino et al.	2014	Metaanalysis	–	92.7%	10.1% (overall complications)	No difference in success or complication rates between RALP/CLP and OP
Cundy et al.	2014	Metaanalysis	–	93.1%	7.3% (overall complications)	No difference in success, reoperation, or complication rates when comparing RALP and OP, or when comparing RALP and CLP
Silay et al.	2016	Comparative	185 RALP 390 CLP	99.5%	3.2% (overall complications)	No difference in success rates between RALP and CLP; higher complication rate in CLP than RALP
Salo et al	2016	Comparative	39 RALP 84 OP	96%	3.2% (grade 3 complications)	No difference in success or complication rate between RALP and OP

[a]Among the six patients with follow up imaging at time of publication

[b]This manuscript defined success strictly as complete resolution of hydronephrosis or improvement in hydronephrosis; success defined as no need for repeat intervention was 98.3%

surgical scars over the open scar resulting from a flank incision [33]. However, a recent crowd sourced survey demonstrated that if dorsal lumbotomy incision is included as well as flank and laparoscopic incisions, the majority of patients would prefer the dorsal lumbotomy scar [34]. Ultimately, cosmesis is a personal choice and the patient's preferences should be considered when discussing possible approaches to pyeloplasty.

A recent multicenter study compared RALP to CLP, and found that operative time was not different but LOS was significantly shorter following RALP [29]. Smaller series have demonstrated a shorted operative time for RALP than CLP, with no difference in LOS or narcotic requirement [27, 35]. Thus it appears that both RALP and CLP confer the same benefits of minimally invasive surgery, but RALP may be preferred due to shorter operative time and the relative ease of learning robotic skills compared to conventional laparoscopy [8]. Table 2 summarizes the published studies comparing RALP to OP and CLP [11, 14, 18, 20, 22, 23, 25–28, 33, 35].

Additional considerations

RALP in infants

With increased experience, robotic surgeons have recently begun to expand the application of RALP to include

Table 2 Summary of comparative studies assessing RALP vs OP and RALP vs CLP, highlighting operative time, length of stay, and/or narcotic use

Study	Year	Comparison	Patients	Mean OT (mins)	LOS (days)	Narcotic use	Pertinent findings
Lee et al.	2006	RALP vs OP	33 RALP 33 OP	219 181	2.3 3.5	1.5 (mg/kg morphine) 2.8 (mg/kg morphine)	Shorter LOS and decreased narcotic requirement for RALP; longer OT for RALP
Yee et al.	2006	RALP vs OP	8 RALP 8 OP	363 248	2.4 3.3	7.4 (total mg morphine) 22.0 (total mg morphine)	Shorter LOS and decreased narcotic requirement for RALP; longer OT for RALP
Sorensen et al.	2011	RALP vs OP	33 RALP 33 OP	326 236	2.2 2.6	Not assessed	Longer OT for RALP; No difference in LOS or postoperative pain scores between RALP and OP
Dangle et al.	2013	RALP vs OP (infants)	10 RALP 10 OP	160 123	2.1 2.2	Not assessed	OT longer for RALP; no difference in LOS, EBL, or LOS
Murthy et al.	2014	RALP vs OP	52 RALP 40 OP	203 135	2.6 2.6	0.44 (mg/kg morphine) 0.44 (mg/kg morphine)	OT longer for RALP (equal after 40 RALP cases); no difference in LOS or narcotic requirement
Franco et al.	2007	RALP vs CLP	15 RALP 12 CLP	236 223	Not assessed	Not assessed	No difference in OT; LOS and narcotic use not assessed
Subotic et al.	2011	RALP vs CLP	19 RALP 20 CLP	165 248	6 7	Not assessed	RALP with shorter OT; no difference in LOS; narcotic use not assessed
Riachy et al.	2012	RALP vs CLP	46 RALP 18 CLP	209 298	2 1	0.052 (mg/kg/day morphine) 0.067 (mg/kg/day morphine)	RALP with shorter OT; no difference in LOS or narcotic requirement
Casella et al.	2013	RALP vs CLP	23 RALP 23 CLP	200 265	1 1	Not assessed	OT shorter for RALP compared to CLP; no difference in LOS; narcotic requirement not assessed
Autorino et al.	2014	Metaanalysis	–				Compared to OP: longer OT for RALP/CLP, shorter LOS for RALP/CLP, no difference in narcotic requirement
Cundy et al.	2014	Metaanalysis	–				No difference in OT between RALP and CLP, longer OT for RALP compared to OP; LOS shorter for RALP compared to both CLP and OP; narcotic requirement not assessed
Silay et al.	2016	RALP vs CLP	185 RALP 390 CLP	173.1 173.8	2.1 4.6	Not assessed	No difference in OT between RALP and CLP; shorter LOS for RALP; narcotic requirement not assessed

