scientific reports

OPEN

Transperitoneal robotic-assisted versus laparoscopic partial nephrectomy for renal duplication: a comparative clinical analysis

Sisi Wang[1,2,3], Jiayue Wu[1,2,3], Wenyun He[1,2], Jingyi Chen[1,2], Jingwen Yang[1,2], Kunbin Tang[1,2], Di Xu[1,2] & Shaohua He[1,2]✉

This retrospective study aimed to compare the efficacy and safety of robotic-assisted laparoscopic partial nephrectomy (RALPN) versus laparoscopic partial nephrectomy (LPN) in pediatric patients with renal duplication. Data from 105 pediatric patients who underwent surgery for renal duplication at the Department of Pediatric Surgery, Fujian Provincial Hospital, between January 2019 and March 2024 were reviewed. Patients were categorized into two groups based on surgical approach: RALPN and LPN. The RALPN group had a significantly higher mean age (5.10 ± 2.63 years) compared to the LPN group (2.67 ± 2.16 years, $p < 0.001$). RALPN patients experienced shorter hospital stay (7.3 ± 1.7 days vs. 9.5 ± 3.3 days, $p < 0.001$)) and higher hospitalization expenses ($5,723 ± 1,322 vs. $1,787 ± 564, $p < 0.001$). No significant differences were observed in gender distribution, follow-up duration, BMI, side of surgery, presenting symptoms, coexisting urinary system diseases, or readmission rates between the groups. Intraoperative data showed that RALPN resulted in a trend towards lower blood loss (8.41 ± 3.58 ml vs. 10.73 ± 4.60 ml, $p = 0.023$) but required a longer total operation time (234.68 ± 58.02 min vs. 185.36 ± 54.07 min, $p < 0.001$). However, the partial nephrectomy duration was shorter in RALPN (125.45 ± 19.27 min vs. 153.49 ± 48.81 min, $p < 0.001$). RALPN had faster recovery with shorter durations of postoperative hematuria and catheterization. At 12 months post-surgery, RALPN showed significantly lower anteroposterior diameter of renal pelvis and maximum cross-sectional area of the cyst, indicating better preservation of renal function. Both RALPN and LPN are safe and effective for treating renal duplication in pediatric patients. Despite RALPN is associated with higher hospitalization costs, its overall cost-effectiveness may be comparable to LPN due to fewer complications and faster recovery. Further multicenter, randomized controlled trials are warranted to validate these findings and assess long-term outcomes.

Keywords Renal duplication, RALPN (robotic-assisted laparoscopic partial nephrectomy), LPN (laparoscopic partial nephrectomy)

The management of renal duplication through nephrectomy has garnered significant attention in the medical community. Renal duplication, a congenital anomaly of the urinary system, is characterized by the presence of two ureters draining a single kidney or a duplicated kidney with two functional ureters. This condition is relatively common in children, with an incidence ranging from 0.8–4.7%[1]. Partial nephrectomy is the preferred approach for managing non-functional segments of renal duplication[2,3], and advancements in laparoscopic technology have greatly enhanced its application[4–6]. Recently, robot-assisted laparoscopic partial nephrectomy (RALPN) for renal duplication has been adopted by various medical institutions, highlighting the benefits of robotic surgery in this condition[7]. This contributes valuable insights into the role of nephrectomy in treating renal duplication, emphasizing the importance of tailored surgical strategies and innovations in surgical techniques.

Despite the potential benefits, there is a notable lack of comprehensive studies directly comparing the efficacy and safety of RALPN and laparoscopic partial nephrectomy (LPN) for treating renal duplication[8]. This gap is particularly significant given the critical need to identify the most appropriate surgical strategy to optimize patient outcomes. Therefore, we conducted a retrospective analysis of patient data from our facility, aiming to

[1]Shengli Clinical Medical College of Fujian Medical University, Fuzhou 350000, Fujian, China. [2]Department of Pediatric Surgery, Children Medical Center, Fujian Provincial Hospital, Fuzhou 350000, Fujian, China. [3]Sisi Wang and Jiayue Wu have contributed equally to this work and are co-first authors. ✉email: cnfjhsh@163.com

assess and compare the efficacy and safety of RALPN and LPN and providing a detailed evaluation of these two surgical techniques in managing renal duplication.

Patients and methods
Ethical review and informed consent
This study was approved by the Institutional Review Board of Fujian Provincial Hospital. Informed consent was obtained from all patients after a thorough explanation of the novel robotic system. All experiments were performed in accordance with relevant guidelines and regulations.

Patients and design
We retrospectively reviewed the medical records of 105 patients with renal duplication who were admitted to the Department of Pediatric Surgery of Fujian Provincial Hospital between January 2019 and March 2024. All patients included in the study had completed at least 12 months of follow-up as of the final data collection point in March 2024. Preoperative evaluations were conducted for all patients, including urological ultrasound, CT urography (CTU) or magnetic resonance urography (MRU), renal static imaging, a diuretic renogram, and voiding cystourethrography (VCUG). Baseline data such as age, gender, body mass index (BMI), follow-up duration, and hospitalization expenses were collected, along with clinical characteristics including the side of surgery, hospitalization details, incipient symptoms, and readmission rates. The presence of associated genitourinary anomalies, such as vesicoureteral reflux (VUR) and ureteropelvic junction obstruction (UPJO), was also documented. The management of duplicated ureters in this study followed the principle of resecting the duplicated ureter at the lowest possible position. Complete removal of the entire length of the duplicated ureter was only considered when reflux symptoms were present. Retaining the ureteral stump was deemed safe for most patients[9]. Resection of the distal ureter and duplicated kidney was only considered in cases with extreme ureteral dilation.

