Review Article

Pediatric robotic urologic procedures: Indications and outcomes

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ABSTRACT

Introduction: Robotic-assisted laparoscopic surgery (RALS) has revolutionized minimally invasive surgery in pediatric urology. The robotic platform allows surgeons to maintain the benefits of laparoscopic surgery while having enhanced three-dimensional view, dexterity, range of motion, and control of high-resolution cameras. In this review, we summarize the indications and recent outcomes for various pediatric urologic RALS procedures to illustrate the current state of robotics in pediatric urology.

Methods: We systematically searched the PubMed and EMBASE databases. We extrapolated and summarized recent evidence on RALS in pediatric urology patients, with an emphasis on indications and outcomes, with regard to the following procedures and search terms: pyeloplasty, kidney stone surgery, partial nephrectomy, nephroureterectomy, ureteral reimplantation, appendico-vesicostomy, augmentation cystoplasty, bladder neck reconstruction, and Malone antegrade continence enema. Additional Medical Subject Headings terms used to augment the search included "Treatment Outcome" and "Robotic Surgical Procedures."

Results: Increasing usage of RALS has shown many benefits in perioperative and postoperative outcomes. In addition, there is growing evidence that robotic procedures in pediatric urology result in similar or better surgical outcomes when compared to the standard of care.

Conclusions: RALS has shown considerable effectiveness in pediatric urologic procedures and may achieve surgical outcomes comparable to the standard approaches of open or laparoscopic surgery. However, larger case series and prospective randomized controlled trials are still necessary to validate the reported outcomes, in addition to cost analyses and studies on the surgical learning curve. We believe that the continuous evolution of robotic platforms will allow for enhanced care and quality of life for pediatric urology patients.

INTRODUCTION

The introduction and advancement of robotic-assisted surgical systems have revolutionized minimally invasive surgery in pediatric urology. By utilizing this surgical platform, surgeons maintain the benefits of laparoscopic surgery while having the additional advantages of added dexterity, greater range of movement, enhanced three-dimensional visualization, and increased control of high-resolution cameras.[1] With the advancement of robotic-assisted laparoscopic surgery (RALS), minimally invasive techniques for urologic surgeries have evolved greatly over the past couple of decades, especially in the United States and parts of Europe.

Moreover, RALS has been adopted and optimized for pediatric urologic patients in recent years.[2] The advantages of RALS make this technology ideal for children who require major reconstructive procedures, as this system is able to generate fine movements in limited working spaces.

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Since the initial implementation of RALS for pyeloplasty in pediatric patients, several robotic procedures, including complex reconstructive cases, have been established in the practice of pediatric urologists. This has yielded a growing body of literature on favorable perioperative and postoperative outcomes and patient satisfaction compared with traditional surgical approaches.

In this review, we summarize the indications and outcomes for various pediatric urologic RALS procedures to illustrate the current state of robotics in pediatric urology with a focus on the recent advances in literature.

METHODS

A systematic search of the PubMed and EMBASE databases was performed. Recent evidence on indications and outcomes for RALS in pediatric urology patients was extrapolated and summarized for the following procedures: pyeloplasty, kidney stone surgery, partial nephrectomy and nephroureterectomy, ureteral reimplantation, appendico-vesicostomy, augmentation cystoplasty, bladder neck reconstruction (BNR), and Malone antegrade continence enema (MACE). Additional Medical Subject Headings terms used to augment the search included "Treatment Outcome" and "Robotic Surgical Procedures."

PYELOPLASTY

The gold standard for surgical treatment of ureteropelvic junction obstructions (UPJOs) is open pyeloplasty, but laparoscopic pyeloplasty has been widely accepted since the 1990s and has become the preferred surgical approach.[2,3] Even more recently, robotic-assisted laparoscopic pyeloplasty has garnered significant attention since 2005.

Early retrospective studies within the first 10 years of introducing RALP demonstrated the procedure's safety and feasibility in pediatric patients [Table 1]. While studies showed longer operative times for RALP, durations decreased with surgeon experience.[4] A meta-analysis by Cundy *et al.* analyzing 12 studies comparing RALP to open or laparoscopic pyeloplasty reported that RALP may offer shorter length of stay (LOS), lower estimated blood loss, and lower analgesic dosing at the expense of higher operating cost and longer operating time.[5] More recent studies from the past 5 years have continued to show that RALP is comparable to the alternative approaches [Table 1], and has been suggested by some groups as a universal approach for pediatric patients with UPJO.[6]

RALP in infants has been less well studied. Infant RALP is comparable to both open and laparoscopic pyeloplasty [Table 1].[7,8] Andolfi *et al.* followed 44 infants who underwent RALP for UPJO and found that at a median follow-up of 19 months, the success rate was 100%.[9] To date, the largest study of infant RALP included 60 subjects and found a 91% success rate in reducing hydronephrosis.[10] Further studies have considered the impact of age and weight on RALP patient outcomes, finding no significant disadvantage in younger or lighter patients.[11,12]

