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Shifting Gears in Pediatric Pyeloplasty: A Systematic Review and Meta-Analysis of Robotic vs Conventional Laparoscopic Approaches for Ureteropelvic Junction Obstruction

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Abstract

Background: Ureteropelvic junction obstruction (UPJO) obstructs the flow of urine and can damage the kidney when it is left untreated. Open pyeloplasty (OP) is still the gold standard, yet laparoscopic pyeloplasty (LP) and robot-assisted laparoscopic pyeloplasty (RALP) achieve comparable success rates. This study aimed to evaluate the efficacy and safety of RALP compared with LP in pediatric patients.
Methods: A meta-analysis was conducted on studies published after 2010 that were identified from multiple databases. Comparative studies, including randomized controlled trials (RCTs) and non-RCTs (retrospective cohort and retrospective studies), were included. The primary outcomes were operative success rate, operative time, length of hospital stay, intraoperative blood loss, UPJO recurrence, and complications. The analysis was performed in accordance with the PRISMA guidelines.
Results: Sixteen studies (15 cohort studies and 1 RCT) involving 4,707 patients, with an overall moderate risk of bias, were included. RALP significantly increased the success rate by 2% ($p = 0.03$) and reduced the length of hospital stay by 1.71 days ($p < 0.0001$) compared with LP. In addition, RALP significantly reduced intraoperative blood loss by 4.63 mL ($p = 0.04$) and postoperative complications by 42% ($p = 0.02$). No significant differences were observed in operative time or UPJO recurrence between the two groups.
Conclusion: RALP provided significant advantages over LP in pediatric UPJO, particularly in reducing hospital stay, blood loss, and complications, which supports its use as a safe and effective alternative wherever robotic facilities are available.

Keywords: *robot-assisted, laparoscopy, ureteropelvic junction obstruction, pyeloplasty, children*

Introduction

Ureteropelvic junction obstruction (UPJO) ranks among the urological conditions most frequently encountered in infants and children, and its causes may be intrinsic, extrinsic, or a combination of both. The obstruction restricts the passage of urine between the renal pelvis and the ureter; when it goes unrecognized and untreated, the affected kidney may eventually be lost entirely.[1] In most cases the condition is congenital and comes to attention on routine antenatal ultrasound performed in the second trimester. Another common route to diagnosis is incidental detection while a child or adolescent is being investigated for recurrent urinary tract infections (UTIs). Detecting the obstruction early and managing it appropriately therefore remain crucial, since doing so preserves renal function, prevents recurrent urinary tract infections, and optimizes long-term outcomes.[2]

The Anderson–Hynes dismembered pyeloplasty remains the gold-standard treatment. Alternative techniques are nevertheless available, and the vascular hitch (Hellström technique) suits patients whose obstruction is extrinsic and caused by crossing vessels.1 The procedure traces back to Kuster, who performed the first successful pyeloplasty in 1891; it has been regarded as the standard of care for UPJO ever since, achieving success in more than 90% of cases (90–100%).[3]

Minimally invasive pyeloplasty has grown steadily in popularity over the past two decades and now serves worldwide as an important alternative to open pyeloplasty (OP) in children with UPJO. The first conventional laparoscopic pyeloplasty (LP) was carried out in adults in 1993 and in children in 1995, and it has since produced excellent success rates that match those of OP while causing minimal morbidity. Its recognized benefits are less pain, a shorter admission, and a better cosmetic result; the trade-off is a longer operation, which the demanding intracorporeal suturing makes unavoidable.[4] Among the newest of these approaches is robotic surgery, which pediatric urologists have taken up quickly. What drives the expansion of robot-assisted surgery (RAS) is that complex reconstruction becomes attainable after a far shorter period of training than conventional laparoscopy demands. When OP, LP, and robot-assisted laparoscopic pyeloplasty (RALP) were compared in a meta-analysis of the three techniques, their primary outcomes did not differ significantly, although RALP was favored by a shorter admission and a smaller requirement for analgesia after surgery. A separate multicenter comparison of LP and RALP concluded that the two were equally safe and effective in children and yielded higher success rates.[5] With advances in robot-assisted surgical technology, the limitations of the LP procedure have gradually been overcome. However, robotic systems still have drawbacks, including a lack of feedback, the docking time required to set up the assistive robotic instruments, and high costs in several countries.[4] This study aimed to evaluate the efficacy and safety advantages of RALP compared with LP in pediatric patients.