Table 2 (continued)

Study	Year	Comparison	Patients	Mean OT (mins)	LOS (days)	Narcotic use	Pertinent findings
Salo et al.	2016	RALP vs OP	39 RALP 84 OP	249 167	3.4 4.4	48%[a] 50%[a]	Longer OT for RALP compared to OP; shorter LOS for RALP compared to OP; no difference in narcotic requirement

OT operative time, *LOS* length of stay, *EBL* estimated blood loss, *RALP* robot-assisted laparoscopic pyeloplasty, *OP* open pyeloplasty, *CLP* conventional laparoscopic pyeloplasty

[a]Patients in need of postoperative morphine

younger children and infants. Casale et al. initially described a series of nine infants with a mean age of 5.6 months who were safely and successfully treated with RALP [36]. Subsequent series comparing RALP to OP in infants have demonstrated comparable outcomes with respect to improvement or resolution of hydronephrosis, with either an equivalent [14] or shorter LOS in the RALP cohort [37]. The largest series to report on RALP in infants is a multicenter retrospective review of 60 infants with a mean age of 7.3 months who were all treated with RALP. Improved or resolved hydronephrosis was observed in 91% of these children, with two patients (3.3%) developing recurrent obstruction requiring reoperation [38]. Though infant RALP remains in its early stages and additional study is needed, these initial reports suggest the approach is safe and effective. Table 3 provides our recommendations for successful RALP in infants.

Redo pyeloplasty

The management of recurrent UPJO following initial pyeloplasty poses a significant surgical challenge. Though endoscopic management options such as endopyelotomy can be considered, redo pyeloplasty is associated with a higher success rate and is considered the gold standard intervention by most pediatric urologists [39]. Several small series have assessed redo RALP following a failed open or minimally invasive pyeloplasty, with success rates based on resolution of symptoms and radiographic improvement ranging from 78 to 100% [40–42]. The reoperative setting poses unique challenges including possible abdominal adhesions and scarring of the renal pelvis, which can be overcome with careful and meticulous dissection and the use of an anterior Y-V advancement of pelvic tissue to bridge the stenotic UPJ [42]. The RAL approach also offers the advantage of approaching the UPJ anteriorly, through an unoperated field with minimal scar tissue (in the case of RALP following failed OP). Previously missed anterior crossing vessels may be identified with such an approach, and meticulous tissue handling, dissection, and suturing is facilitated by the enhanced visualization and dexterity offered by the robotic platform [42]. Redo RALP is not recommended for surgeons who are early in their robotic experience, but can be a safe and effective treatment option among experienced robotic surgeons.