Current literature demonstrates that RALP operative time decreases with surgical experience, with operative time decreasing after 15–41 cases.[13-15] Operative times have been estimated to decrease by approximately 4 min per case until a plateau is reached.[13] Previous experience in open or laparoscopic pyeloplasty may streamline the learning curve.[16] Interestingly, in a recent study on the learning curve of infant RALP, Andolfi *et al.* reported that a plateau in operating time is achieved after 13 cases, followed by additional improvement at 37 cases.[17]

As RALP continues to gain popularity, careful cost analysis are needed to aid institutions in considering the adoption of such an expensive technology. Studies have found that RALP can be $1060–$4000 more expensive than open pyeloplasties when considering the patient's operative and postoperative course.[18] The major cost contributors in the setting of pediatric pyeloplasties are operating room (OR) use, equipment costs, and room and board.[18,19] While RALP has major advantages in room and costs related to stay in hospital, expenses for OR use and equipment are significantly higher than open pyeloplasties. Of note, these studies may also not consider personnel training, maintenance, and initial costs to setup new equipment. Thus, RALP may only be cost-effective in high-volume experienced surgical centers.

KIDNEY STONE SURGERY

Rates of nephrolithiasis in the pediatric population have risen over the last decade, with an estimated increase of 4%–10% annually in the United States.[20] According to the American Urological Association and Endourological Society Guidelines, ureteroscopy, retrograde intrarenal surgery, and extracorporeal shock wave lithotripsy (ESWL) are considered for smaller stones, whereas ESWL, and percutaneous nephrolithotomy are standard for larger stones.[21,22] While RALS is not standard treatment, such interventions remain options for patients with more complex diseases.[22]

Robotic removal of kidney stones has been studied in the adult population, but literature remains scarce for the pediatric cohort.[2] As of 2019, there was only one study dedicated to RALS of stone disease in children.[22] Since then, only a handful of studies and case reports on robotic-assisted nephrolithotomies have been published.[23-26] Roth *et al.* conducted a multi-institutional retrospective review of 26 children who underwent endoscopic-assisted robotic pyelolithotomy (EARP).[23] Overall stone-free status was

Table 1: Summary of pyeloplasty primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
Pediatric pyeloplasty									
Minnillo *et al*.	2011	155	155	-	-	Retrospective	198.5 min (±70)	-	-
Singh *et al*.	2012	34	34	-	-	Retrospective	105 min (75–190)	-	-
Atug *et al*.	2005	7	7	-	-	Retrospective	184 min (165–204)	-	-
Murthy and Gundeti	2015	92	52	40	-	Retrospective	203 min (181–226)	135 min (126–144)	-
Song *et al*.	2017	70	10	30	30	Retrospective	254 min (±46.0)	192 min (±67.1)	197 min (±38.9)
Cohen *et al*.	2021	194	100	72	22	Retrospective	80 min (±28.5)	-	-
Silay *et al*.	2019	53	26	-	27	Retrospective	105.19 min±22.87 (70–150)	-	139.26 min±43.21 (80–250)
Chan *et al*.	2017	2219	633	1540	46	Retrospective (multicenter database)	-	-	-
Kawal *et al*.	2018	104	104	-	-	Retrospective	197 min (median) (IQR 164–229)	-	-
Infant pyeloplasty									
Bansal *et al*.	2014	70	9	61	-	Retrospective	115 min (median) (95–205)	166 min (median) (79–300)	-
Neheman *et al*.	2018	34	21	-	13	Retrospective	156 min (median) (125–249)	-	192 min (median) (98–229)
Andolfi and Gundeti	2021	44	44	-	-	Retrospective	142 min (±25)	-	-
Avery *et al*.	2015	60	60	-	-	Retrospective	232 min (±43)	-	-
Kafka *et al*.	2019	30	15	15		Retrospective	67.8 min (±13.4)	66.5 min (±13.4)	-
Kawal *et al*.	2018	34	34	-	-	Retrospective	186 min (median) (IQR 171–230)	-	-

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic) (%)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic) (%)	Follow-up time
Pediatric pyeloplasty										
Minnillo *et al*.	1.95 days	-	-	96	-	-	11	-	-	31.7 months
Singh *et al*.	2.5 days (2–5)	-	-	97	-	-	9	-	-	28.5 months
Atug *et al*.	1.2 days (1–3)	-	-	86	-	-	0	-	-	10.9 months
Murthy and Gundeti	2.6 days (2.3–3)	2.6 days (1.8–3.4)		94	100		13	5		14 months (RALP); 23 months (open)
Song *et al*.	3.2 days (±1.0)	6.6 days (±1.5)	5.8 days (±1.4)	100	96.70	89.70	10	13	13.3	16.6 months (RALP); 49 months (open)
Cohen *et al*.	1.1 day (±0.35)	-	-	98	-	-	6	-	-	6 months
Silay *et al*.	28 h (±12.36)	-	32 h (±14.88)	100	-	93	7.70	-	7.50	12.43 months
Chan *et al*.	1.8 days	2 days	2.4 days	-	-	-	2.10	2.20	3	-
Kawal *et al*.	1 day (median) (IQR 1–1)	-	-	96	-	-	30.8 (median)	-	-	8.3 months

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Table 1: Contd...