Methods

This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We built the search around the four PICO components: Population (pediatric patients aged under 18 years), Intervention (laparoscopic pyeloplasty), Comparator (robot-assisted pyeloplasty), and Outcomes (surgical success rate, operative time, length of hospital stay, volume of blood loss, ureteropelvic junction obstruction recurrence, and postoperative complications). Each database required its own wording, so the search was rewritten to match the controlled vocabulary and indexing terms in use there. The records retrieved in this way were narrowed further against a predefined set of relevant Medical Subject Headings (MeSH) terms and keywords, namely: robotic, robotic surgery, robotic-assisted surgery, robotic surgical procedure, robot-enhanced procedures, laparoscopic, laparoscopy, child, children, pediatric, adolescents, urology, uretero-pelvic junction obstruction, pyeloplasty, and minimally invasive surgery.

The search covered several databases, namely PubMed, ProQuest, SAGE Journals, EBSCOhost, and Euro PMC, and returned 979 citations. Removing 295 duplicate records left 684 articles to be screened. Working independently, four reviewers (AU, GT, PEN, CJ) read the title and abstract of every citation and marked the articles that warranted full-text review; the inclusion criteria placed no restriction on study type, and any disagreement between reviewers was settled by open discussion. Eligibility was limited to work published after 2010 and to comparative designs, which covered randomized controlled trials (RCTs) as well as non-RCTs in the form of retrospective cohort and retrospective studies. From every study that met these criteria we recorded the year, study design, LP or RALP group, age, gender, weight, laterality, and pelvis AP diameter, using data from our databases. Six primary outcomes were specified: surgical success rate, operation time, length of hospital stay, volume of blood loss, UPJO recurrence, and postoperative complications.

Pooling was carried out with a random-effects model, which allowed the data to be examined and broad generalizations to be drawn, and all computations were run in RevMan software. I^2 values quantified heterogeneity. The findings were displayed through ROBINS-I and RoB 2.0 traffic light plots together with sensitivity, specificity, diagnostic odds ratio, and 95% CI. Throughout, the meta-analysis adhered to the PRISMA guidelines.

Results

Study selection

A total of 979 records were identified, of which 295 duplicates were removed. After screening 684 records, 16 studies were assessed for eligibility. As no studies were excluded at this stage, 16 studies were included in the final analysis (Figure 1).

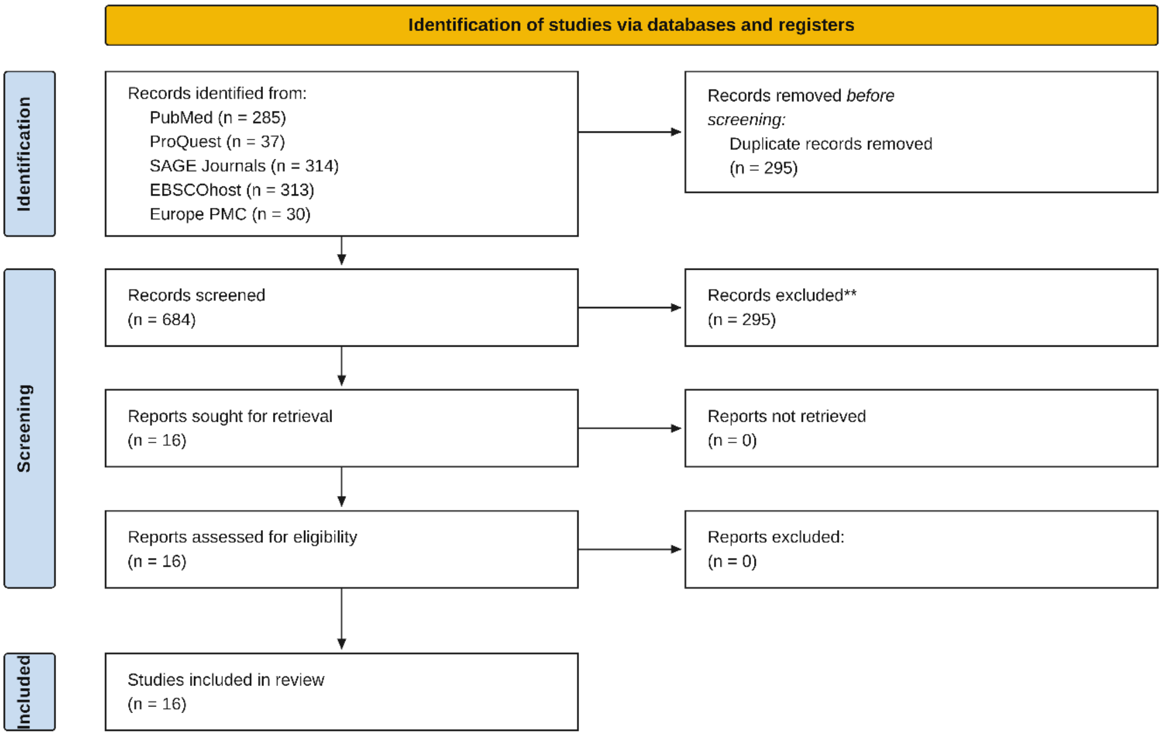

Figure 1. PRISMA flowchart from article identification to inclusion.