Patients were divided into two groups based on the surgical approach: the LPN group and RALPN group. Perioperative and postoperative outcomes were compared between the two groups. The choice of surgical approach was primarily influenced by the patient's age, weight, and the economic status of the parents. RALPN was more challenging in younger and lighter children due to the size of the robotic arms and the need for precise adjustments, which increases anesthesia time and complexity. Additionally, younger patients' families were more likely to prefer conservative treatment, and the higher costs associated with robotic surgery limited its use in economically disadvantaged families. Patients who underwent partial nephrectomy for indications other than renal duplication were excluded from the study. All surgeries were performed by the same two surgeons using the DaVinci Xi robotic platform. Operative times, including setup time for the RALPN group, were recorded from surgical reports. General anesthesia was administered for all procedures, and complications were classified according to the Clavien-Dindo system.

Inclusion and exclusion criteria
Inclusion criteria: Poorly developed or nonfunctional upper kidney, defined as upper renal function measured by static renal scintigraphy < 10% or estimated glomerular filtration rate (eGFR) of the affected kidney < 60 $ml \cdot min^{-1} \cdot (1.73\ m^2)^{-1}$; complicated with hydroureteronephrosis; first surgical procedure for duplicated kidney conditions; upper renal malformations causing recurrent symptoms such as urinary tract infections, hematuria, or pain.

Exclusion criteria: Secondary surgery; contraindications to laparoscopic or robot-assisted surgery, such as severe coagulopathy or unstable hemodynamics; inability to provide informed consent.

Surgical techniques
Transperitoneal approach robot-assisted laparoscopic partial nephrectomy (RALPN) technique

The patients were positioned in a supine position with the affected side slightly elevated and the surgical table tilted 30 to 45 degrees towards the unaffected side. Both arms were placed in a "pitching" stance, and the legs were positioned slightly apart. Pressure points were secured with special sponge pads, and bandages were used to stabilize the limbs. A gastric tube and catheter were inserted prior to the procedure. To optimize surgical access, individualized robotic port TROCAR placement was designed based on each patient's body size and kidney position (Fig. 1A). An 8.5 mm lens was inserted at the umbilicus to establish pneumoperitoneum with a pressure of 8–14 mmHg. Two 8 mm operating channels were placed, two finger-widths below the xiphoid process and two finger-widths above the symphysis pubis. A 5 mm auxiliary operating channel was positioned at the outer edge of the rectus muscle, two finger-widths below the level of the umbilicus. The mechanical arms were positioned at least 4 cm apart, with the channels inserted approximately 1.0 cm deep into the abdominal cavity.

The mesentery was opened in the avascular zone on the inner side of the colon to expose the duplicated upper kidney. If significant fluid accumulation impeded kidney mobility, the fluid was aspirated before proceeding. The kidney was freed along the ureter, and sutures were used to suspend the ureter to enhance visibility and create additional operating space (Fig. 1B). The dissection continued from the distal to the proximal end of the ureter, with the duplicated segment of the ureter serving as a guide. Care was taken to ligate and completely remove the blood supply to the duplicated upper kidney while maintaining hemostasis (Fig. 1C). The duplicated kidney was excised (Fig. 1D). Absorbable sutures were used to intermittently close the mesenteric fissure, and no abdominal drainage tube was left in place.

The wound was rinsed with warm physiological saline to remove any accumulated fluid, and active bleeding was checked. The peritoneum or mesentery window was closed with absorbable sutures. All robotic arm instruments were removed, pneumoperitoneum was terminated, and operating channels were retracted. Finally, the peritoneum and all incisions were sutured.