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic) (%)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic) (%)	Follow-up time
Infant pyeloplasty										
Bansal *et al*.	1 day (median) (1–2)	3 days (median) (1–7)	-	100	98	-	33	6.50	-	10 months (RALP); 43.6 months (open)
Neheman *et al*.	1 day (median) (1–3)	-	7 days (median) (7–12)	95	-	92	23.80	-	30.80	11.5 months (RALP); 5.5 months (laparoscopic)
Andolfi and Gundeti	1.4 days (±0.7)	-	-	100	-	-	15.60	-	-	19 months (median)
Avery *et al*.	1 day (1–2)	-	-	91	-	-	10	-	-	12 months (median)
Kafka *et al*.	1 day (median) (1–2)	2 days median (2–3)	-	100	93.30	-	6.70	6.70	-	6 months (at least)
Kawal *et al*.	1 day (median) (IQR 1–1)	-	-	96	-	-	29.40	-	-	8.3 months

Mean outcomes with range/SD are shown unless otherwise listed. SD=Standard deviation, LOS=Length of stay

approximately 70% and rose to 96.3% after secondary treatment. The authors concluded that in select individuals with concomitant UPJO or altered anatomy, the EARP technique is viable and results in low complication rates and high stone-free rates. Similarly, in an international multi-center retrospective study of 15 children, the authors concluded that in select patients, robotic-assisted stone removal is feasible, effective, and safe.[24] Studies with larger populations and longer follow-up will help to elucidate the role of RALS in stone management.

PARTIAL NEPHRECTOMY AND NEPHROURETERECTOMY

Partial nephrectomies and nephroureterectomies may be indicated for patients with anatomic kidney anomalies with nonfunctioning moiety or segment such as horseshoe or duplex kidney, as well as patients with kidney tumors.[27] While robotic-assisted laparoscopic partial nephrectomy (RALPN) is widely accepted in the adult population, Lee *et al*. were the first to report the feasibility and safety of RALPN in a cohort of nine pediatric patients who presented with functional and anatomical malformations of the kidney.[27] Since this initial study, larger studies on RALPN in the setting of pediatric duplex kidneys have been published [Table 2].

Comparative studies have also been completed on RALPN versus open partial nephrectomy and laparoscopic partial nephrectomy.[28,29] Studies have found that while patients who undergo open partial nephrectomy have significantly shorter operative times, they also experience significantly larger volumes of blood loss, longer postoperative hospital stays, and higher morphine and acetaminophen intake than those who undergo more minimally invasive procedures.[28,29]

The utilization of RALPN in the setting of pediatric malignant renal tumors is also being investigated in its early stages. Blanc *et al*. reported the initial results of utilizing RALPN and RALN in ten pediatric patients (nine with Wilms' tumor and one with renal sarcoma) at a high-volume pediatric care center.[30] Three of ten cases were converted to open technique, complete removal of the tumor without rupture was achieved in all cases, and all patients had an uneventful postoperative course. Compared to the open surgery cohort, there was no difference in operative time, but the median tumor volume was smaller and hospital stay was shorter.

Nephroureterectomy is a procedure similar to partial nephrectomy, but with the additional removal of the ureter. To date, there is only one study on the outcomes of pediatric robotic-assisted laparoscopic nephroureterectomy (RALNU).[31] Bansal *et al*. compared RALNU to laparoendoscopic single-site nephroureterectomy in 32 pediatric patients and reported that RALNU had longer operative times but comparable postoperative narcotics

Table 2: Summary of partial nephrectomy primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
Partial nephrectomy for duplex system									
Lee *et al*.	2009	9	9	-	-	Retrospective	275 min (170–417)	-	-
Mason *et al*.	2014	21	21	-	-	Retrospective	301 min (165–526)	-	-
Malik and Gundeti	2015	16	16	-	-	Retrospective	135 min (±36)	-	-
Neheman *et al*.	2018	59	18	24	7	Retrospective	256 min (median) (163–458)	154.5 min (median) (108–413)	190 min (median) (159–355)
Ballouhey *et al*.	2017	28	15	13	-	Retrospective	201 min (130–245)	178 min (140–230)	-

