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Pediatric Robot-Assisted Laparoscopic Pyeloplasty: Where Are We Now?

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Abstract

Purpose of Review This review aims to provide an in-depth exploration of the recent advancements in robot-assisted laparoscopic pyeloplasty (RALP) and its evolving landscape in the context of infant pyeloplasty, complex genitourinary (GU) anatomy, recurrent ureteropelvic junction (UPJ) obstruction, cost considerations, and the learning curve.

Recent Findings Recent literature highlights the safety and efficacy of RALP in treating the infant population, patients with complex GU anomalies, and recurrent UPJO which were all traditionally managed using the open approach. Cost considerations are evolving, with the potential for RALP to have a lesser financial burden. In addition, the learning curve for RALP is diminishing due to robust training programs and advances in research.

Summary RALP has become the gold standard in the treatment of UPJO in pediatric urology at many children's hospitals. Surgeon comfort and research in this space allow safe and successful reconstruction in the most challenging of cases.

Keywords Pediatric urology · Ureteropelvic junction obstruction · Robot-assisted laparoscopic pyeloplasty · Minimally invasive surgery

Introduction

Ureteropelvic junction obstruction (UPJO) is a blockage between the renal pelvis and proximal ureter leading to increased pressure within the collecting system and hydronephrosis on imaging [1]. UPJO is a common issue in pediatric urology caused by either an intrinsic or extrinsic blockage such as an aberrant lower pole crossing vessel of the kidney [2••, 3]. The increased use of antenatal/postnatal imaging has led to hydronephrosis being one of the most common congenital abnormalities identified [3, 4]. The use of advanced imaging modalities, such as 99mTc-MAG3 and magnetic resonance urography (MRU), has allowed clinicians to differentiate among the various etiologies of hydronephrosis, including transient hydronephrosis, UPJO, ureterovesical junction obstruction, vesicoureteral reflux, and megaureter. These advanced imaging techniques provide critical information regarding the differential renal function, urinary drainage throughout the system, and delineation of anatomy [2••, 3, 5].

The classically described Anderson-Hynes dismembered pyeloplasty is considered the gold standard surgical technique to treat UPJO, with reported success rates ranging from 90 to 100% [6–8]. Indications for surgical management include persistent clinical symptoms, breakthrough UTIs, worsening hydronephrosis, demonstrable poor drainage, and/or worsening differential renal function [5]. Minimally invasive surgical techniques (MIS) have gained popularity for treating a UPJO [9] over the past 3 decades. Pure laparoscopic pyeloplasty (LP) was first reported in 1995 [7] and the use of the robotic platform being used for repair reported in 2002 [10]. Like many urologic procedures, the adoption of MIS techniques for treatment of a UPJO has steadily gained traction worldwide. Robot-assisted laparoscopic pyeloplasty (RALP) has surpassed LP in utilization for many reasons. The three-dimensional vision, articulated wrist movements allowing for precise suturing, and its short learning curve have all been essential benefits to its utilization [11]. At many centers, including our own, RALP is the most common technique used to address UPJO with similarly high success rates as the open approach [2••, 12, 13]. As the utilization of RALP and surgeon comfort with

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the technique has increased, more complex cases are being approached this way.

In this review, we will discuss the advancement of RALP including in cases of infant pyeloplasty, complex genitourinary anatomy, low function pyeloplasty, recurrent UPJO, financial and cost considerations, and our understanding of the learning curve.

Infant Pyeloplasty

In the beginning of the robotic surgery era, there was hesitation in approaching UPJOs in infants, who were less than 1 year, via a RALP. Concerns associated with the low weight of the patient along with the presumed small intrabdominal working space that would lead to greater complications and clashing of the robotic arms led many to advocate for approaching these patients via a traditional open surgery. As more robotic expertise was attained, high-volume surgeons began reporting on their initial success with this cohort [2••]. Kafka et al. compared outcomes of children undergoing RALP with a median age of 8 months and weight of 7 kg to the open procedure; they found comparable success and complications concluding that RALP in this infant cohort is both safe and effective [14]. Furthermore, Kawal et al. looked at postoperative outcomes of children undergoing RALP; they divided the cohort based on age, less than and greater than 1 year of age; both age groups showed comparable postoperative outcomes with no significant differences in complications and failure rate between infants and the older cohort [15].

