Evaluation of robotic-assisted laparoscopic and open pyeloplasty in children: single-surgeon experience

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ABSTRACT

INTRODUCTION Robotic-assisted laparoscopic pyeloplasty (RALP), the most commonly undertaken paediatric robotic urologic surgery, has not been compared against open pyeloplasty (OPN) by a single surgeon. Here, we describe our experience and outcomes.

METHODS Children undergoing RALP or OPN from 2007 to 2013 were reviewed. Clinical success was defined as resolution of presenting symptoms and improved/stable hydronephrosis on ultrasound.

RESULTS RALP and OPN cohorts comprised 52 and 40 patients, respectively. RALP patients were significantly older (6.8 vs 1.2 years, $p<0.01$) and heavier (28.4 vs 8.4 kg, $p<0.01$). Operative times for RALP were longer (203.3 vs 135.0 min, $p<0.01$), but decreased significantly with increasing experience ($r^2=0.42$, $p<0.01$). Seven type-IIIb Clavien–Dindo complications occurred in RALP patients compared with two in OPN cases. There were no differences in postoperative narcotic administration ($p=0.92$) or duration of stay in hospital (DOSH) ($p=0.93$). A total of 11/40 (28%) OPN patients required epidural analgesia but none were placed in the RALP cohort. A total of 49/52 (94%) RALP patients and 40/40 OPN cases had successful outcomes. Three RALP patients required revision RALP.

CONCLUSIONS These data show that outcomes for RALP and OPN were comparable. An initial learning curve with RALP is to be expected, but operative times for RALP approached those for OPN. Previously reported benefits of RALP (reduced analgesic requirements, DOSH) were not observed. This difference may have been due to comparison of a heterogeneous cohort. Close evaluation of complications allowed for improved placement of stents in RALP.

KEYWORDS

Robotic surgery – Paediatrics – Hydronephrosis – Ureteral obstruction

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Robotic-assisted laparoscopic pyeloplasty (RALP) for obstruction of the ureteropelvic junction (UPJ) is the most commonly undertaken paediatric robotic urological surgery.¹ Open Anderson–Hynes dismembered pyeloplasty (OPN) in children carries a prevalence of success of 90–95%. Nevertheless, RALP has gained popularity because of improved visualisation of the UPJ and the ability to carry out intricate intracorporeal suturing with seven degrees of freedom.^{1–4}

The feasibility of RALP in children has been demonstrated.^{5–9} Studies comparing OPN and RALP in children have reported a shorter duration of stay in hospital (DOSH) and reduced analgesia requirements but have been limited by relatively small study cohorts employing multiple surgeons.^{10–12}

We wished to document the progression of robotic pyeloplasty by a single surgeon. This goal was achieved by comparing outcomes with a cohort of patients undergoing OPN and describing the decision-making process in selecting

patients for RALP. We hoped to eliminate the potential bias associated with inter-surgeon variability in terms of: surgical experience; adoption of technology; decision-making; approaches to follow-up.^{5,13}

Methods

The study protocol was approved by the Ethics Committees of the Pritzker School of Medicine and Comer Children's Hospital (University of Chicago, Chicago, IL, USA).

We identified patients that had undergone robotic or open pyeloplasty for UPJ obstruction between November 2007 and March 2013. Patients were eligible for inclusion only if: (i) primary Anderson–Hynes dismembered pyeloplasty was carried out; (ii) preoperative and postoperative ultrasound was available for the assessment of radiological outcomes. A single surgeon (MSG) conducted all procedures at an academic teaching institution (University of

Chicago Medical Center) with the involvement of resident surgeons.

Patients were divided retrospectively into two cohorts based on surgical approach: open or robotic-assisted laparoscopic. OPNs were carried out through a muscle-splitting extraperitoneal flank incision. RALPs were carried out using a transperitoneal approach.

In RALP, a 12mm camera port was placed at the umbilicus. One 8mm working port was sited at the left midline xiphisternum, and one 8mm working port placed on the right, halfway between the umbilicus and anterior superior iliac spine. A 5mm laparoscopic assist port was placed in the midline suprapubic region.