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open)	Success rate (laparoscopic)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic)	Follow-up time (months)
Partial nephrectomy for duplex system										
Lee *et al*.	2.9 days (1.9–4.8)	-	-	100	-	-	22	-	-	6
Mason *et al*.	38 h (19–93)	-	-	-	-	-	9.50	-	-	24
Malik and Gundeti	2 days (1–3)	-	-	-	-	-	13	-	-	22
Neheman *et al*.	2 days (median) (1–4)	3 days (median) (2–24)	1 days (median) (1–2)	-	-	-	-	-	-	-
Ballouhey *et al*.	3.4 days (1–7)	6.3 days (5–8)	-	-	-	-	13	15	-	46.4 (robotic); 58.7 (open)

Mean outcomes with range/SD are shown unless otherwise listed. SD=Standard deviation, LOS=Length of stay use.[31] However, this study was limited by a small sample size and a single surgeon's experience.

In the past 3 years, there has been increasing research interest in RALPN with promising results. While this procedure has been deemed safe and feasible, additional research can help further elucidate the settings and patients for maximum benefit.

URETERAL REIMPLANTATION

Vesicoureteral reflux (VUR), which involves the retrograde flow of urine from the bladder into the ureters and kidneys, is the most common uropathy in children and occurs in approximately 1% of the pediatric population.[32] For patients with breakthrough urinary tract infections while on antibiotics or worsening VUR, open ureteral reimplantation has been the gold standard for surgical management. However, within the last decade, the prevalence of robot-assisted laparoscopic ureteral reimplantation (RALUR) has been on the rise.[2]

In 2011, Smith *et al*. published a retrospective comparative study of patients who underwent extravesical RALUR versus those who underwent open cross-trigonal ureteral reimplantation by a single surgeon.[33] Although the mean operative time was 12% longer in the robotic group, the mean LOS and pain medication usage was significantly less in the robotic group. The overall success rate, defined as no radiographic or clinical evidence of residual reflux, was 97% for the robotic group and 100% for the open group after a mean follow-up of 16 months. Marchini *et al*. published a retrospective case-matched comparative study of children who underwent either intravesical or extravesical RALUR or open ureteral reimplantation.[34] They found that the intravesical RALUR group had a shorter LOS, fewer bladder spasms, and a shorter duration of urinary catheter drainage compared to those who underwent intravesical open ureteral reimplantation. There was no difference in outcomes between the extravesical open and robotic-assisted groups. Moreover, the overall success rates were similar between RALUR and open reimplantation. However, due to higher complication rates and space constraints, the intravesical approach is not commonly used now. Many additional case series of pediatric RALUR have been reported with favorable outcomes [Table 3].

With the literature reporting increasing cases of the extravesical approach for RALUR (RALUR-EV), Gundeti *et al*. performed a retrospective study of RALUR-EV outcomes to standardize technique modifications to improve VUR resolution.[35] They standardized the technique of RALUR-EV, which was termed LUAA to represent the length of detrusor tunnel (L), use of a U stitch (U), placement of permanent ureteral alignment suture (A), and inclusion of ureteral adventitia (A) in detrusorraphy. Due

Table 3: Summary of ureteral reimplantation primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
Ureteral reimplantation									
Peters and Woo	2004	6	6	-	-	Retrospective	-	-	-
Smith *et al*.	2011	50	25	25	-	Retrospective	185 min (117–286)	165 min (116–209)	-
Marchini *et al*.	2011	78	39	39	-	Retrospective	232.6 min (±37.4) (intravesical); 233.5 min (±60.2) (extravesical)	147.5 min (±34.3) (intravesical); 120.0 min (±47.5) (extravesical)	-
Schomburg *et al*.	2014	40	20	20	-	Retrospective	165 min (unilateral), 227 min (bilateral)	109 min (unilateral), 134.5 min (bilateral)	-
Gundeti *et al*.	2016	58	58	-	-	Retrospective	-	-	-
Boysen and Gundeti	2017	260	260	-	-	Retrospective	177 min (±61.4)	-	-
Boysen and Gundeti	2018	143	143	-	-	Prospective	194 min (±62)	-	-
Esposito *et al*.	2021	1362	1362	-	-	Retrospective	175.4 min (92.2–291) (unilateral), 195.2 min (108–285) (bilateral)	-	-
Neheman *et al*.	2019	27	27	-	-	Retrospective	180 min (median) (130–321)	-	-

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Table 3: Contd...