Table 1 Results from studies evaluating robot-assisted pyeloplasty in the infant population in the past 8 years

Study	Technique	Patients, *n*	Median age	Complications (%)	Success (%)
Kafka et al. [14]	RALP[a] OP[b]	RALP—15 OP—15	RALP—7 m OP—7 m	RALP—6.6: post-operative paralytic ileus = 1. OP—6.6: post-operative paralytic ileus = 1.	RALP—100 OP—93.3 (1 had redo surgery)
Neheman et al. [20]	RALP LP[c]	RALP—21 LP—13	RALP—5.8 m LP—6.29 m	RALP—23.8: Urinary leak = 1; UTI= 1; ileus=1; postop umbilical hernia = 1; failure = 1. LP—30.8: port site infection = 1; UTI = 2; failure = 1.	RALP—95.2 (1 had redo surgery) LP—92.3 (1 had redo surgery)
Kawal et al. [15]	RALP	138 (≤ 12 m = 34; > 12 m = 104)	≤ 12 m–0.8 y > 12 m–9 y	≤ 12 m–29.4 (Clavien Grade: I = 3; II = 5; III = 1; IV =1) > 12 m–30.8 (Clavien Grade: I = 16; II = 10; III= 6)	≤ 12 m–94.1 > 12 m–96.2
Baek et al. [19]	RALP	65 (infants = 16; non-infants = 49)	Infants—0.6 y Non-infants—5.7 y	Infants—6.3: paralytic ileus = 1 Non-infants—4.1: UTI =2.	Infants—93.8 (1 pt failure) Non-infants—100
Ganpule et al. [17]	RALP LP	RALP—19 LP—25	RALP (3 m–5 y; mean = 2.7 y) LP (5 m–5 y; mean = 2.4 y)	RALP—5.3: recurrent UTI & persistent hydronephrosis = 1 LP—4: recurrent UTI & persistent hydronephrosis = 1.	RALP > 90 (1 had nephrectomy) LP > 90 (1 had nephrectomy)
Avery et al. [21] — multi-institutional	RALP	60	7.29 m	11: port site hernia = 2; urine leak = 1; UTI = 1; retention = 1; renal calculus = 1; ileus = 1	96.7 (2 pts had redo surgery)
Bansal et al. [23]	RALP OP	RALP—9 OP—61	RALP—9.2 m OP—4 m	RALP—33: urinary leak = 1; ileus = 1; UTI = 1. OP—7: urinary leak = 1; catheter dislodgment = 1; ileus = 1; UTI = 1.	RALP—100 OP—98 (1 had redo surgery)

[a] Robot-assisted laparoscopic pyeloplasty

[b] Open pyeloplasty

[c] Laparoscopic pyeloplasty

Masieri et al. published a systematic review about RALP in the pediatric population; they illustrated that as expertise was gained, and more authors were performing RALP in younger and lighter-weight children [16]. Articles within this systemic review compared patients based on weight, rather than age, from 10 to 20 kg compared to heavier counterparts [14, 16–18] and again showed appropriate outcomes. Over the past decade, several articles (Table 1) have similarly concluded that small infants can be approached via a RALP [15, 19–23]. At our institution, most of our infant patients are approached via RALP, with the minority undergoing an open approach secondary to surgeon preference.

Complex Genitourinary Anatomy

Similar to infant patients, patients with complex genitourinary (GU) anatomy were preferentially treated via an open approach. Patients with complex anatomy included those with a complete intrarenal pelvis, high ureteral insertion, morphological variations such as horseshoe kidney (HSK), duplex collecting systems, ectopic/pelvic kidney, renal fusion anomalies, and renal malrotation [2••]. There were concerns regarding the aberrant vascular anatomy, optimal patient positioning, and port placement and the need for additional trocars/assistants to mobilize surrounding structures and to maintain exposure. These challenging anatomical variants have been successfully completed and reported on as surgeons have gained more experience with the robot technique (Fig. 1).

