REVIEW ARTICLE

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Robot-assisted Laparoscopic Surgeries: Current Use in Pediatric Urology Patients

ABSTRACT

Introduction: The use of robot-assisted laparoscopic surgeries (RALS) has largely increased in recent years, offering faster and safer treatment options for pediatric patients. In the field of urology, RALS has shown a significant advantage over laparoscopic and open surgeries but continues to be controversial in pediatric cases due to limited comprehensive data on its use. **Methods:** In this review, we aim to summarize the factors associated with RALS use in pediatric cases involving pyeloplasty, ureteral reimplantation, heminephrectomy, and lower urinary tract reconstruction. We used PubMed, EMBASE, and the Cochrane Database of Systematic Reviews to systematically search for the literature on the topic. We then critically assessed and compiled data on RALS outcomes, complications, and associated factors. **Results:** To date, numerous comparative studies have been conducted on pediatric RALS, with only one randomized and control trial investigating the nuances of robotic use against standard of care treatments. These robotic approaches have shown promise in post-surgical outcomes for pediatric patients undergoing upper and lower urinary tract reconstruction. Barriers to use still persist, however, showcasing a need to increase access to the technology, refine instruments for pediatric use, address cost barriers, and provide proper training for surgeons. **Conclusion:** RALS provides an opportunity to improve pediatric patient outcomes for numerous urologic complications. Additional studies are required to better compare the use of RALS with current standard practices. Due to the difficult nature of conducting randomized and control trials, additional prospective and observational studies are needed.

Key words: Heminephrectomy, Lower urinary tract reconstruction, Pediatric urology, Pyeloplasty, Robot-assisted laparoscopic surgeries, Ureteral reimplantation

INTRODUCTION

In recent years, there has been a significant increase in the use of robot-assisted laparoscopic surgeries (RALS) among pediatric patients.[1] These minimally invasive techniques have been used to successfully treat pediatric patients with urologic complications including pyeloplasty, radical and partial nephrectomy, ureteral implantation, bladder augmentation, and bladder neck reconstruction.[2] The use of these robots has been largely employed for more complex and technically demanding surgical cases, showcasing an advantage to more conventional surgeries.[3] With these technological advancements, surgeons are benefitting from stable magnified 3-D view, motion scaling, wristed capabilities, three dimensional options, and tremor filtration when compared to the conventional laparoscopy used to treat many of these urologic complications.[4,5] Meanwhile, patients benefit from less post-operative pain, small incision sites, shorter hospital stays and recovery time, and faster return to normal life.[6] Despite these advantages, the financial burden, steep learning curve, and lack of tailored pediatric instrumentation serve as barriers to the use of RALS in pediatric patients.[7]

Among elected procedures for pediatric patients, the use of RALS as a standard of care is quite limited.[8] The treatment of pediatric patients requires a deep understanding of the disease presentations among children and an appreciation of the smaller space, more delicate structures, and more intricate anatomy. In practice, the smaller size of pediatric patients can make the visualization of their anatomy more difficult during surgical cases.[1] This, paired with the difficulty of accessing specific locations within the pediatric anatomy, can make robotic surgeries more time consuming and prone to complications. Therefore, it is imperative to have well-trained, skilled, and experienced surgeons performing these procedures. In the previous studies that have examined the anatomic and physiologic differences in pediatric patients undergoing RALS, there is an evidence of differing

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management to better position and work on a smaller patient. These techniques have included adjustable robotic ports and linear movements of the robotic arm.[9] Other techniques for pediatric RALS have included increasing intra-abdominal space with bowel decompression, handling the tissue delicately, specific port placement, and patient positioning.[10] Given limited instrumental availability, additional adjustments are needed. At present, the robotic instrumentation used on pediatric cases is limited to the robotic instruments that are used on adult patients since surgical technology is not directly made for pediatric patients. The size of the surgical robots and their associated instruments is not usually fit for smaller patients, with robot manufacturer guidelines not achievable in patients with limited anatomic space.[11] The treatment of pediatric patients also requires a knowledge of the congenital urologic anomalies present in this population. The congenital anomalies for pediatric patients lend to increase need for surgical training among physicians. Additional trainings for robotic use, and for robotic use among small children, are necessary since complications may harm the child in a way that it may not do so for adult cases.[1]

