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Pediatric Robot-Assisted Laparoscopic Pyeloplasty

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Abstract

The laparoscopic approach to the pyeloplasty procedure has proven to be safe and effective in the pediatric population. Multiple studies have revealed outcomes comparable to the open approach. However, a major drawback to laparoscopy is the technical challenge of precise suturing in the small working space in children. The advantages of robotic surgery when compared to conventional laparoscopy have been well established and include motion scaling, enhanced magnification, 3-dimensional stereoscopic vision, and improved instrument dexterity. As a result, surgeons with limited laparoscopic experience are able to more readily acquire robotic surgical skills. Limitations of the robotic platform include its high costs for acquisition and maintenance, as well as the need for additional robotic surgical training. In this article, we review the current status of the robot-assisted laparoscopic pyeloplasty, including a brief history, comparative outcomes, cost considerations, and training.

Keywords

Pediatric; Urological Surgery; Robotic; Pyeloplasty

INTRODUCTION

Ureteropelvic junction (UPJ) obstruction occurs as a result of a narrowed lumen, fibrous bands, angled ureter, or aberrant crossing vessels. Regardless of the etiology, obstruction leads to hydronephrosis and can place the kidney at increased risk for parenchymal damage and impaired function. UPJ obstruction (UPJO) is the most common congenital ureteral anomaly, occurring in 1 per 20,000 newborns, and may present in children of all pediatric age groups.¹ Most cases are detected in the perinatal period as hydronephrosis found on routine ultrasonography, but some are discovered later in childhood presenting as symptoms of abdominal discomfort, flank pain, or vomiting.²

Historically, the “gold standard” treatment for UPJO has been the open dismembered pyeloplasty, with the Anderson-Hynes technique being the most common. Success rates of the open approach range from 90% to 100%, overall.^{3,4} Endoscopic options for UPJO management exist, including endopyelotomy^{5,6} and retrograde balloon dilation.⁷ However,

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Conflict of Interest

There is no conflict of interest.

success rates for these two procedures are reported at 60–80%, significantly inferior to definitive surgical treatment.^{8,9} Minimally invasive surgical approaches, such as laparoscopy and, more recently, robot-assisted laparoscopy, have resulted in reduced morbidity and improved recovery compared to the open surgical approach.

Although laparoscopy affords significant advantages to the patient over the open approach, few surgeons perform the advanced techniques required for UPJO treatment, limiting its use to high-volume centers.^{10,11} Robotic technology mitigates the limitations of conventional laparoscopic surgery (CLS), and the robot-assisted laparoscopic pyeloplasty (RALP) has become the most common robotic surgery performed in pediatric urology.¹² The aim of this review is to provide a history of its development and report the present role for the RALP in pediatric urology, including aspects of cost-effectiveness and robotic surgical training.

HISTORY

The first cases of adult laparoscopic pyeloplasty were documented in 1993.^{13,14} In 1995, Peters et al. reported the first pediatric case.¹⁵ This case report provided a basis for further development of minimally-invasive techniques for reconstructive surgery in pediatric urology. The authors demonstrated safety and feasibility of this procedure. However, the authors also identified drawbacks, specifically noting the time-consuming nature and technical challenges of intracorporeal suturing during the anastomosis. Following this report, additional cases of pediatric laparoscopic pyeloplasty were published over the next several years.

Peters subsequently reviewed over 5000 laparoscopic cases performed by 153 pediatric urologists, reporting a 5.4% rate of complications.¹⁶ When focusing only on major complications, such as great vessel laceration and small bowel injury, the overall complication rate was reduced to 1.2%. Only 0.4% of the complications required follow-up surgical intervention. The author also found that laparoscopic experience of the surgeon was the best predictor for complications. Surgeons with fewer than 20 cases reported an average complication rate of 8.3%, whereas the complication rate in surgeons with greater than 100 cases was 2.8%. Yeung et al. published their early experience with 13 pediatric laparoscopic pyeloplasties,¹⁷ followed by El Ghoneimi et al. with their experience in 50 pediatric patients ranging from the age of 22 months to 15 years.¹⁸ Likewise, Reddy et al. completed a series of 16 laparoscopic pyeloplasties in pediatric patients, aged 5 months to 11 years.¹⁹ This study demonstrated improved short-term outcomes, with good drainage on postoperative renogram, improved glomerular filtration rate and resolution of symptoms at 3 months follow-up. These early studies demonstrated the safety and feasibility of the pediatric laparoscopic pyeloplasty and that, although technically demanding, this approach showed comparable success and complication rates to the open dismembered approach.