Study Characteristics

Sixteen studies from various countries entered the review, 15 of them cohort studies and 1 a randomized controlled trial. Coming from different countries, the articles each used an application developed according to their respective research. What they had in common was the comparison they made: the robotic against the conventional laparoscopic approach, both as minimally invasive procedures for treating UPJO in children. Table 1 sets out the basic characteristics of this literature.

Table 1. Basic characteristics of the included studies

Study	Year	Country	Study design	Group (n)		Age (years)	Male (%)	Weight (kg)	Laterality, left / right (%)	Pelvic AP diameter (cm)
				Group	*n*					
Liu	2014	USA	Retrospective study	LP	72	9.3 ± 0.7	80.5	—	—	—
				RALP	320	9.9 ± 0.5	60.0	—	—	—
Sun	2022	China	Retrospective study	LP	21	9.0 (2.0–36.0)	—	—	85.7 / 14.2	2.9 ± 0.9
				RALP	12	17.0 (5.0–36.0)	—	—	75.0 / 25.0	3.3 ± 0.8
Chan	2017	USA	Retrospective study	LP	46	8.6 ± 5.7	63.0	—	—	—
				RALP	633	9.2 ± 5.4	61.0	—	—	—
Esposito	2019	Italy	Retrospective study	LP	30	2.7 (0.6–4.0)	50.0	—	60.0 / 40.0	30.6 ± 9.8
				RALP	37	7.6 (3.0–14.0)	64.8	—	62.2 / 37.8	28.4 ± 10.3
Gonzalez	2022	Multicenter	Retrospective study	LP	87	10.5 (1.0–16.0)	64.0	—	66.3 / 33.7	—
				RALP	161	8.9 (1.0–16.0)	45.4	—	56.3 / 42.5	—
Chen	2022	China	Retrospective study	LP	36	3.0 (0.5–9.0)	77.8	15.0 (8.0–25.0)	66.6 / 30.5	—
				RALP	38	2.5 (0.17–11.0)	78.9	13.9 (5.10–43.0)	63.2 / 31.6	—
Andolfi	2022	USA		LP	26	3.0 (2.0–7.0)	85.0	—	—	—

Study	Year	Country	Study design	Group (n)		Age (years)	Male (%)	Weight (kg)	Laterality, left / right (%)	Pelvic AP diameter (cm)
				Group	*n*					
			Retrospective study	RALP	39	4.0 (2.0–6.0)	77.0	—	—	—
Jun	2024	China	Retrospective study	LP	20	6.5 ± 3.5	60.0	25.2 ± 10.3	65.0 / 35.0	34.8 ± 7.9
				RALP	27	6.6 ± 3.5	59.3	26.6 ± 13.0	63.0 / 37.0	36.0 ± 8.6
Patel	2016	USA	Retrospective study	LP	13	7.0 ± 2.9	69.2	—	—	—
				RALP	55	7.4 ± 1.9	65.5	—	—	—
Ganpule	2015	India	Retrospective study	LP	25	2.5 ± 1.1	84.0	10.8 ± 2.7	44.0 / 31.5	—
				RALP	19	2.7 ± 1.3	78.9	12.3 ± 3.8	68.4 / 31.5	—
Silay	2016	USA	Retrospective study	LP	390	8.6 ± 5.0	60.5	33.0 ± 19.1	40.2 / 29.7	33.0 ± 17.0
				RALP	180	7.7 ± 5.2	62.1	47.2 ± 18.2	41.0 / 58.9	36.0 ± 16.8
Perez Marchan	2022	China	Retrospective cohort	LP	44	6.2†	—	—	—	—
				RALP	42	7.1†	—	—	—	—
Neheman	2017	Israel	Retrospective cohort	LP	13	0.5 ± 0.1	76.9	8.9 ± 1.6	46.2 / 53.8	—
				RALP	21	0.5 ± 0.2	47.6	7.8 ± 1.9	38.0 / 61.9	—
Varda	2013	USA	Retrospective study	LP	1,517	0.9 ± 0.3	69.0	—	—	—
				RALP	690	0.9 ± 0.4	67.2	—	—	—
Song	2017	Korea	Retrospective study	LP	30	10.1 ± 3.4	66.7	40.6 ± 15.0	80.0 / 20.0	3.8 ± 1.8
				RALP	10	11.0 ± 4.5	80.0	45.7 ± 25.3	70.0 / 30.0	2.7 ± 1.4
Silay	2019	Germany	Randomized controlled trial	LP	27	1.5 (0.3–11.0)	66.7	—	77.8 / 22.2	3.0 ± 1.4
				RALP	26	3.0 (0.4–17.0)	65.4	—	57.7 / 42.3	24.4 ± 6.0
Summary¶					**4,707**	**4.4 ± 5.0**	**65.3**	**34.1 ± 20.3**	**52.1 / 36.6**	**29.5 ± 17.8**