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic)	Follow-up time
Ureteral reimplantation										
Peters and Woo	2–4 days	-	-	83	-	-	17	-	-	-
Smith *et al*.	33 h (14–57)	51 h (28–100)	-	97	100	-	-	-	-	16 months (RALUR); 29.1 months (open)
Marchini *et al*.	1.8 days (±1.2) (intravesical); 1.7 days (±1.0) (extravesical)	2.9 days (±1.0) (intravesical); 1.7 days (±1.0) (extravesical)	-	No difference (data not shown)	No difference (data not shown)	-	10 (intravesical); 6 (extravesical)	14 (intravesical); 8 (extravesical)	-	19.4 months robotic/12.1 months open (intravesical); 12 months robotic/12.8 months open (extravesical)
Schomburg *et al*.	1.05 days	1.4 days	-	100	95	-	10	10	-	39 months (robotic); 52 months (open)
Gundeti *et al*.	2 days (1–6)	-	-	82	-	-	0	-	-	30 months
Boysen and Gundeti	1.6 days (±1.1)	-	-	87.90	-	-	9.60	-	-	-
Boysen and Gundeti	1.5 days (±1.0)	-	-	93.80	-	-	7.10	-	-	7.4 months
Esposito *et al*.	1.9 days (0.9–7.4)	-	-	92	-	-	10.70	-	-	19.3 months
Neheman *et al*.	-	-	-	-	-	-	9	-	-	-

Mean outcomes are shown unless otherwise listed. RALUR=Robot-assisted laparoscopic ureteral reimplantation, LOS=Length of stay to complications reported with the intravesical approach, RALUR-EV remains more common in practice.[36] A meta-analysis published in 2020 found that laparoscopic extravesical ureteric reimplantation had shorter operating time, higher success, and shorter hospital stay compared to trans-vesicoscopic ureteral reimplantation, along with comparable overall complication rates.[37]

In 2017, Boysen *et al*. published a multi-institutional retrospective study of outcomes and complications of RALUR-EV for the treatment of primary VUR in children.[38] In a cohort of 260 patients (363 ureters) from nine academic centers from 2005 to 2014, there were 25 complications overall (9.6%) with seven Grade III complications (2.7%) and no Grade IV or V complications. Radiographic resolution of VUR was seen in 246 of 280 ureters (87.9%) studied with postoperative voiding cystourethrogram or radionuclide cystogram. Boysen *et al*. followed this study with a prospective multicenter study of RALUR-EV outcomes in children, in which they found a radiographic success rate of 93.8% overall and 94.1% among children with grades III–V VUR.[39] Among a total of 199 ureters in 143 patients, ureteral complications occurred in five ureters (2.5%), and transient urinary retention occurred in four patients (7.1%) following the bilateral procedure and in no patients after the unilateral procedure. Furthermore, Esposito *et al*. published a systematic review of RALUR for pediatric VUR and showed that among 22 studies from 2008 to 2019 containing a total of 1362 children, the overall patient success rate was 92%.[40] The mean postoperative complication rate was 10.7% and the mean reoperation rate was 3.9%.

Interestingly, in 2019, Neheman *et al*. published a retrospective study of 27 pediatric patients who underwent RALUR-EV as an outpatient procedure, which reported promising results.[41] While additional studies on RALUR as an outpatient procedure are needed to assess its long-term outcomes with larger sample sizes, this innovative care pathway could eventually transform the current landscape of this procedure. With the possibility of performing RALUR as an outpatient procedure, we can potentially cater to the care of children by providing the potential option for them to recover in a comfortable and familiar environment.

There is robust evidence showing safe and effective outcomes in addition to other benefits with RALUR in pediatric patients, which raises the question of whether open ureteral reimplantation will remain the gold standard.[42] However, there is still debate over the cost of robotic surgeries. Kurtz *et al*. published a cost and complication comparison of robotic versus open pediatric ureteral reimplantation and reported higher median operative times, incidence of any 90-day complications and median hospital cost for RALUR ($9128 vs. $7273) compared to open ureteral reimplantation.[43] However, it is important to note that the timeframe of this study (2003–2013) was during the learning phase of RALUR for surgeons. Given that the cohort consisted of 1494 open cases and 108 robotic cases in addition to variable experience and reporting bias among different centers, further studies on financial outcomes are necessary.

APPENDICOVESICOSTOMY

Appendicovesicostomy (APV), also known as a Mitrofanoff procedure, allows for effective emptying of the bladder to maintain continence in patients that are unable or unwilling to perform urethral catheterization. Using the appendix to provide an alternate conduit to the bladder from an abdominal stoma, APV allows for patients to perform clean intermittent catheterization (CIC). While Mitrofanoff APV has traditionally been performed in an open approach, there is a growing body of literature supporting robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy (RALMA).

Several case reports or small case series on RALMA have been published since its initial report in 2004 [Table 4]. In 2016, Gundeti *et al*. published a multi-center study of 88 pediatric patients who underwent RALMA at five different institutions.[44] They reported favorable functional outcomes, with 85.2% of patients initially continent and 92.0% of patients continent at the last follow-up after additional procedures. Moreover, at 90 days' postoperation, 29.5% of patients had complications with 6.8% of patients being Clavien Grade III or higher. Given that these continence rates were comparable to outcomes of open series, they demonstrated that RALMA was safe and effective in their larger pediatric cohort.