ADVANTAGES OF ROBOTIC SURGERY

Laparoscopic surgery has advanced significantly since its inception, allowing more complex reconstructive procedures to be approached using minimally invasive techniques. The increase in cases done by this approach led to an increase in operative time and in the amount of mental and physical stress placed on the surgical team.^{20,21} This manifests as the

so-called “surgical fatigue syndrome,” characterized by impaired dexterity and decision-making capacity. From a technical standpoint, the incision serves as a spherical joint, limiting the instrument to essentially four degrees of freedom. Two-dimensional vision and the absence of shadows and stereovision also make spatial relations difficult to appreciate.^{22,23} Therefore, despite the advantages of being minimally invasive, these drawbacks and the difficulty with intracorporeal suturing have precluded the laparoscopic approach from being widely adopted within pediatric urology.²⁴ Robot-assisted laparoscopic surgery offers a solution to the limitations of conventional laparoscopy.

Initially developed for remote surgical management of injured soldiers in the military, robotic surgery became established within clinical practice in 1990s and early 2000s.²⁵ It has since gained immense popularity in the field of adult urology, particularly for the prostatectomy procedure. In 2001, the first case of robotic surgery in a pediatric patient, a Nissen fundoplication, was reported by Meininger et al.²⁶ This pioneering work opened the door for the advancement of robotic surgery in pediatric patients, and this technology has since expanded into the field of pediatric urology. Many researchers have now published their experience with robot-assisted laparoscopic surgery, which is currently used for almost any procedure that can be performed by conventional laparoscopic surgery.

Robot-assisted laparoscopy is performed using the da Vinci Surgical Platform, manufactured by Intuitive Surgical. The surgeon sits at a console away from the operating field and remotely controls 3–4 robotic arms located at the bedside. The robotic arms attach to ports inserted into the patient, which allow instruments to be placed through the ports and into the peritoneal cavity for surgery. The robotic technology allows for 3-dimensional visualization, motion scaling, tremor filtering, an ergonomic seated position, and wristed instrument motion allowing seven degrees of freedom similar to open surgical instruments. Consequently, the system is capable of generating very delicate movements, ideal for urologic surgery within the smaller pediatric patient. Moreover, these robotic properties have significantly reduced the learning curve for intracorporeal suturing compared to conventional laparoscopy.²⁷ This has also allowed for more facile dissection and reconstruction of the ureteropelvic junction during the pyeloplasty procedure.²⁸

COMPARISON OF MINIMALLY INVASIVE APPROACHES

The standard approach to the open pyeloplasty involves retroperitoneal access through a flank incision. When performing a robotic pyeloplasty, a trans-or retroperitoneal approach may be utilized depending on surgeon preference and patient status (prior surgical history, size, etc.). In 2006, Lee et al. reported a retrospective case-control study of 33 pediatric patients undergoing transperitoneal RALP, matched by age and sex with 33 patients undergoing open pyeloplasty.²⁹ Compared to the open procedure, mean operative time was longer (181 vs. 219 minutes) in the robotic group. Operative time with the robot significantly decreased after 15 cases, approaching times similar to the open group with increasing surgeon experience. The RALP cohort demonstrated a shorter length of stay, lower pain medication requirement, a success rate of 93.9%, with only one complication due to a missed crossing vessel.

Yee et al. reported similar results in a retrospective case-control series of 16 age matched pediatric patients; eight patients with a mean age of 11.5 years (range 6.4 to 16.5 years) underwent transperitoneal RALP, whereas eight patients with a mean age of 9.8 years (range 6.0 to 15.6 years) underwent open pyeloplasty.³⁰ Atug et al. also demonstrated a short length of stay, high rate of success, and a mean operative time of 184 minutes from a transperitoneal approach in seven children.²⁸ In this series, no patient required additional procedures. Sorensen et al. reported no differences in length of stay, postoperative pain, or success rates in 33 pediatric patients undergoing RALP compared to open pyeloplasty.³¹ Recently, Barbosa et al. evaluated long-term results in children, identifying a higher success rate (74% vs. 70%) and shorter time to clinical improvement (12.3 vs. 29.9 months) in patients undergoing RALP compared to open pyeloplasty.³²

Olsen and Jorgensen published the only series of retroperitoneal RALP cases in 13 pediatric patients.³³ Mean operative time (173 minutes) was notably shorter than in the previous transperitoneal RALP series,^{28–30} with no obstruction observed at follow-up. Median hospitalization was 2 days and only 1 complication of ureteral stent occlusion occurred. The authors published an expanded series of 65 children with a follow-up of 5 years in 2007, affirming their earlier results.³⁴ They concluded that a retroperitoneoscopic approach afforded shorter operative time and comparable outcomes and complication rates to that of the transperitoneal RALP.