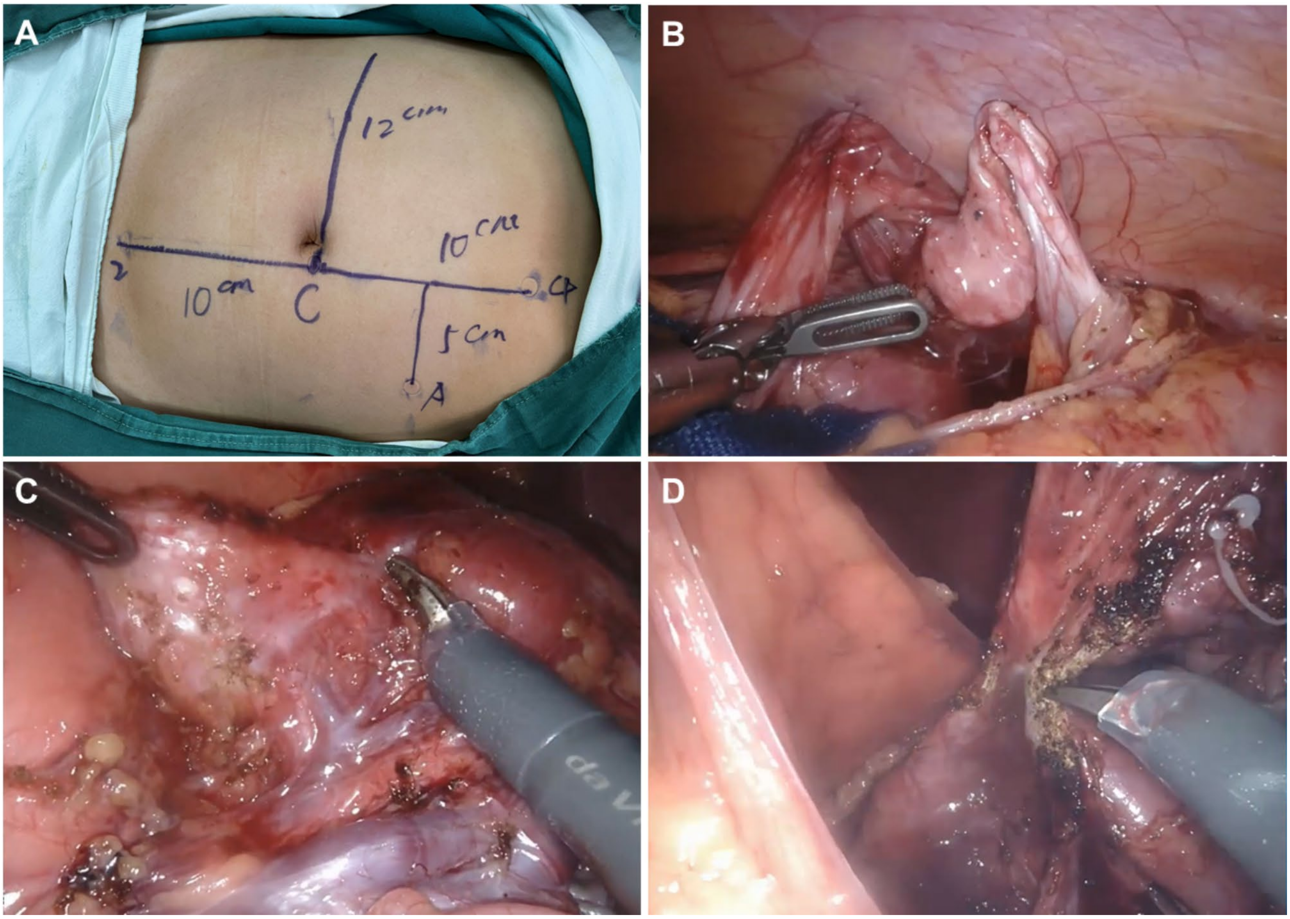

Fig. 1. Surgical technique in RALPN procedure. (**A**) Individualized TROCAR insertion site placement in RALPN based on the child's body size and renal position. (**B**) M-shaped suture suspension method for ureter exposure. (**C**) Exposure and ligation of duplicated renal vasculature. (**D**) Excision of the duplicated upper kidney.

Laparoscopic partial nephrectomy (LPN) technique

The LPN procedure closely mirrors the RALPN approach, with key differences including the absence of additional lateral abdominal operative sheaths, no requirement for robotic docking, and no attachment or removal of robotic arms.

Endpoints of the study

In this study, the endpoints were defined as the absence of recurrent febrile urinary tract infections and confirmation by follow-up ultrasound that the affected kidney had no hydronephrosis or only mild hydronephrosis.

Patient postoperative management

Once the urine no longer showed signs of bleeding, the urinary catheter was removed. If there were no signs of infection, a liquid diet was initiated within 3 days post-surgery, contingent on the restoration of gastrointestinal peristalsis. Postoperative imaging, including a diuretic nephrogram, renal static imaging, and magnetic resonance imaging were scheduled for 6 or 12 months after surgery. Ultrasound of the urinary system was planned for 3, 6, and 12 months post-surgery, with additional evaluations by ultrasound and urinalysis in cases of unexplained fever or suspected urinary tract infection.

Data collection

Patients' characteristics, including age, gender, weight, height, follow-up duration, and hospitalization expenses were recorded. BMI was calculated using weight and height. Preoperative data collected included ureteral diameter, renal cortex thickness (RCT), proportion of renal function the affected kidney (RFAK), maximum cross-sectional area of the cyst (MCSAC), range of renal sinus separation (RRSS), and anteroposterior renal pelvic diameter (APRPD). Operative data, such as total operative time (skin to skin), trocar insertion time, actual partial nephrectomy duration, complications, conversion to laparotomy, and blood loss, were recorded. Postoperative and follow-up data included postoperative hematuria duration, indwelling catheter time, recurrence of urinary tract infection, hospitalization details, various postoperative measurements (ureteral diameter, RCT, RFAK, APRPD, MCSAC, and RRSS), and readmission rates.