In 2015, Grimsby *et al*. published a retrospective study comparing 28 open and 39 robotic APV outcomes.[45] They reported no differences in the number of complications and reoperations between the open and robotic groups at a mean follow-up of 2.7 years. While the time to reoperation was shorter in the robotic cohort, there was no difference in the number of patients who underwent reoperation within the first 12 months postoperatively between groups. In 2021, Galansky *et al*. published a retrospective large single-center study looking at 69 patients who underwent construction of continent catheterizable channels, which included APV, Monti with tapered ileum, and antegrade colonic enema (ACE).[46] Consistent with previously published literature, they reported similar continence rates between open and robotic approaches in addition to nonsignificant differences in the number of Clavien–Dindo grade postoperative complications. Surprisingly, while previous literature typically reported comparable LOS between robotic and open groups, they found significantly decreased LOS in the robotic cohort which was almost half of that of the open group (6.8 days vs. 12.6 days). The most up-to-date systematic review and meta-analysis by Juul *et al*. published in 2022, found comparable overall postoperative

Table 4: Summary of appendicovesicostomy primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
APV									
Pedraza *et al*.	2004	1	1	-	-	Retrospective	6 h	-	-
Storm *et al*.	2007	3	3	-	-	Retrospective	301 min (203–362)	-	-
Nguyen *et al*.	2009	20	10	10	-	Retrospective	323 min (181–507)	267 min	-
Wille and Gundeti	2010	13	11	-	-	Retrospective	347 min	-	-
Famakinwa and Gundeti	2013	18	18	-	-	Retrospective	323 min	-	-
Gundeti *et al*.	2016	88	88	-	-	Retrospective	309 min (±66)	-	-
Grimsby *et al*.	2015	67	39	28	-	Retrospective	-	-	-
Galansky and Gundeti*	2021	69 (includes ACE)	35	34	-	Retrospective	297 min (±62)	253 min (±123)	-
Juul *et al*.	2022	17	5	12	-	Retrospective	249 min (±35)	231 min (±105)	-

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic)	Follow-up time
APV										
Pedraza *et al*.	4 days	-	-	100	-	-	0	-	-	10 months
Storm *et al*.	3 days (2–4)	-	-	100	-	-	0	-	-	1–8 months
Nguyen *et al*.	5 days (median)	8 days (median)	-	-	-	-	15	20	-	14.2 months robotic; 18.7 months open (median)
Wille and Gundeti	6 days (median) (3–8)	-	-	-	-	-	55	-	-	20 months (median)
Famakinwa and Gundeti	5.2 days	-	-	94.40	-	-	39	-	-	24.2 months
Gundeti *et al*.	4.5 days (±2.5)	-	-	85.20	-	-	29.50	-	-	29.5 months (median)
Grimsby *et al*.	-	-	-	-	-	-	26	29	-	1239 days open; 724 days robotic (median)
Galansky and Gundeti*	6.8 days (±3.6)	13 days (±12.6)	-	91.20	91.40	-	38.20	42.90	-	75 months (median)
Juul *et al*.	2.6 days (±0.89)	9.3 days (±3.75)	-	80	83	-	40	33	-	12 months

*Outcomes in Galansky and Gundeti (2021) are for combined catheterizable channel procedures (APV, MACE). Mean outcomes are shown unless otherwise listed. ACE=Antegrade colonic enema, MACE=Malone antegrade continence enemas, LOS=Length of stay, APV=Appendicovesicostomy complication, surgical reintervention, stomal stenosis, and stomal continence rates between groups.[47] They reported shortened postoperative LOS in the robotic group among the studies included in their meta-analysis along with their own study cohort.

Overall, there is robust literature showing that RALMA is as safe and effective as the conventional open approach with the additional benefit of decreased postoperative LOS, suggesting that the robotic approach may soon be the future of this complex reconstructive procedure. Further studies comparing the costs and learning curve of robotic versus open APV are needed.

AUGMENTATION CYSTOPLASTY

Augmentation cystoplasty is indicated in the management of patients with bladder voiding dysfunction, which is characterized by reduced bladder capacity and/or decreased compliance associated with high-pressure voiding refractory to conservative treatment.[48] This impaired bladder function is often secondary to different underlying conditions, including neurogenic bladder (commonly from spina bifida), nonneurogenic voiding dysfunctions, or rare congenital anatomic anomalies (e.g. exstrophy-epispadias complex and cloacal malformations). The ileum is the most common segment of the gastrointestinal tract that is utilized for cystoplasty, and this procedure is known as ileocystoplasty.[49] Open augmentation ileocystoplasty (OAI) remains the gold standard for bladder augmentation; however, open surgery is known to be associated with longer hospital stays, increased surgical scarring, and longer periods of postoperative pain.[2,49]