AP, anteroposterior; LP, laparoscopic pyeloplasty; RALP, robot-assisted laparoscopic pyeloplasty.
* Plus–minus values are means ± standard deviations; values in parentheses are median (range).
† Data values are median only.
¶ Summary values are pooled across all included studies.
— Not reported.

Surgical Success Rate

Of the 16 studies evaluating surgical success rates, 8 reported that RALP was associated with a higher surgical success rate than LP. In a meta-analysis of 9 studies, RALP significantly increased the success rate by 2% (OR 1.0; 95% CI: 1.00-1.04; p = 0.03), as shown in Figure 2.

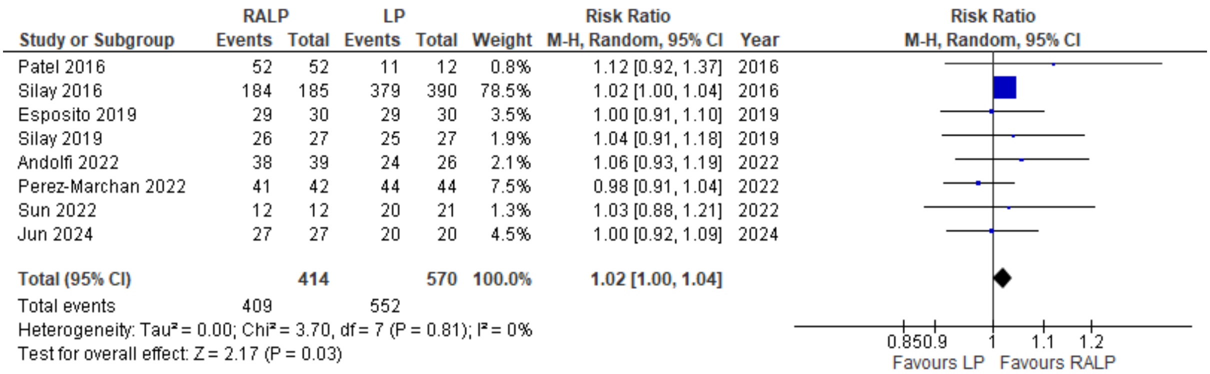

Figure 2. Meta-analysis of the surgical success rate between the RALP and LP procedures for UPJO.

Operation Time

Of the 16 studies evaluating operative time, 9 showed similar operative times for RALP and LP. In a meta-analysis of 9 studies, there were no significant differences in operating time before or after sensitivity analysis, despite high heterogeneity (MD -8.8; 95% CI: -27.2-9.6; p = 0.35), as shown in Figure 3.

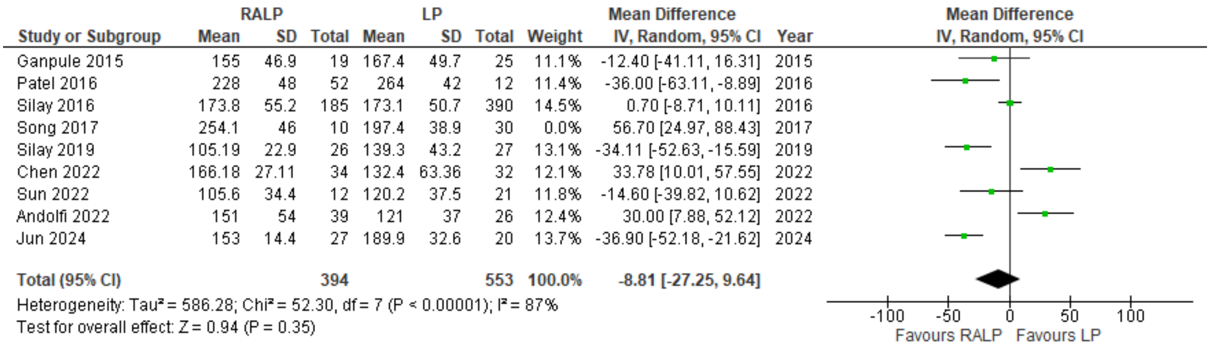

Figure 3. Meta-analysis of the operation time between the RALP and LP procedures for UPJO.