At a physiological level, barriers to RALS use include a lack of haptic feedback, size and footprint of the robotic system, and an inability to make quick switch movements during the procedure.[5] Haptic feedback, the sensing of force feedback, tissue consistency, and instrument stress, is often lost in RALS.[12] This loss can delay surgical training and allows surgeons to be more prone to errors, facilitating damage to structures with rough handling. At a physiologic level, other challenges include anesthetic management in urologic surgeries that may impact respiratory, renal, and nervous system operations.[13] Anesthetic patient access in robotic-assisted surgeries can be complicated, with robotic instrumentation taking up space in the operating room and limiting access to the patient's venous system.[13] Further, patient positioning for RALS can lead to the upper airway and brain edema if the patient is at a steep inclination for a prolonged amount of time.[13] Cardiopulmonary complications may also arise with the use of RALS. Depending on patient positioning, these surgeries may lead to problems such as atelectasis and ventilation and perfusion mismatch.[13] Despite these needed adjustments and barriers, pediatric patients would benefit from RALS use due to the improvements in urologic reconstruction with RALS.[4] Further, the use of robotic-assisted pediatric urological surgery is ideal in procedural cases requiring more delicate suturing.[14] Pediatric use of RALS can prove beneficial to pediatric patients and should be more heavily researched to determine patient outcomes in comparison to more standard laparoscopic or open surgeries.

In this review, we aim to summarize the most recent literature regarding the use of RALS in pediatric urologic cases involving pyeloplasty, ureteral reimplantation, heminephrectomy, and lower urinary tract reconstruction. We hope to provide pertinent information regarding the current state of pediatric RALS use to drive innovation in addressing the barriers to access and improving on its benefits.

PYELOPLASTY

The use of RALS in pediatric patients was first seen in robot-assisted laparoscopic pyeloplasty (RALP) which have since become widespread. The procedure, which serves to correct ureteropelvic junction obstruction (UPJO), has a proven success rate among adult patients.[15] Since the early 2000s, researchers have conducted observational and comparative studies investigating robot-assisted, conventional, and open pyeloplasty in children. Findings from a meta-analysis conducted by Cundy *et al*. found overall success rates for RALP to be 99.3%–96.9% for standard laparoscopic surgeries.[16] The study found no statistically significant differences between the two procedures when queried for operative success, reoperation, conversion rates, post-operative complications, or urinary leaking complication rates.[16] Other studies have supported these important findings including a systematic review and meta-analysis conducted by Greenwald *et al*. in 2022. The study found that, overall, outcomes of the robotic intervention show high efficacy with low complications.[17] Additional retrospective studies comparing RALP and standard procedures have been done, showing success in RALP despite significantly longer operating times in the robotic group than the open repair approach in pediatric patients.[18]

In the past 5 years, there has been an increased reporting of robotic-assisted pyeloplasty in children which have utilized retrospective and prospective data. The majority of these studies have been retrospective case reviews which have showed the advantages of minimally invasive techniques and the high cost of the robotic approach.[19-21] A 2021 retrospective review comparing RALP and standard laparoscopic pyeloplasty in infants aged 12 months or less found that among the 46 infants, RALP was associated with shorter hospital length of stay than the standard (3 vs. 3.8 days; $P = 0.009$).[21] The review also found that 18% of standard laparoscopic pyeloplasty developed post-operative complications in comparison to 13% although the difference was not found to be statistically significant ($P = 0.49$).[21] The post-operative complications were mainly attributed to stents and were deemed to be mostly minor.[21] A 2020 study conducted by Andolfi *et al*. highlighted similar trends toward robotic pyeloplasty rather than standard laparoscopy among infants aged <12 months. Results from this study found that the success rates between the two approaches were comparable with 98.5% success for the robotic intervention and 96.9% for the standard laparoscopic intervention.[22] The study also found that there were lower complication rates in the robotic-assisted laparoscopy versus the standard laparoscopic intervention with rates of 7.2% and 14.3%, respectively.[22] Further, operative times in the study showed that there was an average improvement time of 25 min for the robotic-assisted surgery compared to the standard laparoscopy and that the length of stay was significantly shorter for the robotic assisted surgery compared to the standard with a cumulative average of 2.9 days compared to the 4.2 days for the standard.[22] A