Statistical analysis

Data were presented as median (range) for non-normally distributed continuous variables and mean ± standard deviation for normally distributed variables. Categorical variables were reported as frequencies. Statistical analyses were conducted using SPSS (SPSS, statistics, version 21.0, IBM Corp., New York City, NY, USA). Nonparametric tests (chi-square or Kruskal–Wallis H test) were used for categorical and non-normally distributed continuous variables, while two-way ANOVA was applied for normally distributed continuous variables. A p-value < 0.05 was considered statistically significant.

Results

The numbers of patients in the RALPN and LPN groups were 22 and 83, respectively. Table 1 summarizes the baseline characteristics and highlights differences between the two groups. The mean age for patients undergoing RALPN was significantly higher at 5.10 ± 2.63 years compared to 2.67 ± 2.16 years for LPN ($p < 0.001$). RALPN patients also had a shorter mean hospitalization duration (7.3 ± 1.7 days) and higher hospitalization expenses ($5,723 ± 1,322) compared to LPN patients (9.5 ± 3.3 days, $1,787 ± 564), with both differences being statistically significant ($p < 0.001$). Gender distribution did not significantly differ between groups, with the majority being girls in both RALPN (81.82%) and LPN (71.08%) groups. Other baseline characteristics, including follow-up time, BMI, side of surgery, incipient symptoms, other urinary system diseases, and readmission rates, showed no significant differences between the two surgical approaches ($p > 0.05$).

Table 2 summarizes the key preoperative variables for patients undergoing RALPN and LPN. Analysis revealed no statistically significant differences between the two groups in terms of preoperative ureteral diameter (RALPN: 12.73 mm vs. LPN: 10.15 mm, $p = 0.216$), preoperative APRPD (RALPN: 16.37 ± 5.766 mm vs. LPN: 17.38 ± 6.430 mm, $p = 0.483$), preoperative RCT (RALPN: 1.33 ± 0.411 mm vs. LPN: 1.29 ± 0.500 mm, $p = 0.710$), preoperative proportion of RFAK (RALPN: 44.07% vs. LPN: 43.46%, $p = 0.070$), preoperative MCSAC (RALPN: 4.58 cm^2 vs. LPN: 7.15 cm^2, $p = 0.082$), and preoperative RRSS (RALPN: 7.58 cm^2 vs. LPN: 9.45 cm^2, $p = 0.347$). These findings indicate comparable baseline characteristics between the RALPN and LPN groups.

Table 3 presents intraoperative data for both surgical approaches. The RALPN group exhibited significantly lower blood loss compared to the LPN group (8.41 ± 3.58 ml vs. 10.73 ± 4.60 ml, $p = 0.023$), though the clinical significance of this difference is limited. Conversely, the total operation time for RALPN was significantly longer in comparison to LPN (234.68 ± 58.02 min vs. 185.36 ± 54.07 min, $p < 0.001$). Trocar insertion time was also notably longer for RALPN (18.73 ± 3.27 min) than for LPN (12.67 ± 3.80 min) ($p < 0.001$). However, the actual time for partial nephrectomy was shorter for RALPN (125.45 ± 19.27 min) compared to LPN (153.49 ± 48.81 min) ($p < 0.001$). Neither group experienced intraoperative complications, conversion to open surgery, or significant differences in the recurrence of urinary tract infections, indicating that both approaches are equally safe.

Characteristic	Surgical approach		Statistic	p-value[2]
	RALPN, $N = 22$[1]	LPN, $N = 83$[1]		
Age (years)	5.10 ± 2.63	2.67 ± 2.16	3.98	< 0.001
BMI (kg/m^2)	18.4 ± 3.4	18.9 ± 3.7	− 0.53	0.598
Follow-up time (years)	2.14 ± 1.08	2.17 ± 1.35	− 0.12	0.907
Hospitalization (days)	7.3 ± 1.7	9.5 ± 3.3	− 4.32	< 0.001
Hospitalization expenses ($)	5,723 ± 1,322	1,787 ± 564	13.63	< 0.001
Gender; n (%)				
Girl	18 (81.82%)	59 (71.08%)	1.02	0.311
Boy	4 (18.18%)	24 (28.92%)		
Side; n (%)				
Left	10 (45.45%)	53 (63.86%)	2.45	0.117
Right	12 (54.55%)	30 (36.14%)		
Incipient symptom; n (%)				
Abdominal pain	2 (9.09%)	3 (3.61%)		0.231
Found by urinary ultrasound	11 (50.00%)	58 (69.88%)		
Urinary incontinence due to an ectopic ureter	5 (22.73%)	11 (13.25%)		
Urinary infection	4 (18.18%)	11 (13.25%)		
Other urinary system diseases; n (%)				
None	16 (72.73%)	48 (57.83%)		0.343
UPJO	1 (4.55%)	4 (4.82%)		
VUR	5 (22.73%)	31 (37.35%)		
Readmission; n (%)				
None	22 (100.00%)	82 (98.80%)		
Yes	0 (0.00%)	1 (1.20%)		

Table 1. Patient demographics and baseline characteristics. [1]Mean ± SD; n (%). [2]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.