Esposito et al. reported on a multi-institutional study looking at postoperative outcomes of pediatric patients with complex UPJOs undergoing RALP [24••]. This cohort included patients with anatomic variations such as HSK, ectopic kidney, duplex kidneys, and recurrent UPJO after failed open pyeloplasty. The study included 48 patients with a median age of 8 years (range 5–12) and a dismembered Anderson-Hynes pyeloplasty was performed in all patients; reported success rate was 95.8% inferring RALP as a safe and feasible procedure for patients with complex UPJO [24••]. In addition, another multi-center study focused on pediatric patients with horseshoe kidney undergoing RALP; the study included a small cohort of patients ($n = 14$), but with the mean follow-up time after surgery of 15.5 months, reported a success rate of 92.8% [25].

Recent literature showing promising results of RALP being performed on challenging cases, such as those with complex GU anatomy, has paved the way and encouraged pediatric urologists to expand indications for using the robot while treating UPJO. Technical advances, improved anatomic assessment with preoperative imaging, and comfort with the robotic platform have broadened the RALP treatment capacity.

Low Function Pyeloplasty

One unique clinical situation arises when the differential renal function (DRF) of the obstructed kidney is significantly diminished. Traditionally, patients with less than

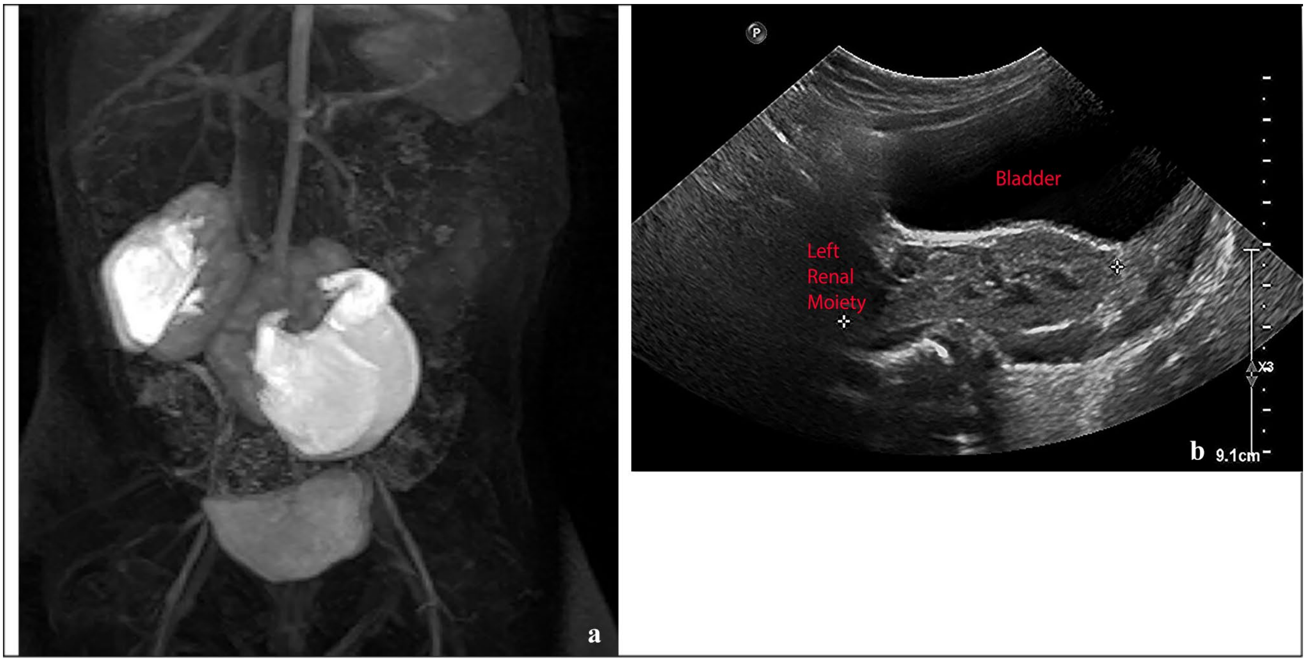

Fig. 1 **a** Three-year-old female with cross-fused renal ectopia and left moiety UPJO. Symptomatic with recurrent abdominal pain. Intraoperatively, found to have crossing vessel from left common iliac artery. **b** Post-RALP ultrasound with near complete resolution of hydronephrosis and symptoms