Table 1: Summary of outcomes and overall complications in pediatric RALP

Study	Year	Study type	RALP success (overall) (%)	Complication rate (Type of complications) (%)	Pertinent findings
Murthy *et al.*[23]	2015	Retrospective review	94	13.5 (CDG III)	Operative times for RALP were significantly longer than open pyeloplasty but deceased with increasing experience There were no differences in postoperative administration of narcotics or duration of hospital stay compared to open pyeloplasty
Silay *et al.*[25]	2020	Prospective, randomized, and control trial	100	7.7 (CDG III)	The success and complicate rates were comparable between RALP and laparoscopic pyeloplasty Total operative time was shorter in RALP Total cost was higher in the RALP procedure than the laparoscopic pyeloplasty
Andolfi *et al.*[22]	2020	Systematic review	98.5	7.2 (overall)	RALP success rates were comparable to laparoscopic pyeloplasty There are conflicting results regarding robotic platform and costs RALP decreased operative times, had shorter length of stay, and lower complication rates than laparoscopic pyeloplasty
Kumar *et al.*[20]	2021	Retrospective and case series review	93.3	10 (overall)	The mean operative time was 148 min and the mean hospital stay was 3.5 days
Wong *et al.*[21]	2021	Retrospective review	96	13 (overall)	Operating time decreased with increasing case experience of RALP Length of hospital stay was significantly lower in RALP compared to laparoscopic pyeloplasty
Chandrasekharam and Babu[24]	2021	Systematic Review and meta-analysis	97.5	16 (overall)	There was no significant difference between RALP and laparoscopic pyeloplasty The duration of surgery was significantly higher in RALP than in the laparoscopic pyeloplasty
Greenwald *et al.*[17]	2022	Systemic review and meta-analysis	95.4	12 (overall)	There was no significant difference between success rates of laparoscopic pyeloplasty and RALP Surgical duration and overall complication were significantly higher in RALP The mean discharge time was lower in RALP

2015 study conducted by Murthy *et al*. examined robot-assisted laparoscopic and open pyeloplasty in children, showing similar benefits of the robotic approach.[23] In this study, researchers examined 52 patients in the RALP group and 40 patients in the open pyeloplasty group. Results showed that although operation times were longer in the RALP group (203.3 vs. 135.0 min, $P < 0.01$), increased experienced of the surgeons allowed for decreased times (r2 = 0.42, $P < 0.01$). The study also showed that no differences existed between the two groups in regards to narcotic administration ($P = 0.92$) or duration of hospital stay ($P = 0.93$).[23] A systemic review and meta-analysis conducted by Chandrasekharam and Babu in 2021 also assessed conventional laparoscopic versus RALP in infants.[24] As indicated by other studies, there appeared to be no significant difference between the conventional approach and the robotic approach in regards to success rates.[24] Duration of surgery was significantly higher for the robotic approach with 137 ± 45 min for the laparoscopic intervention and 179 ± 49 min for the robotic intervention ($P = 0.0001$). The time for discharge was higher for the conventional approach whereas the overall complication rate was higher for the robotic approach ($P = 0.03$) due to port-site hernias.[24] This is possibly due to learning curve of various surgeons across the board due to recent adoption.

To date, only a single, randomized, and control trial has compared standard laparoscopy and robotic-assisted pyeloplasty in children. The 2020 randomized trial conducted by Silay and colleagues made this comparison.[25] The trial included 53 patients with UPJO who had a mean age of 55.53 ± 57.25 months.[25] In this trial, researchers utilized the Anderson Hynes dismembered technique for both the standard laparoscopy and the RALP and the DaVinci Si Surgical System (Intuitive Surgical, CA, USA) was used for the robotic operation.[25] Patients in the study were followed up at 1-, 3-, 6-, and 12-month post-operation. Results from the randomized and control trial indicated a longer mean total operative time in the laparoscopic group (139.26±43.21 min) than in the RALP group (105.19±22.87 min).[25] The total cost of RALP was also found to be 4 times greater than the standard laparoscopic procedure despite comparable success rates and complications.[25] Further, no differences were found in post-operative analgesia requirements and mean length of hospital stays.[25] Given that only a single study has used a randomized and control trial approach to understanding RALPs, an increased amount of research is needed to better understand possible outcomes.

Despite limited new randomized and control trials on the outcomes associated with RALPs, there has been an

Table 2: Summary of outcomes and overall complications in pediatric RALUR

Study	Year	Study type	RALUR success (indicated by radiographic resolution) (%)	Complication rate (Type of complications) (%)	Pertinent findings
Gundeti *et al.*[34]	2016	Prospective review	82	0	There are no standardized techniques to for RALUR but they are needed and came up with LUAA
Bowen *et al.*[38]	2016	Retrospective review	NR	NR	Treatment of primary vesicoureteral reflux with ureteral reimplantation is decreasing but use of RALUR is increasing in relation to open reimplantation
Herz *et al.*[40]	2016	Retrospective analysis	100	25 (overall)	Robotic approach offers improved operative times than the open and pure laparoscopic approaches. The robotic approach is more susceptible to complications in comparison to the open approach.
Boysen *et al.*[37]	2018	Prospective and multicenter study	93.8	5.6 (CDG III)	The use of RALUR is comparable to the contemporary open series
Koehne *et al.*[36]	2020	Retrospective review	100	0	The use of RALUR is technically feasible for the treatment of complex congenital bladder diverticula
Carbonara *et al.*[35]	2021	Comparative study	NR	33.3 (overall)	RALUR has significantly shorter operation time and estimated blood loss compared to the open ureteral reimplantation RALUR had a significant difference in length of stay and median catheter removal compared to open ureteral reimplantation