Characteristic	Surgical approach		Statistic	*p*-value[2]
	RALPN, *N* = 22[1]	LPN, *N* = 83[1]		
Ureteral diameter (mm)	12.73 (7.48, 17.87)	10.15 (6.58, 14.73)	1,070.50	0.216
APDRP (mm)	16.37 ± 5.766	17.38 ± 6.430	− 0.71	0.483
RCT (mm)	1.33 ± 0.411	1.29 ± 0.500	0.37	0.710
RFAK (%)	44.07 (41.94, 46.98)	43.46 (38.64, 45.41)	1,143.50	0.070
MCSAC (cm^2)	4.58 (2.13, 8.70)	7.15 (4.28, 10.85)	691.50	0.082
RRSS (cm^2)	7.58 (5.71, 11.12)	9.45 (5.38, 14.02)	793.00	0.347

Table 2. Patients' preoperative data. [1]Median (IQR); mean ± SD. [2]Wilcoxon rank sum test; Welch Two Sample t-test.

	Surgical approach		Statistic	*p*-value
	RALPN, *N* = 22[1]	LPN, *N* = 83[1]		
Blood loss (ml)	8.41 ± 3.58	10.73 ± 4.60	2.30	0.023
Total operation time (min)	234.68 ± 58.02	185.36 ± 54.07	− 3.75	< 0.001
Trocar insertion time (min)	18.73 ± 3.27	12.67 ± 3.80	− 6.83	< 0.001
Actual time of partial nephrectomy(min)	125.45 ± 19.27	153.49 ± 48.81	4.15	< 0.001
Complication (yes/no)				
No	22 (100.00%)	82 (98.80%)		
Yes	0 (0.00%)	1 (1.20%)		
Conversion to laparotomy (yes/no)				
No	22 (100.00%)	81 (97.59%)		
Yes	0 (0.00%)	2 (2.41%)		
Recurrence of urinary tract infection (yes/no)				
No	21 (95.45%)	78 (93.98%)		
Yes	1 (4.55%)	5 (6.02%)		

Table 3. Patients' intraoperative data. [1]Mean ± SD; n (%). [2]Welch Two Sample t-test. [3]Fisher's exact test.

	Surgical approach		Statistic	*p*-value
	RALPN, *N* = 22[1]	LPN, *N* = 83[1]		
Ureteral diameter (mm)	4.85 (4.12, 5.45)	5.36 (3.99, 6.76)	841.50	0.576
APDRP (mm)	8.14 (7.08, 9.58)	9.42 (8.19, 11.26)	565.00	0.006
RCT (mm)	2.43 ± 0.44	2.51 ± 0.53	− 0.76	0.452
RFAK (%)	46.8 (44.2, 49.3)	45.2 (41.8, 47.5)	1,140.00	0.075
MCSAC (cm^2)	1.3 (0.3, 3.4)	3.4 (1.2, 6.3)	541.50	0.003
Range of renal sinus separation (cm^2)	3.7 (1.7, 5.8)	4.6 (3.2, 8.2)	717.50	0.12
Hematuria time (days)	2.00 (1.00, 3.00)	3.85 (2.22, 5.00)	410.00	< 0.001[2]
Indwelling catheter time (days)	3.50 (2.25, 4.00)	5.93 (4.83, 6.81)	342.00	< 0.001

Table 4. Patients' postoperative and follow-up data. [1]Median (IQR); mean ± SD. [2]Wilcoxon rank sum test. [3]Welch Two Sample t-test.

Table 4 details the postoperative outcome based on the surgical approaches. There was no significant difference in postoperative ureteral diameter between RALPN and LPN (4.85 (4.12–5.45) mm vs. 5.36 (3.99–6.76) mm, $p = 0.576$). However, the postoperative APRPD (8.14 (7.08–9.58) mm vs. 9.42 (8.19–11.26) mm, $p = 0.006$) and MCSAC (1.3 (0.3, 3.4) cm^2 vs. 3.4 (1.2, 6.3) cm^2, $p = 0.003$) were significantly lower in the RALPN group compared to the LPN group. Other postoperative characteristics, including RCT, proportion of RFAK, and RRSS, showed no significant differences between the groups. A total of 16 children with "urinary incontinence due to an ectopic ureter" symptoms were included in this study, and none experienced urinary leakage after undergoing surgical treatment and being discharged. Notably, postoperative hematuria time and indwelling catheter time were significantly shorter in the RALPN group (2.00 (1.00–3.00) days and 3.50 (2.25-4.00) days, respectively) compared to the LPN group (3.85 (2.22-5.00) days and 5.93 (4.83–6.81) days), with *p*-values less than 0.001. These findings suggest potential advantages of RALPN over LPN in terms of postoperative recovery and specific renal parameters.

Discussion

The first reported renal duplication in a child was performed by Ross M. Decter, MD of The Milton S. Hershey Medical Center, The Pennsylvania State University in 1997[1]. In children with renal duplication, upper kidney development is poor or non-functional, hydroureteronephrosis is obvious, and ureteral drainage is poor, whether it is combined with ectopic opening or ureteral bulging, upper half nephrectomy is the first choice for treatment[10]. Minimally invasive surgery offers clear benefits over traditional open surgery, including decreased postoperative pain, shorter hospital stays, and improved cosmetic outcomes, all while maintaining high clinical success rates[4,11]. In 2000, Daniel Yao and Dix P. Poppas reported the successful use of laparoscopic techniques for partial nephrectomy in children with duplicated kidney malformations[12]. Laura Zaccaria, MD, believes that robotic surgery can offer advantages over traditional laparoscopic methods, especially in cases requiring repeated partial nephrectomy[13]. Recent advancements have seen an increase in robotic-assisted surgeries, overcoming the technical limitations traditionally associated with laparoscopic surgery[14].