Despite evidence supporting the many advantages of a minimally invasive approach relative to open pyeloplasty, few studies have directly compared the robot-assisted and conventional laparoscopic pyeloplasty (LP) in children. The major drawback to laparoscopy is the steep learning curve for mastering intracorporeal suturing which can be technically challenging and time consuming. One study by Gettman et al. identified a distinct advantage with robotic compared to pure laparoscopic mean overall operative time (140 vs. 235 minutes) and suturing time (70 vs. 120 minutes) during pyeloplasty in adults.³⁵ Franco et al. performed a retrospective comparison of 15 RALPs and 12 LPs, in patients averaging 11.8 years of age.³⁶ The authors reported similar success rates (100%) and overall operative times, showing that the slower time for laparoscopic suturing balanced with the longer time for robot set-up. A more recent study by Riachy et al. compared the two approaches in pediatric patients, with 18 undergoing conventional and 46 undergoing robot-assisted laparoscopic pyeloplasty.³⁷ Their results indicate comparable outcomes, with postoperative improvement of hydronephrosis in 85%, complication rate of 4%, and median length of stay of 2 days in patients who had undergone RALP, compared to 89.5%, 10%, and 1 day in patients who had undergone LP. Notably, the robotic pyeloplasty had a significantly shorter operative time (209 vs. 298 minutes).

The largest pediatric RALP series was published by Minnillo et al. from Boston Children's Hospital.³⁸ This study included 155 patients aged 11.5 years on average. Nearly all (98%) of the procedures were performed by the transperitoneal approach by individual surgeon preference. Operative time averaged 198.5 minutes, length of stay was 1.96 days on average, and the success rate at a mean follow-up of 31.7 months was 96%. The authors highlighted collaboration between surgeons, anesthesiologists, and nursing staff as critical to achieving operative times and length of hospital stay that were comparable to the open approach. A

summary of pediatric pyeloplasty robotic case series and comparative studies is included (Tables I and II).

CHALLENGES TO ROBOTIC PYELOPLASTY IN INFANTS

Given the success of RALP in the pediatric population, some urologists have utilized this approach on infants. Small children and infants provide a more confined intraabdominal working space (0.5–1.0 L), as compared to adults (5–6 L). When conventional laparoscopic pyeloplasty was first introduced, size constraints limited the procedure to children older than 1 year of age. With increased range of motion and instrument precision, the robotic approach can now be safely performed in children as young as 3 months of age (6–11 kg).^{44,45} Recently, Dangle et al. reported a comparison between RALP and open pyeloplasty in a total of 20 infants.⁴⁶ The authors found a longer operating time in the robotic group (242 vs. 199 minutes), but no significant difference in success rate, recovery time, or length of stay. Another recent study by Finkelstein et al. suggested safe and efficient size parameters for utilizing a robotic approach.⁴⁷ Rather than relying on age or weight, they measured the distance between the anterior iliac spines (ASIS) and the pubo-xyphoid (PXD) distance in 45 infants. Their results showed significantly fewer instrument collisions with ASIS lengths >13 cm and PDX >15 cm, while minimizing operative time. This may serve as a useful method for selecting infants appropriate for undergoing a robotic approach to pyeloplasty.

REDO ROBOTIC PYELOPLASTY

The incidence of open pyeloplasty failure is approximately 5%, and the management of recurrent obstruction presents a significant dilemma. Treatment options include endopyelotomy or reoperative pyeloplasty. Endoscopic management by endopyelotomy, whether antegrade or retrograde, is inferior to that of redo pyeloplasty, with success rates of 39% to 70% in pediatric patients.^{48,49} The robot-assisted laparoscopic redo pyeloplasty has demonstrated success and may be better able to address the causes of initial failed reconstruction, including missed crossing vessels, periureteral fibrosis, and ureteral stricture.⁵⁰