Table 3: Summary of outcomes and overall complications in pediatric robot-assisted partial and heminephrectomies

Study	Year	Study type	Success (overall)	Complication rate (Type of complications) (%)	Pertinent findings
Malik *et al.*[44]	2015	Retrospective chart review	NR	13 (CDG III)	Robot-assisted laparoscopic heminephrectomy surgeries have comparable outcomes with open and laparoscopic heminephrectomies in regard to complication rates and renal function
Ballouhey *et al.*[45]	2017	Retrospective study	NR	13.3 (Overall)	Robot-assisted heminephrectomies offer comparable renal outcomes with open surgery
Buse *et al.*[46]	2018	Comparative study	NR	23.3 (Overall)	Robot-assisted partial nephrectomies had a lower cost and fewer perioperative complications than open partial nephrectomies
Varda *et al.*[49]	2018	Retrospective and cohort study	NR	11 (Overall)	The robotic approach has shorter length of stays compared to the open approach The robotic approach had a similar median operation time and safety outcomes compared to the open approach
Zeuschner *et al.*[43]	2021	Longitudinal comparison	NR	NR	Robot-assisted partial nephrectomy surgery had fewer complications, less blood loss, and shorter length of stay than open partial nephrectomies Robot-assisted partial nephrectomy surgery had higher complications for the first 4 years due to the learning curve

interest in better understanding the learning curve associated with these new techniques. A 2021 study conducted by Spampinto assessed the learning curve of RALP use between senior and junior surgeons at three pediatric surgery centers between November 2007 and November 2018.[26] The surgical procedure for this study included a transperitoneal Anderson-Hynes dismembered pyeloplasty and the evaluation of competence by the surgeons was defined by operating time, complications present, and surgical success.[26] Results from the study indicated that there was no overall difference in the mean composite factor of the two groups with the senior surgeons having a composite of 220.6 ± 13.2 and the junior surgeons having a copositive score of 207.4 ± 18.7 (P = 0.48).[26] In 2018, a study conducted by Kassite *et al.* found that more than 41 cases are needed in RALP to achieve mastery of the procedure among surgeons.[27] A 2021 study built on this assumption, assessing whether the previous experience in open and laparoscopic surgeries may shorten the

Table 4: Summary of outcomes and overall complications in pediatric robot-assisted lower urinary tract reconstruction

Study	Year	Study type	Success (overall)	Complication rate (Type of complications)	Pertinent findings
Murthy *et al.*[59]	2015	(RALI) Retrospective	88.2%	64.7% (overall)	RALI had a significantly longer operative time compared to the open approach RALI had a shorter median length of stay RALI and the open approach had similar increases in bladder capacity, narcotic use, and complication rates
Chung *et al.*[57]	2015	(APV) Description of technique	100%	33% (overall)	Robotic APV resolved all of the APV leakage
Grimsby *et al.*[61]	2016	(BNR) Retrospective	58%	16% (overall)	Robotic bladder neck procedures were significantly longer in the robotic group and had longer operative times Robotic approach does not result in increased complications or length of stay
Gargollo and White[60]	2019	(BNR) Review	NR	NR	Robotic bladder neck procedures can be used to create equivalent continence rates Robotic bladder neck procedures have improved cosmesis, less intraoperative blood loss, and less post-operative pain. Robotic bladder neck procedures have longer operative times
Adamic *et al.*[53]	2020	(RALI) Retrospective review	83.3%	35% (Overall)	RALI has similar outcomes and complications compared to the open ileocystoplasty approaches RALI had a decreased length of stay but longer operative time compared to the open approach
Rodriguez *et al.*[54]	2020	(BNR) Case study	100%	0% (Overall)	Robotic bladder neck reconstruction with APV was an effective treatment for a neurogenic bladder pediatric patient
Juul *et al.*[58]	2022	(APV) Case review	NR	40% (Overall)	Operating time between the robotic APV was comparable to the open procedure Robotic APV had a shorter length of stay than the open approach Stomal continency was similar in both the robotic and open APV approaches

BNR: Bladder neck reconstruction, APV: Appendicovesicostomy, RALI: Robotic-assisted laparoscopic augmentation ileocystoplasty

learning curve associated with RALP in children.[28] Results from this study indicated that the previous experience may be a contributing factor to the shorter learning curve of RALP.[28]

The use of RALP is promising among pediatric patients with clear advantages over open pyeloplasty and comparable outcomes with standard laparoscopic techniques, as seen in Table 1. Additional standardized and control trials are needed to further prove these advantages and to determine if the promise of RALP measures up to the high cost of the procedure. Existing research conducted by Bennett Jr. *et al*. showed that although RALP is more expensive, the rate of complications and shorter length of stay cut down on some of the expenses.[29] Additional work to cut down on the costs of the operating room and on the anesthesia utilized could further bring down costs of RALP.[29] Further, the disruptive technology phenomena will reduce the capital cost of the machine through supply and demand.