In particularly complex cases with scarring of the renal pelvis that prevents appropriate reconstruction, there are two additional robotic options for reconstruction. Frist, robot-assisted laparoscopic ureterocalicostomy has been described and can be considered as a viable alternative to RALP [43]. Using this approach, identification of an inferior calyx can be facilitated using a flexible cystoscope or

Table 3 Technical considerations for successful infant pyeloplasty

Experience of at least 25–50 toddler or teenage cases prior to infant
Positioning: contralateral (“down”) arm is flexed and padded, ipsilateral (“up”) arm is secured at the infant’s side; flank position with slight flex in table to maximize exposure of UPJ
Port placement is crucial: always place ports under vision with manual control of the camera, and consider “port-in-port” technique to avoid injury
Elevating ports (“burping”) will increase working space in abdominal cavity
Zero degree lens is preferable for entire procedure
Diligent tissue handling, avoid damage to ureter; 6-0 PDS suture for reconstruction
Pneumoperitoneum pressure minimized to 6–8 mmHg during procedure and 8–10 mmHg during port placement
Intraoperative bowel distention is common and can pose technical challenge; consider oragastric and/or rectal tube to decompress, particularly for left sided cases
Meticulous closure of all ports under vision will minimize risk of hernia

ureteroscope passed through one of the laparoscopic ports and into the renal pelvis [44]. Once an appropriate site is identified for anastomosis, the harmonic scalpel can be used to incise the renal cortex with minimal bleeding. With a robotic approach, the anastomosis can be more easily performed due to the dexterity of the instruments. Alternatively, reconstruction of the UPJ using buccal mucosa grafts has been described with good outcomes on short term follow up [45]. This technique involves incising the strictured ureter along the anterior surface and performing an anterior onlay graft of buccal mucosa.

Different techniques for pyeloplasty

The Anderson Hynes dismembered pyeloplasty remains the most commonly performed technique for UPJO correction, but alternate approaches have been described. The VY plasty can be used in cases of UPJO with a nondilated intrarenal pelvis. A bypass technique has been described in which a side-to-side anastomosis is created between the ureter distal to the UPJ obstruction and the dependent portion of the renal pelvis, without disrupting the UPJ or reducing the renal pelvis. The bypass technique can be useful to provide a physiologic repair in patients with UPJO due to a high insertion of the ureter to the renal pelvis [46]. Alternatively, a flap of redundant tissue from the dilated renal pelvis can be used to create a tubularized segment to bridge a gap when the distal ureter cannot reach the pelvis for a tension free anastomosis [47]. Lastly, as discussed previously, buccal mucosa grafts can be used to bridge a gap between the healthy distal ureter and renal pelvis.

Financial considerations

The cost associated with RALP remains a concern, as there is no question that there is a large initial investment in purchasing a robotic platform as well as costs for maintenance and disposable instruments. However, there are also savings associated with RALP that result from the decreased length of stay and associated hospital charges. Unfortunately the financial analysis is difficult with complex health care costs, but within these constraints cost effectiveness analyses have been performed at the institutional level and in national databases with mixed results. Dangle et al. compared the direct costs of RALP to OP among infants, and found no difference in costs [14]. Similarly, Cassella et al. compared the costs of RALP to CLP and found no difference in overall costs [35]. Though not focusing exclusively on pyeloplasty, Rowe et al. found that direct hospital costs were 11.9% lower among patients undergoing robotic surgery compared to open, primarily due to the charges associated with increased LOS in the open cohort. However, when the indirect costs of the robot purchase and maintenance were included, the open approach was less expensive [48]. At a population level, two studies have assessed costs of pyeloplasty in children. The first found no difference in overall costs between minimally invasive pyeloplasty and OP [49], while the second found that RALP was associated with higher costs than OP [50].

An important caveat when interpreting most financial analyses is that these studies typically include a robotic surgeon's early cases and are influenced by prolonged operative times during the learning curve. The population based study by Bennett et al. showed that the primary driver of increased cost for RALP is related to increased OR time and charges, and demonstrated that there was a trend toward decreased cost of RALP over time that is likely related to decreased operative times [50]. At our own institution, we have found that operative time for RALP approaches that of OP with increased surgeon experience [22], suggesting that future studies evaluating the relative costs of these procedures may show little difference if the learning curve is excluded.