Length of Hospital Stay

Sixteen studies that analyzed the length of hospital stay found that RALP was associated with a shorter hospital stay. A meta-analysis of the extractable data showed a significant reduction in the length of hospital stay of 1.71 days after RALP compared with LP (MD -1.7; 95% CI: -2.3-(-1.1); p < 0.0001), as shown in Figure 4.

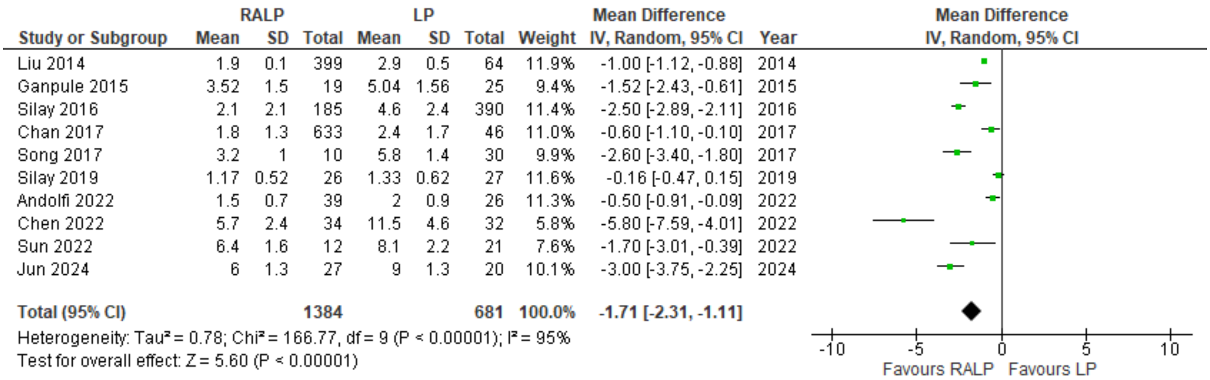

Figure 4. Meta-analysis of the length of hospital stay between the RALP and LP procedures for UPJO.

Volume of Blood Loss

Of the 16 studies that analyzed the volume of blood loss, 3 showed that RALP was associated with a decreased volume of blood loss. RALP significantly reduced intraoperative blood loss by 4.63 mL (95% CI: -9.0 – (-0.3); p = 0.04), as shown in Figure 5.

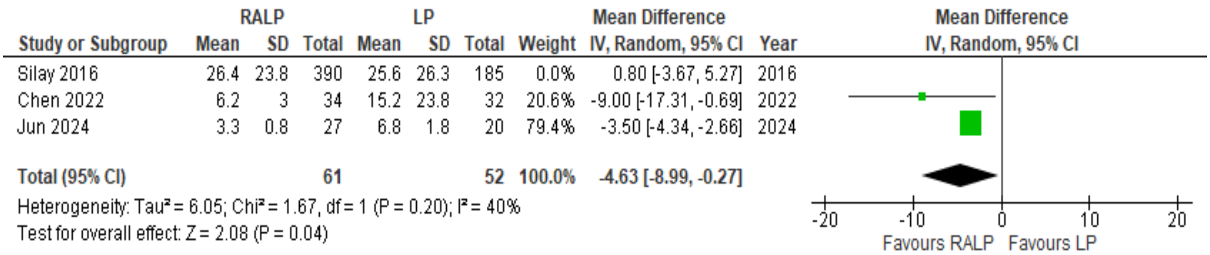

Figure 5. Meta-analysis of the volume of blood loss between the RALP and LP procedures for UPJO.

Ureteropelvic Junction Obstruction (UPJO) Recurrence

Of the 16 studies that analyzed UPJO recurrence, 3 reported similar results for RALP and LP regarding recurrence risk. There were no significant differences in UPJO recurrence between the two groups (OR 0.6; 95% CI: 0.2-2.0; p = 0.37), as shown in Figure 6.