10–20% DRF were recommended to undergo nephrectomy as the potential risk for complications both short and long term related to reconstruction were thought to outweigh the benefit [26–29]. As the outcomes in terms of success and safety increased with RALP, many high-volume centers began attempting reconstruction of these lower-functioning kidneys. The existing body of literature regarding the use of RALP in poorly functioning kidneys is limited. Initial experiences via the open approach for these situations showed favorable outcomes. Sarhan et al. published a multi-institutional study evaluating outcomes of pyeloplasty in children with a DRF ≤ 20%; they noted favorable outcomes with resolution of hydronephrosis postoperative shown on RBUS [30]. Bowen et al. published one of the first retrospective studies looking at outcomes of different surgical approaches (OP, LP, and RALP) for pyeloplasty. They further stratified the DRF into 3 groups (0–10%, > 10–≤20%, and > 20%). Through regression analysis, they showed that DRF did not affect pyeloplasty success rates and hence RALP is a viable option to treat patients with low functioning kidneys [26].

An important consideration in these cases is the ipsilateral ureter. Severely low functioning kidneys can be associated with atretric, poorly formed ureters which may theoretically affect success. This associated pathology is difficult to predict pre-operatively and our group utilizes retrograde pyelograms to gain insight into the health and caliber of the ureter prior to reconstruction. An informed discussion preoperatively must be had with families about the possible conversion to nephrectomy. In light of the limited research in this specific domain, it is imperative to conduct further investigations regarding this clinical scenario and the long-term consequences of retaining poorly functioning, although unobstructed, renal units.

Recurrent UPJO

Despite the high success reported for both open and robotic pyeloplasty, recurrent or persistent UPJO occurs in 3–11% of cases. There is no gold standard approach for these patients [31]. Previous literature has shed light on complications of secondary RALP, mainly related to delineating the anatomy in the presence of scar tissue [2••, 32, 33]. However, no surgery is without complications and utilization of RALP in redo procedures has gained popularity due to ease of visualization of the etiology of recurrent UPJO, especially missed crossing vessels [2••]. This initial hesitation regarding the technical ability of the console surgeon to navigate through a previously operated, presumably scarred field has been shown to be unfounded.

Mittal et al. published a single institutional comparative study looking at outcomes between primary RALP and redo-RALP [34••]; they performed the largest cohort study comparing primary and redo-RALP and concluded that there is no significant difference in success between the 2 procedures [34••]. In addition, Jacobson et al. looked at postoperative outcomes of pediatric patients who underwent a redo-RALP with a prior failed primary pyeloplasty [35], and found 100% symptomatic improvement and 91.2% radiographic improvement in their cohort after treatment, confirming the feasibility and effectiveness of performing RALP after a failed primary pyeloplasty [35]. Furthermore, Baek et al. published an article comparing perioperative parameters between primary and redo-pyeloplasties [36], in which primary surgery was either open or a laparoscopic procedure whereas redo-procedures were all RALP; they found out that redo-RALP was associated with a significant longer operative time but overall comparable success rate [36].

In addition, Chandrasekharam and Babu published a systematic review and meta-analysis comparing outcomes of open pyeloplasty (OP), laparoscopic pyeloplasty (LP), and RALP for the treatment of recurrent UPJO. They analyzed 18 articles and found that MIS techniques (RALP and LP) had comparable success rates and is a good alternative to treat recurrent UPJO [37]. As more MIS expertise has been attained, many surgeons have opted to use the robot for treatment of recurrent UPJO, a complex condition traditionally treated using the open approach.

Furthermore, when performing RALP to treat recurrent UPJO, situations can arise where performing a traditional RALP can be impossible. This can occur in the setting of dense scarring, significant intrarenal pelvic dilation only, or non-viability of the proximal ureter. Creating a ureterocalicostomy (UC) can be a great option in this scenario. To perform this, a lower pole calicostomy is created, the ureter is appropriately mobilized and spatulated, and a tension-free anastomosis is made. Traditionally done via an open approach, the robotic approach has shown promise.