As the rising cost of healthcare delivery becomes an issue of greater concern worldwide, further study is critical to determine the relative costs of RALP, CLP, and OP. Even if RALP proves to be the more expensive option, it is important to consider that the value of the benefits of RALP to patients and families may outweigh the increased financial cost.

Training and the learning curve

There is currently not a standardized robotic curriculum or training protocol in existence, which can pose a challenge for surgeons seeking to begin utilizing the robotic approach. Without guidelines on formal credentialing, it is the responsibility of each individual surgeon to engage in a stepwise training program and critical self-assessment of skills and ability prior to embarking on unsupervised RAL surgery. Simulation can play a key role in early training, by allowing trainees to learn the basic controls of the instrument and practice surgical skills. Current robotic simulators can track a trainee's progress in specific performance areas such as task time and instrument collisions, which serve as surrogates for surgical skill [51].

Simulation alone is not sufficient to train a robotic surgeon, and the importance of mentorship cannot be overstated. A mentor in the operating room can help guide a trainee through the procedure and intervene when needed to ensure patient safety and outcomes are not compromised. Bowen et al. studied the role of proctors in robotic training, and found that an open surgeon can quickly attain expertise in RALP by working with a proctor and experienced surgical team [52].

We recommend a comprehensive training program consisting of simulation and mentorship. If a mentor is not available at a local institution, a mini-fellowship (such as at our institution) can be pursued and provide experienced open surgeons with a brief but immersive introduction to robotic surgery. These minifellowships typically consist of a combination classroom didactics, observed RAL surgery, access to robotic simulator, or a wet lab with a porcine model. An experience such as this can help jumpstart a trainee's robotic experience.

The duration of proctoring needed will vary by individual surgeon, and critical self-assessment and reflection is essential during the training period. Though some may develop proficiency at different rates, Sorensen et al. observed that operative times for RALP were initially longer than OP, but became equivalent after 15 to 20 cases, suggesting that this is the approximate length of the initial learning curve for RALP [20]. Thus, depending on an individual's case volume, a considerable amount of time with proctorship and practice may be needed prior to achieving proficiency.

System and instrumentation

Recent technological advancements in robotics have simplified the system and provide a more streamlined design. The Xi model of the da Vinci robotic platform allows for greater flexibility in camera and arm positioning, which can be particularly useful given the smaller working space afforded by pediatric patients. However, instrumentation remains an area of potential improvement. Although 5 mm robotic instruments are available for pediatric use, these instruments have a pulley system that limits articulation and precludes certain movements needed to perform fine dissection and reconstruction in a confined space like the pelvis. For this reason, the senior author routinely uses 8 mm instruments for all pediatric cases. Future efforts to improve the quality of 5 mm instruments or to develop 3 mm instruments similar to those used in conventional laparoscopy are needed to advance the field. The 8.5 mm telescope lens is an option rather than the 12 mm, but unfortunately there is no available balloon port for this lens.

We are further constrained by the current availability of a single generic system. Newer models designed specifically for pediatric use, either by existing manufacturers or new competitors, could help to further improve the quality of RAL surgery in children. A competitor may also help to decrease cost, as there is currently a monopoly in place that inflates the cost of the platform, maintenance, and disposables.

Conclusion

Utilization of RALP is increasing rapidly, suggesting that the robotic approach may be the new gold standard for minimally invasive pyeloplasty. RALP is associated with excellent success rates on par with the open approach without increased complications. Further study on the cost of RALP and the role of RALP in managing infants with UPJO are needed. Offering the benefits of decreased LOS, decreased postoperative narcotic requirement, improved cosmesis, and decreased human capital losses to the parents, RALP is an appealing management option for UPJO in children.

Compliance with ethical standards

Conflict of interest Boysen, none; Gundeti, Intuitive Surgical (consultant and course director).

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