Passerotti et al. reported a series of six pediatric patients undergoing redo robotic pyeloplasty after a failed open procedure.⁵¹ Each operation was successful and no complications were reported. Comparable results were later published by Hemal et al. in six pediatric patients at an average age of 13.2 years.⁵⁰ In 2012, Lindgren et al. published a retrospective reviews of 13 cases of robotic redo pyeloplasty in children age 6.1 years on average; 11 were performed after an unsuccessful open approach 2 after a failed robotic approach.⁵² Endoscopic procedures had been performed after the initial failed surgery, with some patients having undergone more than one before the study period. The results illustrate the superiority of the robotic reoperation over endoscopic management and a high success rate (100%) comparable to open reoperative pyeloplasty. More recently, Asensio et al. reported a retrospective study of 5 pediatric robotic redo pyeloplasties, confirming the benefits of robotic reoperation.⁵³ Overall, these studies suggest that the robotic approach for reoperative cases is feasible and has a distinct advantage over endoscopic treatments.

COST

The relatively high cost of robot-assisted surgery is a major disadvantage limiting widespread adoption. The high expenditure includes purchasing the system, servicing contracts, and limited use instruments. In pediatric urology, few studies have examined the cost-effectiveness of this surgical approach. Behan et al. investigated the impact of a shorter length of stay on the cost for pediatric patients undergoing robot-assisted pyeloplasty.⁵⁴ The authors discovered an average human capital savings of \$90.01, due to earlier parental return to work, and a significant reduction in hospitalization costs by \$612.80, reflecting a reduced length of stay (1.6 vs. 2.8 days), per RALP case. However, taking into account amortized robotic costs using an annual robotic case volume of 100 resulted in an added cost of greater than \$5,000.00 per RALP over 5 years and greater than \$3,000.00 per RALP over 10 years.

A recent retrospective study by Casella et al. analyzed the cost differences between 23 conventional laparoscopic and 23 robot-assisted pyeloplasty procedures in children.⁵⁵ The authors identified a reduction in operative time for the robotic group, but found no significant difference in institutional cost of the two minimally invasive approaches. This study focused primarily on direct costs, with the indirect costs of purchasing the robotic system equally absorbed across all surgical cases at their institution. In a large retrospective study by Rowe et al., cost was evaluated in 146 pediatric patients undergoing either open or robotic urological surgery, including pyeloplasty.⁵⁶ They found that RALS cost 12% less than open surgery. However, when indirect cost estimates were included, the cost of robot purchase and equipment maintenance overshadowed the savings in room and board expenses. Thus, the overall cost of robotic surgery was found to be higher for robotic surgery compared to open surgery.

In addition to the costs of the robotic system, the learning curve to become proficient adds to the cost. This is reflected in the cost of OR time, which can be increased early as a surgeon adopts this skill but decreases as the surgeon becomes more adept. In a meta-analysis by Steinberg et al., the authors found that the learning curve for robotic prostatectomy in adults ranged from 13 to 200 cases, with 77 being the average.⁵⁷ Taking into account operating room time and anesthesia services, the associated costs of the learning curve were estimated at greater than \$200,000. Enhanced training using virtual reality simulators may help to minimize this cost of acquiring proficiency. Therefore, we must also evaluate training methods for utilizing robotic technology.

TRAINING

High-volume surgeons more commonly have better surgical outcomes.⁵⁸ Since the introduction of robotic technology to the pediatric population, many practicing urologists may not have received adequate training in robotic surgery during their graduate medical education to reach proficiency. Therefore, it is beneficial to establish standardized protocols for training and evaluating residents and fellows, to ensure safe use of this technology in children.

Training on animals or cadaveric models allows the opportunity to build comfort with the robotic system and tissue manipulation.⁵⁹ More recently, virtual-reality robotic surgery

simulators have been introduced, and initial results are encouraging.^{60,61} These studies demonstrate the face, content, and construct validity of the Mimic dV-Trainer and its ability to improve da Vinci surgical system skills similar to improvement seen with da Vinci surgical system training alone. This virtual simulation training has not shown utility in overcoming the limitations of experience gained only in the operating room, but has also shown efficacy as a means to preoperatively “warm-up” for a robotic case.⁶²