In 2008, Gundeti *et al*. reported their first successful robotic-assisted laparoscopic augmentation ileocystoplasty (RALI) and Mitrofanoff APV, termed RALIMA, in a pediatric patient.[50] Since then, the usage of robotic assistance for augmentation ileocystoplasty has expanded in select medical centers, leading to studies with larger patient cohorts that highlight longer term perioperative and postoperative outcomes. In 2015, Murthy *et al*. published a study comparing 17 patients undergoing RALI and 13 patients undergoing OAI by a single surgeon.[51] They reported that the median operative time was significantly longer in RALI (623 min) compared to OAI (287 min) while the median LOS was shorter in RALI (6 days) compared to OAI (8 days). Of note, RALI resulted in similar functional outcomes as OAI, as the postoperative complication rates, percentage increase in bladder capacity, and narcotic use did not differ between cohorts. In 2016, Cohen *et al*. reported on the outcomes of patients undergoing RALI or OAI by two surgeons at two centers.[52] They reported similar functional outcomes between RALI and OAI approaches using matched controls, with longer operative times in the RALI cohort compared with OAI.

Together, these studies demonstrate the similar safety and efficacy of RALI compared with OAI, making it a feasible approach that may offer the benefits of reducing postoperative LOS in addition to offering cosmetic advantages.[2,53] However, given the limited literature on pediatric patients, further investigation of longer term outcomes is necessary. With the continuous growth and usage of robotic technology in pediatric urology, the learning curve of this complex procedure will undoubtedly lessen, which will help reduce the longer operating times associated with the robotic approach.

BLADDER NECK RECONSTRUCTION

Bladder neck incompetence can lead to urinary incontinence and often stems from neurogenic bladder that is secondary to myelodysplasia, sacral agenesis, or other congenital lesions affecting the spinal cord. BNR is indicated in patients with an incompetent urethral sphincter to prevent incontinence.[54] Similar to other reconstructive procedures, BNR has traditionally been performed with an open approach. However, with the growing use of minimally invasive surgical techniques, there have been increasing but still limited reports of robotic-assisted BNR.

One of the first reports of robotic-assisted BNR was by Bagrodia and Gargollo in 2011 [Table 5].[55] Four patients with neurogenic bladder and sphincteric incompetence underwent robot-assisted BNR, bladder neck sling, and Mitrofanoff APV. Although one of the four patients required conversion to open surgery, all patients were completely dry on CIC postoperatively. Years later, Gargollo reported on the outcomes of 38 patients who underwent robot-assisted BNR and APV at their institution.[56] Thirty-one patients (82%) were completely dry during the day on CIC, while four of the seven patients who were wet were noncompliant with CIC. Other postoperative complications included de novo reflux in four patients and bladder stones in two patients.

In 2016, Grimsby *et al*. published a retrospective study of perioperative and short-term outcomes in 45 patients who underwent either robotic-assisted or open BNR.[57] They reported no difference in preoperative urodynamics, age at surgery, or LOS, but operative time was significantly longer in the robotic group (8.2 h) versus the open group (4.5 h). Notably, there was no difference in complication rates within 30 days of surgery and the number of subsequent procedures for incontinence between the groups. More recently, Gargollo and White published a comprehensive literature review on robotic-assisted bladder neck procedures and compared them to a published series of open bladder neck procedures.[58] While they found that robotic-assisted approaches are associated with longer operative times, there was evidence that there are many potential benefits such

Table 5: Summary of bladder neck reconstruction primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
BNR									
Bagrodia and Gargollo	2011	4	4	-	-	Retrospective	465 min (356–738)	-	-
Gargollo	2015	38	38	-	-	Retrospective	5.8 h (3.6–12.25)	-	-
Grimsby *et al.*	2016	45	19	26	-	Retrospective	8.2 h (±1.9)	4.5 h (±1.4)	-

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic)	Follow-up time
BNR										
Bagrodia and Gargollo	85.7 h (45.0–208.3)	-	-	100	-	-	0	-	-	-
Gargollo	52 h (34–86)	-	-	82	-	-	16	-	-	21 months
Grimsby *et al.*	4 days (median) (2–30)	4 days (median) (1–8)	-	58	44	-	16	12	-	2.8 years

Mean outcomes are shown unless otherwise listed. BNR=Bladder neck reconstruction, LOS=Length of stay

as decreased blood loss and improved cosmesis along with equivalent continence rates as open procedures.

Although there is very limited literature on robotic-assisted BNR outcomes, the initial reports allow us to speculate that robotic BNR appears safe and results in similar outcomes to open BNR. Further comparative studies are necessary to substantiate whether the robotic approach is truly as safe and effective as the traditional open approach.