URETERAL REIMPLANTATION

Ureteral reimplantation is a widely used surgical technique to treat vesicoureteral reflux.[30] Robot-assisted laparoscopic ureteral reimplantation (RALUR) has been in use since 2004 and has shown a steady increase in use for its minimally invasive advantages.[31] The Lich-Grégoire procedure, a technique often used to treat vesicoureteral reflux in conjunction with laparoscopy, has shown a high rates of success as well as less complications.[32] This technique, however, has also shown a need for advanced laparoscopic skills, particularly with intracorporeal suturing and night tying, as well as sub-par ergonomics for the surgeon.[33] To optimize this technique and that of RALUR, a 2016 study conducted by Gundeti *et al*. sought to standardize RALUR techniques by introducing the LUAA technique stands for the length of the detrusor tunnel (L), the use of a U stitch (U), the placement of permanent ureteral alignment suture (A), and the inclusion of ureteral adventitia (A) in detrusorraphy.[34]

The previous studies into RULAR have found positive outcomes of the procedure in comparison to open ureteral reimplantation. A single-center and comparative study conducted by Carbonara and colleagues in 2021 assessed outcomes of open ureteral reimplantation to robot-assisted ureteral reimplantation.[35] The study, which had 21 patients who underwent RALUR and 28 patients who had the open operation, found that there was a significant difference in favor of RALUR for median operating time (216 vs. 317 min,

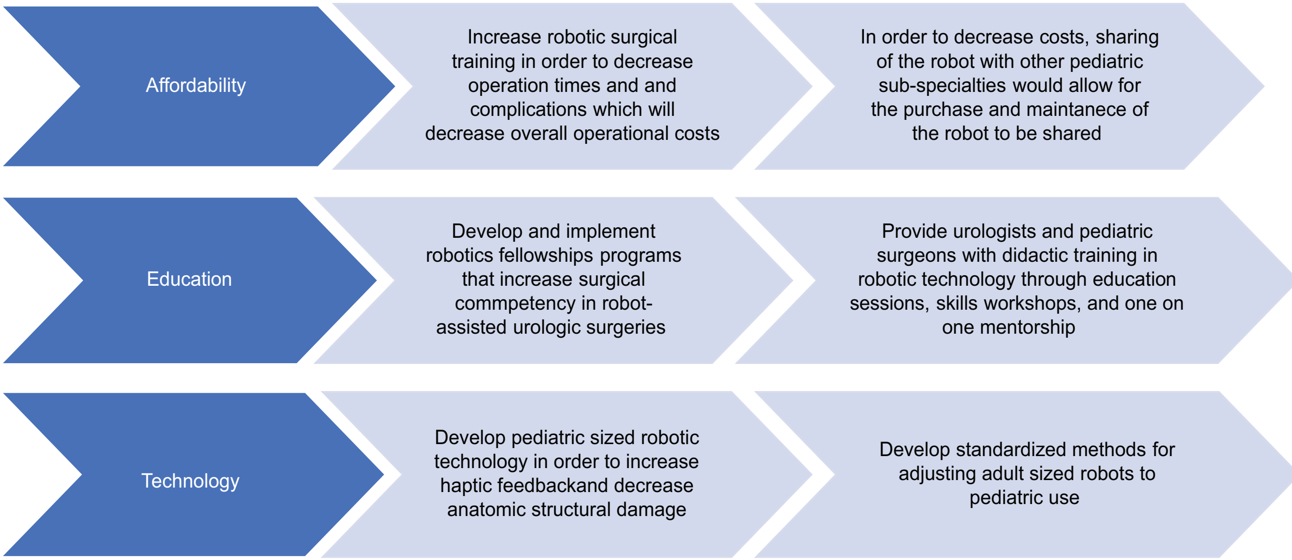

Diagram 1: Future directions for better access and use of robotic-assisted laparoscopic surgeries in pediatric urology patients