A shorter learning curve allows more surgeons to offer a minimally invasive approach to the pyeloplasty, reduces operating room times and subsequently cost, and reduces the risk of complications in patients as the surgeon acquires proficiency. O'Brien et al. have demonstrated a shortened learning curve for the robotic pyeloplasty, showing that it requires little prior laparoscopic or robotic experience. This was based on comparing outcomes, analgesic requirements, and length of stay with age-matched laparoscopic and open patients from the pediatric literature.⁶³ Sorenson et al. evaluated the learning curve and outcomes, comparing RALP against the open approach.³¹ Similar results were reported between the two procedures after approximately 20 cases, which is a much abbreviated course compared to the steep learning curve for pure laparoscopy. Therefore, in addition to its utility in smaller patients, RALP may be easier to learn compared to conventional laparoscopic pyeloplasty, expanding access to minimally invasive approaches in the field of pediatric urology. Nevertheless, robotic surgery is still technically challenging and requires maintenance of proficiency, which may be achieved with either case volume or virtual reality training.

CONCLUSION

In the past, laparoscopic pyeloplasty has been the most widely adopted minimally invasive surgical modality for children with UPJO. The advantages of robotic surgery have become increasingly apparent, especially in regards to intracorporeal suturing and the learning curve. A growing body of evidence suggests that RALP is appropriate for small infants and reoperation after a failed pyeloplasty. Robotic technology has allowed more surgeons to offer a minimally invasive approach to their patients, compared to the limited number of surgeons able to perform a pure laparoscopic pyeloplasty. Despite its benefits, there is currently no clear advantage of the robot over laparoscopy in terms of clinical outcomes, while cost-effectiveness of the robotic approach remains a major limitation. The introduction of additional robot manufacturers is expected to drive down costs, making RALP more economically feasible. Finally, standardized robotic training and credentialing for urologists is essential to achieve expertise, ensure patient safety and achieve optimal outcomes.

Biography

Michael V. Hollis is a fourth-year medical student at Michigan State University College of Human Medicine in Lansing, Michigan. He is completing a one-year Robotic Surgery Research Internship in the Department of Urology at Boston Children's Hospital under the mentorship of Dr. Richard Yu. His current research interests include robotic surgery education, surgical oncology, and outcomes research.

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Table I

Robotic case series.

Study	Patients (n)	Age (y)	Operative time (min)	Hospital stay (d)	Success (%)
Atug et al. 2005 [29]	7	13.0 (6–15)	184 (165–204)	1.2 (1.0–3.0)	100
Kutikov et al. 2006 [41]	9	0.5 (0.3–0.7)	123	1.4	100
Olsen et al. 2007 [35]	67	7.9 (1.7–17.1)	143 (93–300)	2.0 (1.0–6.0)	94
Freilich et al. 2008 [42]	5	9.5 (3.4–14.0)	384 (285–541)	2.4 (1.3–3.6)	100
Chan et al. 2010 [43]	5		219 (105–420)		100
Minnillo et al. 2011 [39]	155	10.5 ± 6.5	198.5 ± 70.0	1.9	96
Singh et al. 2012 [44]	34	12	105 (75–190)		97

Table II

Comparative studies.

Study	Approach	Patients (n)	Age (y)	Operative time (min)	Hospital stay (d)	Success (%)
RP versus open						
Lee et al. 2006 [30]	RP	33	7.9 (0.2–19.6)	219 (133–401)	2.3 (0.5–6.0)	94
	OP	33	7.6 (0.2–19.0)	181 (123–308)	3.5 (2.7–5.0)	100
Yee et al. 2006 [31]	RP	8	11.5 (6.4–16.5)	363 (255–522)	2.4 (1–5)	100
	OP	8	9.8 (6.0–15.6)	248 (144–375)	3.3 (1–8)	87.5
Sorenson et al. 2011 [32]	RP	33	9.2	326 ± 77	2.2	97
	OP	33	8.2	236 ± 54		97
Barbosa et al. 2013 [33]	RP	58	7.2 (147d–18.2y)			76.9
	OP	154	1.2 (13d–26.6y)			67.9
RP versus LP						
Franco et al. 2007 [37]	RP	15	11.8 (4–22)	223.1 (150–290)		
	LP	12	11.8 (4–22)	236.5 (200–285)		
Subotic et al. 2012 [40]	RP	19	9.6 (4.8–14.9)	165 (104–225)	6 (4–12)	100
	LP	20	0.92 (0.08–2.75)	248 (165–334)	7 (5–12)	100
Riachy et al. 2013 [38]	RP	46	8.8 (0.4–22)	209 (106–540)	2 (1–6)	100
	LP	18	8.1 (0.25–18)	298 (145–387)	1 (1–4)	87.5