MALONE ANTEGRADE CONTINENCE ENEMA

MACE, also known as appendicostomy, involves using the appendix and/or cecum to create a continent channel from the skin to the proximal colon to allow for enema administration in patients with bowel dysfunction.[59] This technique can be used to achieve fecal continence in patients with neurogenic bowel, which may stem from conditions such as spinal cord injury, spina bifida, tethered cord, cerebral palsy, or sacral agenesis. Since patients with neurogenic bowel disorders frequently co-present with neurogenic bladder, the construction of MACE and APV catheterizable channels serve as viable treatment options to achieve social continence. While MACE is also traditionally performed in an open approach, there has been a steady expansion of the application of laparoscopic or robotic-assisted minimally invasive surgery for this complex reconstruction.

After the initial reports of robotic MACE in pediatric patients in 2008, additional case reports and small case series have been reported [Table 6]. Galansky *et al.* reported on the outcomes of a decade of robotic versus open catheterizable channel procedures in pediatric patients at their single institution.[46] While a total of 69 patients were included in the study, there were 11 MACE constructions performed each in both the robotic and open groups. Overall, including patients who underwent APV channel construction; there was no difference in continence rates between the robotic and open groups. Furthermore, one of the most recent case series comparing robotic and open MACE outcomes in a cohort of 28 patients was published in 2022 by Saoud *et al.*[60] Among patients who underwent ACE construction at their institution between 2008 and 2020, there was no difference in estimated blood loss, median LOS, and median time to return to a regular diet. Importantly, the risk of Clavien–Dindo Grade III or higher complications and rate of ACE channel stenosis were significantly higher in the open group. Additionally, rates of channel stenosis were higher in patients with an appendix ACE channel compared to those with cecal flap ACE.

Overall, there is a growing body of evidence supporting the use of robotic-assisted ACE channel creation. Additional evidence of outcomes with longer follow-ups and larger sample sizes are needed, but the usage of robotic assistance for ACE construction appears promising. Concerns about the

Table 6: Summary of malone antegrade continence enema primary outcomes

Author (s)	Year published	Number of patients (total)	Number of robotic patients	Number of open patients	Number of laparoscopic patients	Type of study	Operation time (robotic)	Operation time (open)	Operation time (laparoscopic)
MACE									
Lendvay *et al.*	2008	1	1	-	-	Retrospective (case report)	8 h	-	-
Thakre *et al.*	2008	1	1	-	-	Retrospective (case report)	200 min	-	-
Zee *et al.*	2017	1	1	-	-	Retrospective (case report)	-	-	-
Halleran *et al.*	2018	7	7	-	-	Retrospective	526 min (313–724)	-	-
Galansky and Gundeti*	2021	22	11	11	-	Retrospective	292 min (±59)	294 min (±154)	-
Saoud and Gundeti	2022	28	13	15	-	Retrospective	-	-	-

Author (s)	LOS (robotic)	LOS (open)	LOS (laparoscopic)	Success rate (robotic) (%)	Success rate (open) (%)	Success rate (laparoscopic)	Postoperative complication rate (robotic) (%)	Postoperative complication rate (open) (%)	Postoperative complication rate (laparoscopic)	Follow-up time
MACE										
Lendvay *et al.*	5 days	-	-	100	-	-	0	-	-	9 months
Thakre *et al.*	5 days	-	-	100	-	-	0	-	-	-
Zee *et al.*	2 days	-	-	100	-	-	-	-	-	-
Halleran *et al.*	5 days (median) (4–7)	-	-	86	-	-	29	-	-	0.8 years (median)
Galansky and Gundeti*	6.8 days (±3.6)	13 days (±12.6)	-	91.20	91.40	-	38.20	42.90	-	75 months (median)
Saoud and Gundeti	7 days median) (6–10)	8 days (median) (7–11)	-	84.60	87	-	23.10	40	-	66.5 months (robotic); 81 months (open) (median)

*Outcomes in Galansky and Gundeti (2021) are for combined catheterizable channel procedures (APV, MACE). Mean outcomes are shown unless otherwise listed. MACE=Malone antegrade continence enema, LOS=Length of stay, APV=Appendicovesicostomy expenses of robotic surgery in addition to the steep learning curve serve as major limitations. As the field of robotic surgery in pediatrics continues to grow and institutions invest more in robotic equipment, it is expected that robotics will become a more affordable treatment modality due to the disruptive technology phenomenon. These developments warrant increased formalized education in training programs with growing technology to assist. Ultimately, with the continuous advancement of this field, we believe that robotics in pediatric urology will allow for enhanced care and quality of life for children in the near future.

CONCLUSIONS

Increasing usage of minimally invasive techniques has shown many benefits in postoperative outcomes such as improved cosmesis, shorter hospitalizations, and decreased postoperative pain. In addition, there is growing evidence that robotic procedures in pediatric urology result in comparable or better outcomes than the traditional open approaches. However, the current literature consists primarily of retrospective studies. Prospective randomized controlled trials are needed to validate and substantiate the reported outcomes.

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