Involvement of resident surgeons and surgical fellows in each case was $\approx 50\%$, with each patient being supervised by the attending surgeon. The four main steps were: exposure of the UPJ; transection and spatulation of the UPJ; anastomoses of the posterior wall; anastomosis of the anterior wall/closure of the pelvis. Resident surgeons, based on experience, undertook two (often three) of these steps. Occasionally, Penrose (perirenal) drains were left *in situ* for ≈ 24 h. Foley catheters were left *in situ* after surgery for 12–24 h.

The surgical approach was dependent on the age and weight of the patient as well as the preference of the parent(s). Initially, RALP was offered only to children aged >2 years because the surgeon felt comfortable with the operating space and endoscopic anatomy. Positive outcomes after 24 cases in this age group allowed us to offer RALP to younger children and, ultimately, to infants. Better working relationships with surgical staff and familiarity with the set-up in the operating room were also important factors. OPN and RALP were carried out over an identical time frame. Initially, some patients experienced recurring stent migrations, so stent positioning was confirmed by radiography before extubation. In later cases, a new method for stent placement was used to limit the amount of anaesthetic required for stent removal.¹⁴

We collected data on: preoperative patient characteristics (eg demographic information, imaging); perioperative information (eg operative time, blood loss, analgesia use, epidural use, DOSH, stent placement) and long-term outcomes (eg complications, outcomes). ‘Operative time’ was defined as the time elapsed from the skin incision to closure of the skin inclusive, in robotic cases, of the time taken to place ports and dock the robot. Postoperative opioid use was converted to intravenous morphine equivalents and divided by body weight.¹⁰ Patients receiving epidurals were excluded from analyses of narcotic levels, limiting only our comparison of the requirements of pain medication to 52 RALPs and 29 OPNs. Complications were graded according to the Clavien–Dindo classification system (CDCS).¹⁵ Multiple complications occurred only in those patients in which primary pyeloplasty was not successful. Criteria for hospital discharge included pain controlled by oral non-opioid medications as well as resumption of normal diet and activity.

Indications for surgery were symptomatic, grade-IV or worsening hydronephrosis on ultrasound, and/or poor drainage on renal imaging with decreased renal function.

A considerable proportion of patients did not undergo post-operative MAG-3 renal scans owing to parental preference because of the invasive nature of the procedure. Postoperative MAG-3 renal scans were only performed if the patient experienced increasing or no improvement in hydronephrosis on ultrasound scans. The primary outcome measure was clinical success, which was defined as relief of associated symptoms with improved or stable ultrasound findings.^{16,17} Ultrasound images were obtained at 3, 6, 9 and, if possible, 12 and 24 months after surgery. Hydronephrosis was graded according to criteria set by the Society of Fetal Urology.¹⁸ Secondary outcomes were comparisons of perioperative data as well as the prevalence of short-term (<30 days), intermediate (31–90 days) and long-term (>90 days) complications.

If the assumptions for parametric statistical analyses were met, continuous data were described using mean values and 95% confidence intervals (CIs) and compared using the two-tailed Student’s *t*-test. The Wilcoxon–Mann–Whitney test was used to compare differences in ordinal variables (eg hydronephrosis grade). Owing to differential follow-up, the Cox proportional hazards model was used to assess the probability of experiencing a postoperative complication based on the type of surgery. Categorical variables were described by sample size and proportion, and compared using Fisher’s exact test. Binary variables were assessed by simple logistic regression. All statistical analyses were conducted using Stata v12.0 (StataCorp, College Station, TX, USA).

Results

Of the 104 patients that satisfied the criteria for study inclusion, 92 had adequate follow-up data: 40 of 43 OPN patients and 52 of 61 RALP patients. Preoperative characteristics are summarized in Table 1. The OPN cohort was significantly younger (1.2 vs 6.8 years, $p<0.01$) and lighter (8.4 vs 28.4 kg, $p<0.01$). The RALP cohort trended to decrease in age with increasing number of procedures ($b=-0.10$, $p=0.052$), but OPN did not ($b=-0.02$, $p=0.63$). Follow-up times from the date of surgery were 14 months for RALP and 23 months for OPN. We discontinued follow-up on patients 12 months after surgery if sufficient improvement in hydronephrosis was observed.