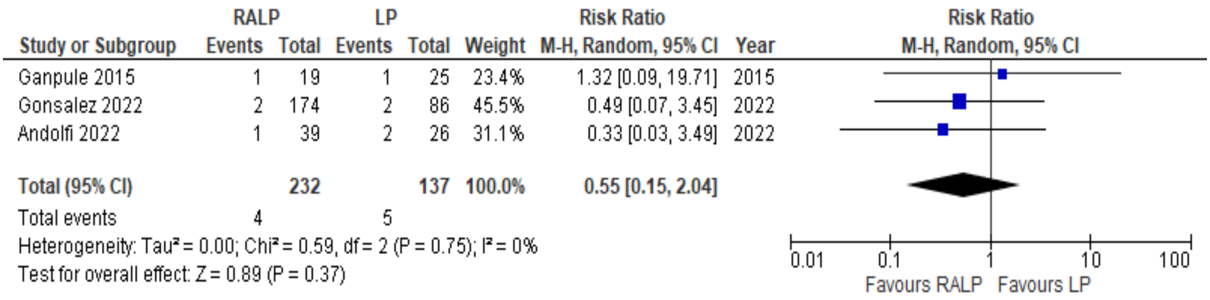

Figure 6. Meta-analysis of UPJO recurrence between the RALP and LP procedures for UPJO.

Postoperative Complications

Sixteen studies analyzed postoperative complications and found that RALP also significantly decreased postoperative complication events by 42% after sensitivity analysis, both with low heterogeneity (OR 0.7; 95% CI: 0.4-1.2; I² = 64%; p = 0.02), as shown in Figure 7.

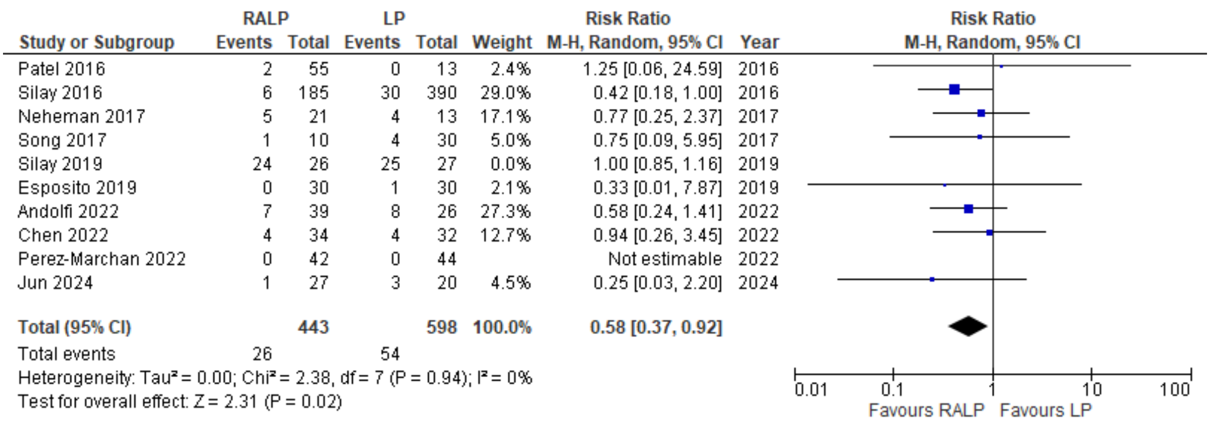

Figure 7. Meta-analysis of postoperative complications between the RALP and LP procedures for UPJO.

Risk of Bias

Risk of bias was appraised with the ROBINS-I and Risk of Bias 2.0 tools. One study carried a high risk of bias. The concern raised most often across the remaining studies was missing outcome data, since dropout rates were unequal and the reasons for discontinuation differed, either of which may have introduced bias. Publication bias is also difficult to rule out in this field: robotic technology has entered pediatric surgery only recently, the published literature is correspondingly small, and a single randomized controlled trial has been reported so far. Figure 8 presents all ROBINS-I and RoB 2.0 traffic light plots.

Figure 8. ROBINS-I and RoB 2.0 traffic light plots.