While laparoscopic surgery can be challenging and involves a steep learning curve[11,15]. It is important to emphasize that surgery carries risks and should only be performed by an experienced laparoscopic surgeon[16]. Proper selection of surgical methods for different types of duplex kidneys is essential for effective treatment[17]. The complexity of LPN can be daunting, however, robot-assisted laparoscopic technology, such as the Da Vinci system, can ease this process for less experienced pediatric urologists[18]. This robotic system offers a three-dimensional view and enhanced maneuverability, with its robotic arms providing superior movement and flexibility compared to the human hand. It also corrects hand tremors automatically, significantly reducing the complexity of intracavity procedures[19].

In this study, preoperative data revealed that children undergoing RALPN (5.10 ± 2.63 years) were older compared to those who underwent LPN (2.67 ± 2.16 years). This age difference may be related to the technical requirements of RALPN, which involves larger ports and more time-consuming operations in a smaller abdominal space. This complexity increases the difficulty of instrument insertion and surgical manipulation. Furthermore, the need for precise calibration of the robotic system for younger children, and the increased risks associated with prolonged anesthesia in infants. For infants under one year of age, the median duration of robotic-assisted single-port surgery may be longer due to the restricted working space[20]. Moreover, families of younger children often prefer conservative treatment options due to the perceived risks of surgery, particularly robotic-assisted surgery. These insights are crucial for evaluating surgical indications for children with duplex kidneys.

Economic considerations are also important when choosing surgical methods[21,22]. The hospitalization costs for RALPN ($5,723 ± 1,322) were significantly higher than for LPN ($1,787 ± 564). This disparity is likely due to the higher initial investment and maintenance costs of robotic surgical systems compared to traditional laparoscopic equipment. Nevertheless, economic factors must be weighed in conjunction with the safety and efficacy of the surgical procedure[23]. Robotic surgery was efficacy in minimizing intraoperative bleeding and postoperative complications, thereby potentially diminishing hospitalization duration and expediting patient recovery. Consequently, the overall cost of robotic surgery may be equivalent to or less than that of traditional laparoscopic procedures. Furthermore, the minimally invasive nature of robotic surgery may also result in decreased postoperative nursing requirements, leading to additional cost savings in overall treatment expenses.

In this study, the results showed that RALPN had a shorter actual time for partial nephrectomy (127 ± 22 min) compared to LPN (153 ± 50 min). While the mean blood loss was slightly lower in RALPN (7.5 ± 3.7 ml) than in LPN (10.7 ± 4.6 ml), the difference is unlikely to be clinically significant. The increased precision and flexibility of robotic-assisted techniques allowed for more controlled tissue dissection, mobilization, and excision, which likely contributed to reduced trauma and bleeding[24] Robot-assisted laparoscopic techniques can offer detailed and magnified visualization of anatomical structures, making it particularly beneficial in managing complex renal anomalies. The accuracy and operability of robot-assisted laparoscopic techniques have been enhanced compared to traditional laparoscopic techniques, assisting surgeons in addressing rare anatomical variations that are clearly distinct from normal structures, thereby improving surgical outcomes and reducing the risk of complications in patients with duplicated renal anomalies. Notably, this study did not specifically analyze the docking time for RALPN. Due to the unique physiological structure of children compared to adults, robotic surgery requires individualized measurement and calculation of TROCAR placement based on each child's body size and kidney location. Additionally, appropriate models and positions for auxiliary operation channels are selected according to the abdominal cavity size of the child, leading to relatively prolonged docking times. This is also reflected in the significantly longer total operative time for RALPN compared to LPN.

APRPD is a reliable indicator of the severity of urinary tract obstruction or hydronephrosis. An increase in APRPD suggests impaired urinary drainage, leading to elevated renal pelvic pressure and renal dysfunction[25]. MCSAC reflects the size of cystic lesions, which may compress the renal parenchyma and impair renal function. Larger cystic lesions, particularly those greater than 2 cm, are considered clinical warning signs of potential renal dysfunction[26]. We observed that the APDRP and MCSAC in the RALPN group (8.14 (7.08, 9.58), 1.3 (0.3, 3.4)) were significantly lower than those in the LPN group (9.42 (8.19, 11.26), 3.4 (1.2, 6.3)) after 12 months of follow-up. Several reasons account for these findings. Firstly, the high accuracy and flexibility of the robotic surgery system reduce damage to surrounding tissues, thus decreasing postoperative kidney swelling and inflammation. Secondly, it reduces warm ischemia time during the operation and shortens the time of renal blood flow occlusion, which helps in preserving renal function[27]. Thirdly, the robotic surgical system minimizes the surgeon's hand tremors and enables more precise suture techniques, aiding in the accurate reconstruction of renal wounds, potentially resulting in a reduced anteroposterior diameter of the renal pelvis post-surgery. However, we must still consider the impact of certain confounding factors. As previously mentioned, the children in the RALPN group are older, and both the rate of recovery of renal function and renal development are faster after RALPN. These factors may also contribute to the outcomes mentioned above.