Esposito et al. reported on a multicenter study comparing laparoscopic ureterocalicostomy (LUC) and robot-assisted ureterocalicostomy (RALUC) with LP and RALP for treatment of both primary and recurrent UPJO. The study noted similar success rates between the 2 groups (100% vs. 97.4%) and deemed that LUC/RALUC as safe and effective alternative approaches to LP/RALP for treatment of recurrent UPJO [38]. In addition, Mittal et al. published a multi-institutional study looking at outcomes of RALUC for treatment of recurrent or complex UPJO and reported a success rate of 92% concluding that RALUC is an effective option for treatment of failed pyeloplasty or complex anatomy [39].

Cost

The utilization of minimally invasive techniques, such as RALP, comes with a higher financial burden compared to the open approach. However, these financial differences have decreased with time and institutional experience [2••]. In 2021, a study performed in a low-volume center in Finland looked at the cost difference between RALP and OP between 2019 and 2020; the study did not find any significant cost differences between the two approaches [40]. The major driver of cost differences between the two techniques is the utilization of double-J stents that require an additional procedure for subsequent removal. In this study, surgeons began to utilize magnetic stents allowing for retrieval without the use of anesthesia and concluded that RALP was economically justifiable [2••, 40].

In 2018, Varda et al. published an insurance claims-based study looking at US national trends of pyeloplasty in the USA from 2003 to 2015 and analyzed median cost data [9]. The study noted a significantly higher cost for RALP compared to OP. However, during the years analyzed, the cost of RALP steadily declined year over year and remained constant for OP [2••, 9]; this can be correlated with the increased experience of the robot leading to a shorter operative time leading to a lower OR turnover time and also a shorter length of hospital stay. This is promising as a comparable financial burden between RALP and OP could be achieved in the near future. In addition, Bodar et al. were the first to use time-driven activity-based costing (TDABC) to evaluate RALP. TDABC calculates the cost of healthcare resources as a patient moves through care. They found that increasing capacity utilization of the robotic console is necessary to reduce TDABC costs [41••]. Strategies have been proposed to lower costs and improve the financial burden including increasing robot utilization, optimization of preoperative holding time, and lowering OR turnover time [2••, 41••, 42].

Learning Curve

Like all procedures, proficiency of RALP is attainable with rigorous practice and training. Many pediatric surgeons who have traditionally performed OP may be apprehensive to adopt a radically different approach. Bowen et al. looked at the learning curve (LC) of an experienced open surgeon being proctored by a robotic surgeon while performing RALP and concluded that an open surgeon can quickly attain expertise with a proper robotic surgical program [43].

In addition, Pakkasjärvi et al. performed a systematic review aimed at deciphering the learning process for pediatric RALP [44]; the review included 15 studies and found that proficiency in RALP was reached after 18 cases while competency would require around 31 cases [44]. Furthermore, Pio et al. systematically reviewed the LCs of different surgical procedures and its impact on fellowship programs. The review included 17 articles, 9 of which were looking at RALP; the authors found a downward trend in operative times as surgeons gained more experience robotically [45]. They also reinforced the importance of hands-on training robotic courses such as the ones offered by the European Association of Urology (EAU) and other societies through simulation and dry labs to minimize risks and shorten learning curves before approaching pediatric patients [45–49].

The learning curve for pediatric RALP is likely to shorten further in the future. The incorporation of a significant number of robotic procedures during urologic training, the use of cutting-edge technologies like virtual reality simulations, and artificial intelligence promises a swifter acquisition in mastering robotic procedures.

Conclusion

Over the past decade, an exponential surge in the adoption of minimally invasive surgery, particularly robot-assisted, has been witnessed in the field of pediatric urology. In the case of UPJO, RALP has unequivocally emerged as the gold standard across many institutions, which has facilitated the execution of more complex reconstructive surgeries.

Nonetheless, the horizon of progress in pediatric urology is far beyond our current achievements, mainly in the realm of surgical simulation and coaching/automated video analysis, all while addressing critical issues of accessibility and cost. The introduction of additional surgical platforms into the global market is poised to serve as a catalyst for broadening access, decreasing costs, and indications for which patients can benefit from.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest.

Human and Animal Rights Consent and Informed Consent All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/ national research committee standards, and international/national/institutional guidelines).

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