Discussion

This systematic review brought together one RCT and fifteen cohort studies in which RALP was compared with LP for treating UPJO in children. A random-effects model was chosen for the analysis because it takes heterogeneity between studies into account and therefore yields the more conservative estimate. Pediatric surgery as a whole has been reshaped by minimally invasive surgery (MIS), yet no other pediatric surgical field has felt the robotic approach as strongly as pediatric urology has in its development and daily practice. Laparoscopy and RAS also traced comparable trajectories over time, whether measured by how often the supporting manuscripts were cited or by the level of evidence those manuscripts provided.[5] Among the sixteen studies evaluating surgical success rates, eight reported that RALP significantly increased the success rate and decreased postoperative complications after sensitivity analysis, both with lower heterogeneity than LP. Sun et al. arrived at a comparable picture, recording success in 100% of RALP cases against 95.2% of LP cases; the single failure in their LP group involved a patient who developed progressive hydronephrosis postoperatively, which was traced to a second point of obstruction.[6] In a randomized series of 53 children with UPJO, Silay et al. allocated 27 to LP (Group 1) and 26 to RALP (Group 2) and obtained success rates that were comparable between the arms, the only two failures occurring after LP. The lower figure in the LP arm did not reach statistical significance. Taken together the series succeeded in 96.2% of cases, a figure in line with earlier reports of minimally invasive pyeloplasty.[5] Neither Patel et al. nor Esposito et al. detected a significant difference in success rates between LP and RALP, though both noted that RALP was technically less demanding.[7,8] As robotic platforms have matured, RALP has become a progressively more popular option for UPJO, and its flexibility, safety, and efficacy relative to LP and OP account for its wide acceptance. The refined design of the fourth-generation da Vinci Xi system has eased robotic surgery further and extended its reach to infants and young children.[6]

Nine studies reported similar operative times for RALP and LP, with no significant differences observed before or after sensitivity analysis, despite high heterogeneity. Chen et al. reached a comparable conclusion in 74 patients younger than 14 years, among whom operative and trocar insertion times differed significantly across four groups: Laparoscopic Multiport Pyeloplasty (LMPY), Laparoscopic Single-port Pyeloplasty (LSPY), Robotic-assisted Multiport Pyeloplasty (RMPY), and Robotic-assisted Single-port-plus-one Pyeloplasty (RSPY). Operating was fastest in the LMPY group, and the two single-port groups (LSPY and RSPY) took significantly longer than their multiport counterparts (LMPY and RMPY) ($P < 0.001$).[9] A mean operating time favoring RALP over LP has been reported in several studies. Ganpule et al., for instance, measured 155 ± 46.59 minutes for RALP against 167.4 ± 49.7 minutes for LP ($p > 0.05$), and finished a quarter of the RP procedures (25%, n = 3) within 90 minutes, whereas only one LP case fell below that mark.[10] Operating time did not differ statistically between the two groups in the series of Neheman et al., where the median stood at 156 minutes for RP (range 125–249) and 192 minutes for standard LP (range 98–229) ($P = 0.35$).[11] Part of the explanation probably lies in the time that docking consumes. Case volume and the experience of the surgical team matter as well, since better coordination and greater operative speed shorten the procedure.[11] Total operating time fell further as familiarity and experience with the da Vinci robotic system grew. In young patients the working space available during LP is narrow, which makes suturing and surgical knot tying technically demanding, and this constraint may be why the operating time advantage of RALP is most apparent in infants and young children.[6]

Intracorporeal suturing and complex dissection are widely regarded as the hardest parts of pure laparoscopic surgery, and both are made easier by the robotic approach, since conventional laparoscopic instruments offer limited dexterity and no articulation. Pyeloplasty demands extensive reconstruction, so a surgeon working laparoscopically must be thoroughly at ease with intracorporeal suturing. This is precisely why robot-assisted laparoscopic surgery (RALS) appealed to surgeons when it reached the market: it simplified intracorporeal suturing and shortened the learning curve for laparoscopic surgery.[12] Across the 16 studies that examined length of hospital stay, RALP shortened the admission significantly, by 1.71 days relative to LP. Drawing on several USA datasets, Liu et al. recorded a reduction of 1.96 days for RALP compared with the 2.86 days observed after LP.[13] Reviewing the records of infants under 12 months of age, Andolfi et al. likewise put the saving at 1.5 days in favor of RALP over LP.14 Varda et al., by contrast, saw no difference in median length of stay.15 Both RALP and LP nevertheless sent patients home sooner than open surgery did. Where no comorbidity is present, how long a patient remains in hospital serves as a dependable index of surgical trauma, and the shorter admission after