$P = 0.01$) and median blood loss (35 vs. 175 mL, $P = 0.001$).[35] It also found that the median length of stay was shorter for the robotic procedure (2 vs. 6 days; $P = 0.001$), as well as median catheterization time (16 vs. 28 days; $P = 0.005$).[35] Among pediatric patients, a 2020 study conducted by Koehne *et al*. assessed the use of RALUR in a 7-year-old male who needed a synchronous dismembered extravesical ureteral reimplantation.[36] The RALUR resulted in no intraoperative complications, resolution of the diverticulum, and minimal blood loss.[36] Researchers in this study note that among pediatric patients undergoing RALUR, it may be beneficial to perform a cystoscopy before the robotic portion, use traction suture in the ureter, and place a "hitch stitch" to suspend the bladder during reimplantation.[36] Overall, patient success rate in pediatric RALUR remains high, with a rate of 92% across 22 studies between 2008 and 2019.[33] Although treatment for vesicoureteral reflux remains relatively uncommon, RALUR is seen as a first line surgical approach but not without its caveats.[33] A similar multicenter study conducted by Boysen *et al*. in 2018 showed the radiographic resolution of vesicoureteral reflux with robot-assisted laparoscopic extravesical ureteral reimplantation.[37] This prospective and multicenter study had 143 patients who were treated with RALUR and a radiographic success rate of 93.8%.[37] In total, 8 patients (5.6%) experienced CDG Type III complications but only five of these complications were connected to the robotic approach with the other three being attributed to an incisional hernia and sequelae of defective equipment.[37]

Like the previously discussed use of RALP in pediatric patients, the use of RALUR has mixed reviews. A 2016 study conducted by Bowen *et al*. sought to characterize the use of this procedure, in comparison to open and laparoscopic procedures among 14,581 ureteral reimplantations.[38] In the study, the mean length of hospitalization was 1.6 ± 1.3 days for RALUR and 2.4 ± 2.6 for open reimplantation ($P < 0.0001$). The median charges for these procedures were $22,703 for open and $32,409 for RALUR ($P < 0.0001$).[38] Like RALP, RALUR has shown promise of decreased hospitalization but at a greater procedural cost which serves as a barrier to its use. Despite this general rule of thumb, a 2020 study conducted by Elizondo found that although operating room charges were higher for patients undergoing RALUR, the shorter hospital stay length lead to no significant differences in total overall charges.[39] Benefits to its use in pediatric cases have not only included shorter operative times than the Liche-Gregoire procedure, but also a potential use for duplex renal systems.[33] Further, a shortened learning curve due to the possibility of two consoles in the operative theater allows for less experienced surgeons to work with expert proctors in ureteral reimplantation.[33] As outlined in Table 2, the use of RALUR can be beneficial to both the patient and to the surgeon but it must be balanced with the high cost of the procedure.

PARTIAL AND HEMI-NEPHRECTOMIES

Heminephrectomies, the removal of part of a kidney which is non-functional, have both risks and rewards in pediatric patient populations. The use of laparoscopic heminephrectomy in pediatric populations has been reviewed in recent years, pointing to successful use of the minimally invasive technique and its challenges. The previous research has shown that the use of laparoscopic heminephrectomy surgical techniques has led to complications including severe loss of function in remaining moiety in some pediatric patients.[41] Laparoscopic techniques in this population requires extreme diligence especially with small infants and children with dilated collecting systems which can lead to vascular damage to the remaining moiety.[42] The use of robot-assisted partial nephrectomies was largely studied in a 2021 meta-analysis, showing the advantages and disadvantages of the procedure in adult patients. Overall, the study by Zeuschner *et al*. found that the robot-assisted partial nephrectomy had fewer complications, less blood loss, and shorter length of stay than the open surgery.[43] On the other hand, these procedures had a large learning curve which were attributed to the higher complications in the first 4 years, although they were subsequently reduced.[43] These advantages and disadvantages point to a greater need to understand their implications in pediatric patients.

As of late, the use of pediatric robot-assisted laparoscopic heminephrectomies (RAL-HN) has increased and garnered greater attention. In a 2015, Malik *et al*. compared renal and clinical outcomes of RAL-HN with open and laparoscopic procedures.[44] In this study, seen in Table 3, sixteen children had RAL-HN. Researchers pointed to the advantages of RAL-HN use in pediatric cases, showing that it allows for easy identification of the ureters, reduced risk of resultant ischemic damage, and reduced traction on vasculature.[44] Further, the use of RAL-HN allowed for improved dexterity and magnification.[44] Other advantages of RAL-HN were found in a study among 15 small children who underwent robot-assisted heminephrectomy. The study, like those of the robot assisted pyeloplasty and ureteral reimplantation, found that the mean hospital stay was statistically longer for patients in open surgeries (6.3 days, range 5–8 days vs. 3.4 days, range 1–7 days; $P < 0.001$).[45] It also found that total post-operative morphine use was statistically larger for patients in the open surgery group (0.52 mg/kg/day vs. 1.08 mg/kg/day; $P < 0.001$).[45] The study did not, however, find differences in operating times that were seen in the aforementioned operations.[45]