Perioperative data are summarized in the lower portion of Table 1. Operative times were significantly longer for RALP (203.3 vs 135.0 min, $p<0.01$). Figure 1 displays a significant trend towards decreasing operative time as operative experience increased in RALP, but not in OPN (r^2 for RALP = 0.42, $p<0.01$). The mean operative times of our 10 most recent RALPs did not differ significantly from the mean operative time in OPN patients ($p=0.06$).

Fifty-one of 52 (98.1%) RALP patients had a stent implanted. Forty-one were antegrade double-J stents placed at the time of surgery and removed six weeks after surgery. Two were antegrade percutaneous nephroureteral stents (through the renal parenchyma and only into the upper portion of the ureter). Eight were antegrade cutaneous pyeloureteral stents (CPUs; through only the renal pelvis and

Table 1 Patient demographics and perioperative findings

	Robotic	Open	<i>p</i> -value
Number of patients	52	40	
Months follow-up (95% CI)	14.3 (10.5–18.0)	23.3 (18.3–28.4)	<0.01
Age (years, 95% CI, range)	6.8 (5.2–8.4, 0.2–21.2)	1.2 (0.4–1.9, 0.01–11.8)	<0.01
Weight (kg, 95% CI, range)	28.4 (22.6–34.2, 5.2–97.9)	8.4 (6.5–10.4, 2.19–31.8)	<0.01
% Male	73.1 (38/52)	72.5 (29/40)	0.95
Laterality of UPJ obstruction			0.39
Right	15	16	
Left	36	24	
Horseshoe	1	0	
Preoperative grade of hydronephrosis			0.68
II	1	0	
III	14	11	
IV	37	29	
Renal function	44.6	43.0	0.63
Operative time (min, 95% CI)	203.3 (181.0–225.7)	135.0 (125.9–144.1)	<0.01
EBL (ml, 95% CI)	14.1 (10.2–18.0)	12.3 (10.3–14.4)	0.46
Length of stay (95% CI)	2.6 (2.3–3.0)	2.6 (1.8–3.4)	0.93
IVME/kg (mg/kg, 95% CI)**	0.44 (0.2–0.7)	0.46 (0.0–0.9)	0.92
% Epidural use	0.00 (0/52)	27.50 (11/40)	<0.01

**IVME = intravenous morphine equivalent; EBL = estimated blood loss;
UPJ = ureteropelvic junction

into the upper part of the ureter).^{14,19} Nephroureteral stents and CPU stents were used in only the final ten cases. Ultimately, the surgeon preferred the CPU stent because minimal bleeding during placement was observed. Thirty-five of 40 (87.5%) OPN patients had a stent implanted; 7 were indwelling double-J stents placed and removed in the same manner as that for RALP, and 28 were percutaneous nephroureteral stents.

There was one conversion to open surgery in the first attempted RALP. This patient had a 'horseshoe' kidney, with a left-sided 'pancake' kidney and a malrotated right kidney, the severity of which was not known preoperatively. This patient is considered in the RALP cohort. No intraoperative complications were noted in either group, and we did not observe a significant difference in DOSH (RALP = 2.6 days vs OPN = 2.6 days, $p = 0.95$). Multivariate regression analyses using age, weight and number of procedures as predictors of DOSH revealed a significant positive relationship between age and DOSH ($b = 0.22$, $p = 0.048$), but no significant relationship for the other two variables. Narcotic use for postoperative pain management between the cohorts was similar (RALP = 0.44 vs OPN = 0.46 mg/kg, $p = 0.92$). Multivariate linear regression analyses showed a trend towards increasing narcotic requirements with increasing age ($b = 3.63$, $p = 0.059$).