RALP or LP, established in earlier work, carries real weight for patients, caregivers, and healthcare institutions.[12] That difference matters, because admitting a child to hospital places a considerable burden on working parents. RALP is therefore linked both to gains in human capital and to lower inpatient costs. The economic value extends past the hospital bill: parents whose pain and emotional distress are reduced benefit too, given the long period of care a child needs before recovering adequately.[16] Blood loss was also lower with RALP in the present analysis, which showed a significant reduction of 4.63 mL intraoperatively ($p = 0.04$). Chen et al. observed the same direction of effect, with less blood lost in the robotic groups (RMPY and RSPY) than in the laparoscopic groups (LMPY and LSPY), although their difference fell short of statistical significance ($P = 0.11$).9 In 47 children with UPJO operated on between October 2020 and September 2022, Jun et al. found the two groups to be equivalent in the volume of blood lost.[17]

Across the sixteen studies that examined UPJO recurrence, the two groups did not differ significantly. Gonzalez et al., comparing techniques across multiple centers, saw recurrence in only five patients (1.55%) over a median follow-up of 42.3 months, again with no significant difference between the groups. In those five, the SFU grade fell but stayed above 2, and obstruction was confirmed on MAG3 renal scan.[18] Complication profiles were similar in the series of Andolfi et al., where UPJO recurred in 2 OP patients (5%) and 2 LP patients (8%), every one of whom needed re-intervention, and in 1 RALP patient (3%) who required ureterolysis after the uretero-pelvic anastomosis was compressed extrinsically. The remaining CDG-III complications were a urine leak following OP, a ureteral double-J stent retained after LP, and two incisional hernias following RALP. Of the fourteen studies that examined postoperative complications, ten showed a significant reduction in complication rates with RALP after sensitivity analysis, with low heterogeneity.

These data agree with the series of 575 children reported by Silay et al., in which estimated blood loss and intraoperative complication rates were similar between the LP and RALP groups. Complications there were graded on the Satava system for intraoperative events and the modified Clavien system for postoperative ones. Rates during surgery matched, but complications after surgery arose more often in children treated by LP.[5] None of the events exceeded Satava Grade IIa or Clavien Grade IIIb, which speaks to the safety of minimally invasive pyeloplasty in children. Difficulty inserting the DJ stent was the intraoperative complication encountered most often (n = 24, 4.1%), and it was handled in several ways, by external pyelostomy, by leaving the repair unstented, by a second cystoscopic procedure, or by converting to open surgery. On univariate analysis, the type of stenting significantly predicted complications.[8] Underlying medical comorbidity was significantly associated with the complication rate: the odds of a complication were three times higher in patients carrying such comorbidity than in those free of it.[19]

The application of robotic techniques in pediatric populations has only recently been described in the literature, and the available case series remain limited. However, early evidence suggests that robot-assisted procedures, including pyeloplasty and stone removal, yield favorable outcomes in this group, with effective resolution of the condition, low recurrence rates, and a good safety profile. Although current evidence is still scarce, children presenting with ureteropelvic junction obstruction accompanied by nephrolithiasis may represent a distinct subgroup with a strong indication for robot-assisted surgical management.[20] This study has several limitations worth acknowledging. Its retrospective, nonrandomized design left it inherently open to selection bias, which may in turn have produced heterogeneity that the available variables may not fully capture. Sample sizes were modest, especially in the RALP cohort, which limited the statistical power available to detect differences between the groups. Few studies have been published on this question, and only one randomized controlled trial could be included. Both LP and RALP have nonetheless become central to the management of UPJO in the era of minimally invasive surgery, and both are now widely adopted, achieving success rates on a par with the standard open technique. Robotic systems continue to be refined to address what the laparoscopic approach cannot do. Higher-quality evidence on the comparative effectiveness and safety of RALP and LP in pediatric UPJO will require large-scale, multicenter prospective studies and randomized controlled trials. Reporting perioperative, functional, and long-term outcomes in a standardized way, and adding cost-effectiveness analyses together with assessments of learning-curve effects, will help define more precisely where robot-assisted surgery belongs in this population.

Conclusions

In summary, RALP offered modest but significant advantages over LP in pediatric UPJO, RALP significantly increased the success rate and associated with shorter hospital stays, reduced blood loss, and fewer complications, supporting its use as a safe and effective alternative, particularly in centers with robotic capabilities. However, high hospitalization costs continue to limit its wider clinical application.

Declaration concerning generative AI and AI-augmented technologies in the compositional process

In the course of preparing this paper, the authors utilized ChatGPT to enhance readability and linguistic quality. Subsequent to utilizing this tool/service, the writers assessed and amended the information as necessary and assume complete accountability for the publication's content.

Declarations of competing interest

No potential competing interest was reported by the authors.

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