In this study, neither group experienced intraoperative complications, conversion to open surgery, or recurrence of urinary tract infections during the follow-up period, indicating that both approaches are safe in the short term. However, compared with reports, including Escolino et al.[5], which cite a complication rate exceeding 10%, this finding may reflect the small sample size and limited follow-up duration. Complications such as distal ureteral stump issues reported by Lui et al.[3], occurring at a median of 22 months (IQR 6–27), were not observed in our study due to a follow-up period of only 12 months. Acknowledging these limitations, we recommend future multi-center, long-term studies to evaluate complication rates more comprehensively.

This study has limitations that need to be addressed. Firstly, the single-center, retrospective design, lack of randomization, and the unequal comparison between the two groups may impact the results. Additionally, the postoperative renal function indicators and the impact of various factors on recovery warrant further validation in future studies. The surgeon's familiarity with robotic systems can also influence outcomes. Future studies should include multi-center, large-sample randomized controlled trials to compare the economic costs and clinical outcomes of robotic and traditional laparoscopic surgeries. Comprehensive evaluations of postoperative recovery, long-term prognosis, and reoperation rates will help healthcare providers make informed decisions balancing economic costs and clinical benefits.

Conclusion

A retrospective analysis was conducted to compare the efficacy and safety of RALPN and traditional LPN in treating renal duplication. The study found no significant differences between the two methods in terms of intraoperative complications, conversion to open surgery, or recurrence of urinary tract infections. However, RALPN demonstrated a potential advantage in accelerating postoperative recovery and showed some improvement in the severity of hydronephrosis and cystic lesions.

Data availability

Data will be made available on request from the correspondence author.

Received: 12 October 2024; Accepted: 11 March 2025
Published online: 25 March 2025

References

1. Decter, R. M. Renal duplication and fusion anomalies. *Pediatr. Clin. North. Am.* **44** (5), 1323–1341. https://doi.org/10.1016/s0031-3955(05)70559-9 (1997).
2. Gundeti, M. S., Ransley, P. G., Duffy, P. G., Cuckow, P. M. & Wilcox, D. T. Renal outcome following heminephrectomy for duplex kidney. *J. Urol.* **173** (5), 1743–1744. https://doi.org/10.1097/01.ju.0000154163.67420.4d (2005).
3. Lui, H., Onyeji, I., Durbin-Johnson, B. P. & Kurzrock, E. A. Pre-operative factors associated with the development of distal ureteral stump syndrome after upper pole heminephrectomy. *J. Pediatr. Urol.* **19** (6), 782. https://doi.org/10.1016/j.jpurol.2023.09.001 (2023).
4. Singh, M. et al. Laparoscopic transperitoneal heminephrectomy for treatment of the nonfunctioning moiety of duplex kidney in adults: A case series. *Investig Clin. Urol.* **60** (3), 210–215. https://doi.org/10.4111/icu.2019.60.3.210 (2019).
5. Escolino, M. et al. Retroperitoneoscopic partial nephrectomy in children: A multicentric international comparative study between lateral versus prone approach. *Surg. Endosc.* **33** (3), 832–839. https://doi.org/10.1007/s00464-018-6349-z (2019).
6. Leclair, M. D., Vidal, I., Suply, E., Podevin, G. & Heloury, Y. Retroperitoneal laparoscopic heminephrectomy in duplex kidney in infants and children: A 15-year experience. *Eur. Urol.* **56** (2), 385–389. https://doi.org/10.1016/j.eururo.2008.07.015 (2009).
7. Gettman, M. T. et al. Robotic-assisted laparoscopic partial nephrectomy: Technique and initial clinical experience with davinci robotic system. *Urology* **64** (5), 914–918. https://doi.org/10.1016/j.urology.2004.06.049 (2004).
8. Batra, N. V. & Dangle, P. A review of robotic-assisted laparoscopic partial nephrectomy in the management of renal duplication anomalies. *Front. Surg.* **11**, 1364246. https://doi.org/10.3389/fsurg.2024.1364246 (2024).
9. Cain, M. P. et al. Natural history of refluxing distal ureteral stumps after nephrectomy and partial ureterectomy for vesicoureteral reflux. *J. Urol.* **160** (3 Pt 2), 1026–1027. https://doi.org/10.1097/00005392-199809020-00017 (1998).
10. Sakellaris, G. et al. Outcome study of upper pole heminephroureterectomy in children. *Int. Urol. Nephrol.* **43** (2), 279–282. https://doi.org/10.1007/s11255-010-9869-6 (2011).
11. Piaggio, L., Franc-Guimond, J., Figueroa, T. E., Barthold, J. S. & Gonzalez, R. Comparison of laparoscopic and open partial nephrectomy for duplication anomalies in children. *J. Urol.* **175** (6), 2269–2273. https://doi.org/10.1016/S0022-5347(06)00342-9 (2006).
12. Yao, D. & Poppas, D. P. A clinical series of laparoscopic nephrectomy, nephroureterectomy and heminephroureterectomy in the pediatric population. *J. Urol.* **163** (5), 1531–1535 (2000).
13. Zaccaria, L., Fichtenbaum, E. J., Minevich, E. A., Schulte, M. E. & Noh, P. H. Long-term follow-up of laparoendoscopic single-site partial nephrectomy for nonfunctioning moieties of renal duplication and fusion anomalies in infants and children. *J. Endourol.* **34** (2), 134–138. https://doi.org/10.1089/end.2019.0393 (2020).
14. Raison, N. et al. Challenging situations in partial nephrectomy. *Int. J. Surg.* **36(Pt C)**, 568–573. https://doi.org/10.1016/j.ijsu.2016.05.070 (2016).
15. Polok, M., Dzielendziak, A., Apoznanski, W. & Patkowski, D. Laparoscopic heminephrectomy for duplex kidney in children-the learning curve. *Front. Pediatr.* **7**, 117. https://doi.org/10.3389/fped.2019.00117 (2019).
16. Singh, R. R., Wagener, S. & Chandran, H. Laparoscopic management and outcomes in non-functioning moieties of duplex kidneys in children. *J. Pediatr. Urol.* **6** (1), 66–69. https://doi.org/10.1016/j.jpurol.2009.04.005 (2010).
17. Neheman, A. et al. Pediatric partial nephrectomy for upper urinary tract duplication anomalies: A comparison between different surgical approaches and techniques. *Urology* **125**, 196–201. https://doi.org/10.1016/j.urology.2018.11.026 (2019).
18. Jacobson, J. C. & Pandya, S. R. Pediatric robotic surgery: An overview. *Semin Pediatr. Surg.* **32** (1), 151255. https://doi.org/10.1016/j.sempedsurg.2023.151255 (2023).
19. Deguet, C. D. E. Accelerating surgical robotics research: A review of 10 years with the Da Vinci research kit. *IEEE Rob. Autom. Magazine*. **28** (4), 56–78 (2021).
20. Chen, J. et al. Robot-assisted pyeloplasty and laparoscopic pyeloplasty in children: A comparison of single-port-plus-one and multiport surgery. *Front. Pediatr.* **10**, 957790. https://doi.org/10.3389/fped.2022.957790 (2022).
21. Higgins, R. M., Frelich, M. J., Bosler, M. E. & Gould, J. C. Cost analysis of robotic versus laparoscopic general surgery procedures. *Surg. Endosc.* **31** (1), 185–192. https://doi.org/10.1007/s00464-016-4954-2 (2017).