Table 2 Postoperative findings

	Robotic	Open	p-value
Success (%)	94 (49/52)	100 (40/40)	
Total complications*	18	6	0.09
Type I	6	2	
Type II	1	0	
Type IIIb	11	4	
Revision pyeloplasty**	3	0	
Grade of hydronephrosis			0.38
0	3	3	
I	15	14	
II	20	15	
III	13	7	
IV	1	1	

*Fourteen patients and six patients experienced complications in RALP and OPN, respectively. Hazard ratio = 2.29
 **Already counted as type IIIb; no additional complications

and decreased requirements with increasing weight ($b = -1.00$, $p = 0.060$). Eleven OPN patients (28%) received epidural anaesthesia, and were excluded from analyses of pain medication only; epidural anaesthesia was not used for patients undergoing RALP.

Outcomes and postoperative complications are documented in Table 2. At the final follow-up, 14 RALP patients (27%) and 6 OPN patients (15%) experienced at least one complication (hazards ratio (HR) = 2.29, $p = 0.09$). A total of 11 type-IIIb complications occurred in the robotic cohort in seven patients (13%); multiple complications occurred only in patients ultimately requiring revision robotic pyeloplasty, and all were classified as type IIIb. In patients in which the primary RALP was successful, the first two complications were due to migration of double-J stents (<30 days and 30–90 days, respectively). The other type-IIIb complications were a port-site hernia (<30-day) and stone formation (30–90 days). In addition to revision robotic pyeloplasty, one patient experienced a port-site hernia (<30 days), another patient required placement of a nephrostomy tube due to urine leakage from the anastomoses (30–90 days) and the third patient experienced two instances of stent placement to improve drainage (<30 days and >90 days). All three robotic-assisted laparoscopic revision pyeloplasties occurred late (>90 days). Two type-IIIb complications occurred in our open cohort (5%). One was due to stent migration (<30 days) and another involved re-stenting for a narrowed UPJ visualized on retrograde pyelography (>90 days); however, imaging after stent removal documented improved hydronephrosis and drainage.

Forty out of 40 (100%) OPN patients and 49/52 (94%) RALP patients had clinical success. Two of the three clinical failures for RALP had extrinsic fibrosis and secondary

obstruction, possibly secondary to subclinical urine extravasation. Both underwent revision robotic pyeloplasty 22 and 32 months, respectively, after initial surgery, and have been clinically well after revision repair. The third patient had an accessory-crossing vessel that was not recognised during the initial surgery, possibly owing to severe hydronephrosis that distorted the anatomy and obscured the vessel. The patient underwent robotic revision pyeloplasty with transposition of the renal vessels nine months after the original repair.

Discussion

The literature suggests that RALP in the paediatric population is technically feasible and associated with a prevalence of success that is similar to that seen with OPN.^{5,5,7–9,12} However, the present study provides data of procedures undertaken by a single surgeon at a single institution, thereby allowing for consistent surgical decision-making and follow-up care.

Our study shows that RALP may be as effective as OPN in the treatment of congenital obstruction of the UPJ in children based on the clinical success of OPN, and that the operative time of the RALP approaches that of OPN as the experience of the surgeon increases.

Our lead surgeon has been carrying out open pyeloplasty since 1995, but his robotic experience of pyeloplasty began in 2005. Therefore, implementation of robotic surgery at our institution led to cohorts that were different with respect to age and weight. However, these disparities permit assessment of how the prevalence of complications, operative times, patient selection, and intraoperative decision-making (eg stent use) in our RALP cohort compared with those of the well-established OPN method. Such heterogeneity may be one of the factors influencing these outcomes, but also reflects the learning curve and patient selection when adopting new technologies. Moreover, surgeon skill, the decision to undertake surgery, follow-up care and definition of success were standardised because of the single-surgeon setup, so we feel that the cohorts are comparable.

The goal of pyeloplasty is repair of the obstruction with minimal morbidity. The prevalence of success for OPN is 90–100%, and we did not identify failures in the cohort that underwent open pyeloplasty.^{2,5} In comparison, in the present study, 94% of RALPs were successful, a prevalence that was lower (albeit not significantly) but within the range stated in other reports.^{2,5} Therefore, with an appropriate degree of caution based on the excellent outcomes associated with open repair, it appears that RALP is comparable with OPN in terms of perioperative benefits for the patient and surgeon.