Like the previously analyzed robotic-assisted surgeries, the use of robot-assisted partial nephrectomies is often criticized for its high cost. Disputes regarding its cost effectiveness have been noted, with some centers reporting higher costs than open surgeries whereas others report lower costs.[46] A 2018 study conducted by Buse *et al*. assessed these costs with an understanding that patients with and without complications should be differentiated. The study found that mean in-hospital costs were $14,824 (95% CI $13 368–$16 898) for the robotic procedure and $15,094 (95% CI $13 491–$17 140) for OPN and that perioperative complications occurred in of 23.3% (95% CI 20.0–25.8%) of the patients after the robotic surgery and in 36.1% (95% CI 35.6–36.6%) after the open surgery.[46] This study shows that lower costs in hospital stays and complications can lead to lower total costs in patients undergoing robot-assisted partial nephrectomies.[46] Although this study found reduced costs, there exist conflicting data that point to higher costs for robotic surgeries. Mir *et al*. found that both laparoscopic and open partial nephrectomies were more cost effective than their robotic counterparts.[47] Laydner and colleagues found similar findings, showing that robotic partial nephrectomies had higher costs than laparoscopic surgeries with slightly higher costs than open surgeries.[48] Additional studies are required to better understand the factors that influence cost of robot assisted partial nephrectomies in different institutions.

LOWER URINARY TRACT RECONSTRUCTION

Augmentation cystoplasty (AC) is a common treatment for neurogenic and other bladder conditions among children. A 20-year review conducted by Taghavi *et al*. indicates that although the operation provides urodynamic improvements, it also carries substantial chronic morbidities.[50] The associated complications include bladder urolithiasis, symptomatic UTIs, reservoir perforations, and malignant transformation.[50] AC is usually done in conjunction with other operations to use the same cuts for all procedures. An appendicovesicostomy (APV), also known as a Mitrofanoff Procedure, is usually paired with AC. In a study conducted by Lefevre in 2018, researchers conducted a retrospective study on 34 pediatric patients. Results from this study showed a 50% of complication percentage and a 38% of surgical revision percentage.[51] APV has also been paired with bladder neck reconstruction, which often serves as a surgical intervention for urinary incontinence. The high-risk nature of complications for both AC and APV has pointed to a need for better approaches for these treatments, as seen in Table 4.

Robotic-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff APV (RALIMA) has been used as a new approach for AC and APV in a pediatric population since first description by Gundeti *et al*. 2010.[52] In a study conducted by Gundeti *et al*., researchers examined six pediatric patients with neurogenic bladder secondary to spina bifida.[52] Patients presented with constipation, incontinence, and recurring urinary tract infections.[52] Further, patients also had previously failed at anticholinergic therapy and clean intermittent catheterization.[52] Results from this study showed no interoperative complications, but it did show a single post-operative wound infection, a venous thrombus, and a unilateral lower extremity paresthesia that has since resolved.[52] In a study conducted by Adamic *et al*. in 2020, 24 pediatric patients undergoing robot-assisted laparoscopic augmentation ileocystoplasty (RALI) were assessed.[53] Of the 24 patients, 20 dually underwent APV while 30% underwent a bladder neck procedure.[53] Results of the study showed a mean operative time of 573 min, a mean change in bladder capacity of 244% postoperatively, and a 35% of patients obtaining complications.[53] Similarly, robot-assisted bladder neck reconstruction with Mitrofanoff APV has been studied. A 2020 study conducted by Rodriguez *et al*. assessed the results of a bladder neck reconstruction with APV in a 7-year old patient with neurogenic bladder.[54] In this patient, no complications were reported and operative time was 5 h with an estimated blood loss of 50 mL.[54] RALIMA showed feasibility and effectiveness in AC, APV, and bladder neck reconstruction.

APV

Robot-assisted laparoscopic Mitrofanoff APV (RALMA) in pediatric patients has been used more recently in the field of urology. The use of this approach has allowed for surgeons to have fine suturing and precise dissection under magnified vision which has allowed for positive outcomes in a complex reconstructive urinary tract surgery.[55] Initial studies into the robotic approach have found it to have comparable outcomes to the open appendicoveiscostomy.[55] Outcomes of RALMA among pediatric patients in a 2013 study show a mean operative time of 494.1 with a mean hospitalized stay of 5.2 days.[56] The continence rate was 94.4% with a 27.8% of complication percentage.[56] Among pediatric patients who underwent robotic APV revision, the median operative time was 165 min with blood loss of ≤5mL.[57] APV leakage was solved for all of the patients.[57] In comparison to open APV, the robotic approach in a 2022 study showed that there was a significantly shortened post-operative length of stay and a comparable 1-year complication rates to the open approach.[58] The open and robotic APVs also had similar reinterventions and stomal stenosis.[58] A 2016 study by Gundeti *et al*. also showed the functional outcomes for pediatric APV. This multi-institutional study showed that for robotic APV, the length of stay was 5.2 ± 2.8 days and that operative times were 424 ± 120 min. There was an initial success rate of 85.2% and with additional procedures, a success rate of 92%. This study showed a robotic APV complication rate of 29.5%.