22. Rowe, C. K. et al. A comparative direct cost analysis of pediatric urologic robot-assisted laparoscopic surgery versus open surgery: Could robot-assisted surgery be less expensive? *J. Endourol.* **26** (7), 871–877. https://doi.org/10.1089/end.2011.0584 (2012).
23. Stringfield, S. B. et al. Experience with 10 years of a robotic surgery program at an academic medical center. *Surg. Endosc.* **36** (3), 1950–1960. https://doi.org/10.1007/s00464-021-08478-y (2022).
24. Ruiz Guerrero, E., Claro, A. V. O., Ledo Cepero, M. J., Soto Delgado, M. & Fernandez, A. O. Robotic versus laparoscopic partial nephrectomy in the new era: Systematic review. *Cancers (Basel).* **15** (6). https://doi.org/10.3390/cancers15061793 (2023).
25. Krill, A. J. et al. Objective sonographic measurements of renal pelvic diameter and renal parenchymal thickness can identify renal hypofunction and poor drainage in patients with antenatally detected unilateral ureteropelvic junction obstruction. *J. Pediatr. Urol.* **20** (5), 921–928. https://doi.org/10.1016/j.jpurol.2024.06.011 (2024).
26. Jin, C. et al. Multiple and large simple renal cysts are associated with glomerular filtration rate decline: A cross-sectional study of Chinese population. *Eur. J. Med. Res.* **29** (1), 11. https://doi.org/10.1186/s40001-023-01552-2 (2024).
27. Delgado-Miguel, C. & Camps, J. I. Robotic-assisted versus laparoscopic splenectomy in children: A costeffectiveness study. *J. Robot Surg.* **18** (1), 51. https://doi.org/10.1007/s11701-023-01783-9 (2024).

Author contributions
S.S.W. wrote the main manuscript and worked with S.H.H. to review and revise it. S.S.W., J.Y.W., W.Y.H and S.H.H. conceived the research programme and were responsible for the management of the research. S.S.W., J.Y.W., W.Y.H., J.Y.C., J.W.Y., K.B.T. and D.X. collected, managed and analyzed the data. All authors reviewed the manuscript.

Funding
This study was supported by grants from the Natural Science Foundation of Fujian Province (Grant Number 2023J011169).

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study was approved by the Institutional review board (IRB) of the Fujian Provincial Hospital (Ethics No: K2022-04-012). A written informed consent has been obtained from the patient to publish this paper.

Additional information
Correspondence and requests for materials should be addressed to S.H.