The surgeon may prefer robotic pyeloplasty to laparoscopy owing to the improved ability to carry out fine intracorporeal suturing, magnification of the operating space, and three-dimensional visualisation. The operative time of RALP (which in our series included the time taken to set up and dock the robot) was longer but did not approach that of open surgery as surgeon experience increased. Admittedly the logistics of the robotic approach were

Table 3 Comparative pyeloplasty studies

	Present study (95% CI)		Lee <i>et al</i> (2006) (range)		Yee <i>et al</i> (2006) (range)		Sorensen <i>et al</i> (2011) (SD)	
	RALP	OPN	RALP	OPN	RALP	OPN	RALP	OPN
Number of patients	52	40	33	33	8	8	33	33
Age (years)	6.8 (5.2–8.4)	1.2 (0.4–1.9)	7.9 (0.2–19.6)	7.6 (0.2–19)	11.5 (6.4–16.5)	9.8 (6.0–15.6)	9.2±6.3	8.2±4.5
Operative time (min)*	203.3 (181.0–225.7)	135.0 (125.9–144.1)	219 (133–401)	181 (123–308)	363 (255–522)	248 (144–375)	245±67	148±42
Duration of hospital stay (days)	2.6 (2.3–3.0)	2.6 (1.8–3.4)	2.3 (0.5–6.0)	3.5 (2.7–5.0)	2.4 (1–5)	3.3 (1–8)	2.2±1.6	2.6±0.7
IVME (mg/kg)**	0.44 (0.2–0.7)	0.46 (0.0–0.9)	0.8 (0.0–2.0)	2.5 (0.1–13.4)	0.19 (0–23 mg)	0.71 (0–100 mg)	–	–
% complications***	26.9 (14/52)	15.0 (6/40)	3.0 (1/33)	0 (0/33)	12.5 (1/8)	0 (0/8)	15 (5/33)	9 (3/33)

*Operative time for Yee *et al* includes cystoscopy and robot docking
 **IVME (mg/kg) for Yee *et al* is back-calculated from total administration (mg)
 ***Only Gundeti *et al* used the Clavien–Dindo classification system
 IVME = intravenous morphine equivalent

initially challenging and added considerable time to carry out the procedure. However, a consistently measurable difference between the robotic and open approaches in our study was not observed, even accounting for the time taken to place ports and dock the robot. For RALP, our operative time (203 min; Table 3) was shorter than the time taken for OPN by Yee *et al* (248 min) and was similar to that of Lee *et al* (181 min).^{10,11} Therefore, our experience would suggest that, once the learning curve for the surgeon and operating-room staff is overcome, RALP can approach the efficiency seen in OPN.

Reported benefits of RALP include decreased DOSH and reduced requirements of narcotics after surgery.^{5,10–12} We did not observe significant decreases in these two outcome measures, and this finding could be attributed to cohort heterogeneity. Acetaminophen and ibuprofen with narcotics as needed is the baseline protocol for pain control for RALP at our institution but younger, lighter OPN patients may have an intrinsically decreased narcotic demand.²⁰ There was a trend towards decreased narcotic requirements with increasing weight, but there was also a trend towards increased requirements with older age, thereby making conclusions between the type of surgery and narcotic requirements difficult to obtain. OPN patients were given epidurals routinely, but these patients were not included in narcotic analyses owing to the difficulty in converting epidural analgesia to morphine equivalents. No epidurals were placed in RALP patients to avoid the time and risk associated with this procedure.

We did not observe a significant decrease in DOSH for patients who underwent robotic surgery. Our analyses showed a significant, positive relationship between age and DOSH, and our RALP patients were significantly older. There was no relationship between weight and DOSH. Adequate pain control influenced DOSH and there was a trend towards decreasing narcotic requirements with increasing weight, so the expected positive relationship

was not observed. The same factors that caused reduced use of narcotics in our OPN patients may have led to decreased DOSH in OPN patients as well. However, RALP may be particularly beneficial in heavier paediatric patients. In comparison with other studies (Table 3), the DOSH for RALP patients (2.6 days) was shorter than that for the similarly aged OPN patients in the studies of Lee *et al* (3.5 days) and Yee *et al* (3.3 days).^{10–12} However, this finding may be related to temporal differences in administrative, medical and patient expectations with regard to routine perioperative care. These temporal trends may also be responsible (at least in part) for the decreased narcotic requirements observed in our RALP cohort.