Cystoplasty

Like its counterparts, robotic cystoplasty had similar outcomes than the more conventional approach. A 2015 study conducted by Murthy reviewed series of 17 pediatric patients undergoing RALI compared to 13 pediatric patients with open augmentation ileocystoplasty.[59] Results of this study showed that the median operation time was longer when compared to their own for the robotic intervention in comparison to the open approach (623 vs. 287 min; $P < 0.01$),[59] though a national standard for open surgery time is not available. The median length of stay was shorter in the robotic approach in comparison to the open approach (6 vs. 8 d; $P = 0.01$).[59] Outcomes of the procedures, increase in bladder capacity, narcotic use, and complication rates were not different between the robotic or open approaches.[59]

Bladder Neck Reconstruction

Research into robotic-assisted bladder neck procedures in children with neurogenic bladder and incontinence has been limited but has increased in recent years. A study conducted by Gargollo and White examined the outcomes of robotic-assisted bladder neck procedures in 2019. The systematic review by Gargollo and White assessed published articles in the past 20 years and showed robotic-assisted approaches had longer operative times, largely impacted by the experience of the surgeons.[60] Results also indicted that those robotic approaches had lower intraoperative blood loss, improved cosmesis, and a decrease in intra-abdominal adhesion formation.[60] In comparison to the open surgeries, the robotic procedures had comparative continence rates.[60] The robotic approach for bladder neck procedures proves useful for increased magnification and dexterity and can be used for pediatric patients.[61]

FUTURE CONSIDERATIONS

The use of robot-assisted laparoscopies in pediatric cases of pyeloplasty, ureteral implantation, partial and hemi-nephrectomies, and lower urinary reconstruction has shown promise in the past 10 years. With the increasing use of these techniques, surgical training is necessary to match increased use. In particular, hands-on training can accompany the existing training courses and online modules. Through a 5-day mini-fellowship training program at our institution, surgeons have gotten training in robotic pediatric upper and lower urinary tract surgery.[62] The training fellowship was designed for fully-trained pediatric surgeons and urologists and requires mentor-preceptor-proctor experiences with one to one teacher and attendee ratios.[62] The fellowship includes did active tutorial sessions, skills training, animal model training sessions, and operating room observations. Outcomes from this program showed that didactic training allows for surgeons to incorporate robotic use into their practice although additional training through an outfitted robotic laboratory would allow for greater comfort and increased practice.[62] Other programs have also found the importance of dedicated training for robotic-assisted surgeries in pediatric urology. Requirements for the surgeries, at times, necessitate mandated completion of online modules before skill training and peer—peer training.[63] In these programs, hands-on training was found to be incredibly useful and important for participants.[63] These training sessions and programs can provide increased benefit to the field growing field of pediatric urology. By cutting down the learning curve for pediatric surgeons and urologists, the operative time can decrease which works to decrease operative costs in robotic-assisted urologic surgeries. Given the current high cost of the technology, these dedicated training sessions can dually serve as an intervention to increase accessibility.[63]

With the increased use of RALS, the future of surgical care will be based on machine learning, augmented reality, and 3D printing. These technological advancements will allow surgeons to have increased precision during operations, better health outcomes, and less complications. The benefits of these technologies will be largely based on the ways in which clinicians are trained to use them and how accessible these technologies will be. The future of digital surgery is here to stay and will likely progress to the practice of remote surgery. The use of robots in transprovidence and transatlantic surgeries has already risen in recent years, with surgeons performing transatlantic operations using fiber optics in 2001.[64] Other telesurgery operations have been done, showing that these types of operations can be carried out successfully and without severe complications.[65] The use of these robots in remote areas, or among surgeons who do not have certain expertise, can be beneficial for a wide array of patients. With universal availability through cost-sharing and increased use to drive down prices, the future of surgery can benefit greatly from robotics. The future of surgery can benefit greatly from robotics, as outlined in Diagram 1.

CONCLUSION

In this review, we outlined the current state of affairs in robot-assisted laparoscopic urology procedures among pediatric patients. These minimally invasive techniques have shown great promise in recent years, garnering more use and equivalent outcomes to the previous standards of care. The robotic surgeries have shown advantageous characteristics, including stable magnified 3D view, motion scaling, wristed capabilities, three dimensional options, and tremor filtration when compared to the conventional laparoscopy. These surgeries have also shown disadvantages, mainly in cost. To better understand the use of robotic technologies in pyeloplasty, ureteral reimplantation, and partial and hemi-nephrectomies, additional studies must be conducted. In particular, randomized and controlled trials should be utilized to determine efficacy, complications, and outcomes in these procedures. With additional technological advancements to come in the following years, embracing new technologies for the treatment of pediatric patients in urology is needed.

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