Complications were standardised and reported according to the CDCS.¹⁵ The Cox proportional hazards model suggested a trend towards greater probability of experiencing a complication if undergoing RALP ($p=0.09$). This finding may be due to the high-grade complications (eg stent migrations, revision robotic pyeloplasties and port-site hernias) occurring early in our operative experience for RALP. Our experience is mirrored by the assessment of the RALP learning curve made by Sorensen *et al*.¹² Of the 7 type-IIIb complications in the RALP cohort, 4 of them arose in our first 13 of 52 cases. The prevalence of complications for RALP in our study (26.9%; Table 3) was higher than that noted by other scholars (Lee *et al*, 3.0%; Yee *et al*, 12.5%; Sorensen *et al*, 15.2%). The reason for our higher prevalence of complications is not clear but may have been due to use of the standardised CDCS and careful follow-up. However, the CDCS was developed for adults, and so may overstate the severity of complications in children where intervention under anesthesia (ie CDCS type III) is the rule for management of complications.^{10,11,15} This comparison of the prevalence of complications allowed us to note that stent migrations tended to occur early in our operative experience, so we modified our method by conducting

radiography of the abdomen and pelvis to ensure that both coils of the stent were *in situ* before extubation. This conclusion also challenged us to modify our method of stent implantation. While we began using antegrade double-J stents, we transitioned to using stents that only went from the renal pelvis to the upper ureter (CPU stents) in our final RALP cases.^{14,19}

Our study had limitations. The first limitation was the heterogeneity of the cohort: robotic surgery was not initially offered to patients aged <2 years. Such heterogeneity may have been an important factor in evaluation of DOSH but a recent meta-analysis by Autorino *et al* showed no noticeable reduction in DOSH for all minimally invasive approaches when compared with open approaches in paediatric patients.²¹ Secondly, although our study represents the largest comparative study to date, the sample size was relatively modest. Larger multicentre studies involving experienced surgeons with standardised approaches may be required to elucidate differences in perioperative and long-term outcomes. Thirdly, discrepancies in age and weight may have complicated the comparison of postoperative narcotic requirements because an objective pain score in this age group was difficult to obtain.²⁰ Fourthly, changing surgical experience played a part in our analyses because ultimately we evaluated the experience of a single surgeon (MSG) as his robotic skills developed in comparison with his extensive experience of open surgery. Based on the wide adaptation of robots and increased training during residency, trainees in certain institutions may find OPN to be a less familiar approach. Finally, the retrospective nature of our study increased the likelihood of failing to document all (particularly low-grade) complications.

Improvements in operative time in the robotic group and equivalent outcomes compared with a very successful open cohort allowed us to maintain our optimism regarding use of the daVinci Surgical System® in the paediatric population. Moreover, the benefits robots offer to surgeons make them the preferred minimally invasive approach for this procedure because pure laparoscopy may involve more technically difficult suturing and a steeper learning curve.^{2,22–24} Patients and parents may prefer ‘robotic scars’ to those of open surgery, and studies have reported greater overall satisfaction with a robotic approach.^{25,26} Ultimately, robotic surgery provides a method of intervention that is often technically preferable for surgeons, aesthetically appreciated by parents and, most importantly, does not appear to compromise excellent outcomes.

Conclusions

Outcomes associated with RALP appear to be comparable with those seen with OPN. An initial learning curve with RALP is to be expected but, ultimately, operative times for RALP approach those of the OPN. RALP may be associated with decreased narcotic requirements and DOSH in comparison with historic cohorts, but we did not observe a difference in these parameters. New technological applications have learning curves, and the benefits of minimally invasive surgery in children should be re-evaluated in the

future as RALP experience and OPN experience become more equal.

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