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Robot-assisted resection of renal tumor in children and comparison with laparoscopic surgery

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Abstract

Background Robot-assisted surgery (RAS) is being performed with increasing frequency in pediatric oncology. We report our experience with RAS for renal tumors in children and compare the outcomes between RAS and laparoscopic surgery (LAS).

Methods A total of 23 patients with renal tumor who underwent minimally invasive surgery (MIS) between January 2020 and December 2023 were included in the study. The inclusion criteria enrolled in this study was unilateral tumors with maximum tumor diameter less than 10 cm. Patients who had enlarged lymph node, venous thrombosis, preoperative tumor rupture, bilateral renal tumor, or extrarenal extension on imaging were deemed contraindications and excluded. Patient demographics, operative details, postoperative outcomes and follow-up were recorded.

Results Among these patients, 17 underwent RAS and 6 underwent LAS. In the RAS group, the median age was 64 months (range, 9–156) with a median weight of 19.48 kg (range, 8.4–46.5); the maximum tumor diameter at operation was 55.65 mm (range, 22–88); the operation time was 188.8 min (range, 120–210), the intraoperative blood loss was 20 ml (range, 5–50), and the length of postoperative hospital stay was 4 days (range 1–9). There was no significant difference in patients' age, weight, location, tumor size, histological pattern and operation time between the two groups ($P > 0.05$). The RAS group had a significantly less intraoperative blood loss ($P = 0.026$) and less length of postoperative stay ($P = 0.01$) than the LAS group.

Conclusion Our initial experience suggested that RAS in pediatric renal tumor was feasible and safe, and it reduced surgical trauma and accelerate postoperative recovery for the patients. Due to the limitations of sample size and study quality, the clinical importance of these findings still needs to be further verified.

Keywords Robot-assisted, Renal tumor, Children, Surgery

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Introduction

Renal tumor is one of the common solid tumors in children, accounts for 6% to 7% of all pediatric cancers [1, 2]. Greater than 75% of pediatric renal tumors are Wilms tumor (WT), other histologies include renal cell carcinoma (RCC), clear cell sarcoma of the kidney, malignant rhabdoid tumor, renal sarcomas, lymphoma, and benign entities such as metanephric adenoma (MA) [3]. Surgical treatment is still the mainstay of curative therapy.

Minimally invasive surgery (MIS) has been widely used in the treatment of adult renal tumors and has achieved good results. The concept of MIS in children with cancer was used for the first time by Holocomb who showed laparoscopy to be highly accurate with minimal morbidity for the patient [4]. Duarte et al. first reported laparoscopic nephrectomy (LN) for WT in 2004, since then this technology has been frequently reported and proved to be safe and feasible [5]. Compared with open nephrectomy, LN is associated with similar spillage rates and mid-term oncological outcomes in carefully selected cases, however, there was no advantage in surgical morbidity and lymph node harvest was inadequate with LN [6, 7].

With the development of MIS technology, the use of robot-assisted surgery (RAS) has gained increasing acceptance over the last decade and is considered preferable to laparoscopic techniques by many pediatric surgeons, especially in patients with congenital ureteropelvic junction obstruction and choledochal cysts [8, 9]. Cost et al. reported the first applications of robot-assisted laparoscopic nephrectomy for WT in 2015 [10]. However, there have been only sporadic reports of RAS for renal tumors in children. Here, we intended to verify the feasibility and safety of RAS of pediatric renal tumors, present our initial experiences and discuss the technical issues; and to compare the outcomes between RAS and laparoscopic surgery (LAS) in the management of pediatric renal tumors.

Patients and methods

We performed a retrospective study of patients who underwent MIS for renal tumor between January 2020 and December 2023. All patients underwent preoperative ultrasound and enhanced CT scan. The treatment protocol of renal tumor and the inclusion criteria for MIS were based on the SIOP strategy which published in 2016 [11]. The enrolled patients in this study were unilateral tumors with maximum tumor diameter less than 10 cm. Patients who had enlarged lymph nodes, venous thrombosis, preoperative tumor rupture, bilateral renal tumor, or extrarenal extension on imaging were deemed contraindications and excluded. The final decision to perform RAS or LAS was made by the surgeon and the guardians' preference.

Enhanced CT was used to measure the maximum tumor diameter, taking the largest value of axial, coronal and sagittal scans. The intraoperative blood loss was estimated according to the weight of gauze which inserted before the surgical procedure.

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Children's Hospital, Zhejiang University School of Medicine (2023-IRB-0178).

Surgical procedures

Robot-assisted surgery

We used Da Vinci Xi Surgical System to perform the surgery with four ports: three 8-mm robotic arm ports and one 5-mm auxiliary port (Fig. 1A). The patient was placed in a 60° contralateral decubitus position after endotracheal intubation under general anesthesia.

An 8-mm incision was made through umbilicus, and pneumoperitoneum was established by a needle inserted to inject CO2 gas, followed by inserting an 8 mm Da Vinci trocar for the 30° 3D video laparoscope. Another two 8-mm robotic canulae were placed at the ipsilateral lower abdomen and contralateral upper abdomen, respectively. The line between the tumor and the umbilicus was perpendicular to the line between the two Da Vinci trocars. Additionally, a 5-mm auxiliary port was placed for the assistant surgeon.

Then, docking was performed. Port placement and the connected instruments for a right robot-nephrectomy were shown in Fig. 1B and C, respectively.

The colon was mobilized and pulled inside. After opening the Gerota's fascia following after dissection of the retroperitoneal adipose tissue, the assistant then provided additional medial retraction of the ascending colon and duodenum (right) or the descending colon, pancreas and spleen (left) though the auxiliary port, making sure the kidney, renal artery, and renal vein were clearly visible. Once the renal hilar anatomy was defined and circumferentially mobilized, multiple hemoclips were used to seal the renal artery prior to its division, followed by the renal vein. The tail of Gerota's fascia was retracted laterally with the ureter and gonadal vein. Once identified, the ureter was ligated with a hemoclip and severed at the distal to the iliac vessels. After releasing superior and lateral attachments of the kidney and tumor, the kidney was fully freed. The nephrectomy process was shown in Fig. 2. After nephroureterectomy, lymph nodes around renal hilum, inferior vena cava (right) and aorta (left) were sampled. A drainage tube was placed at the renal fossa under endoscopic monitoring and removed when

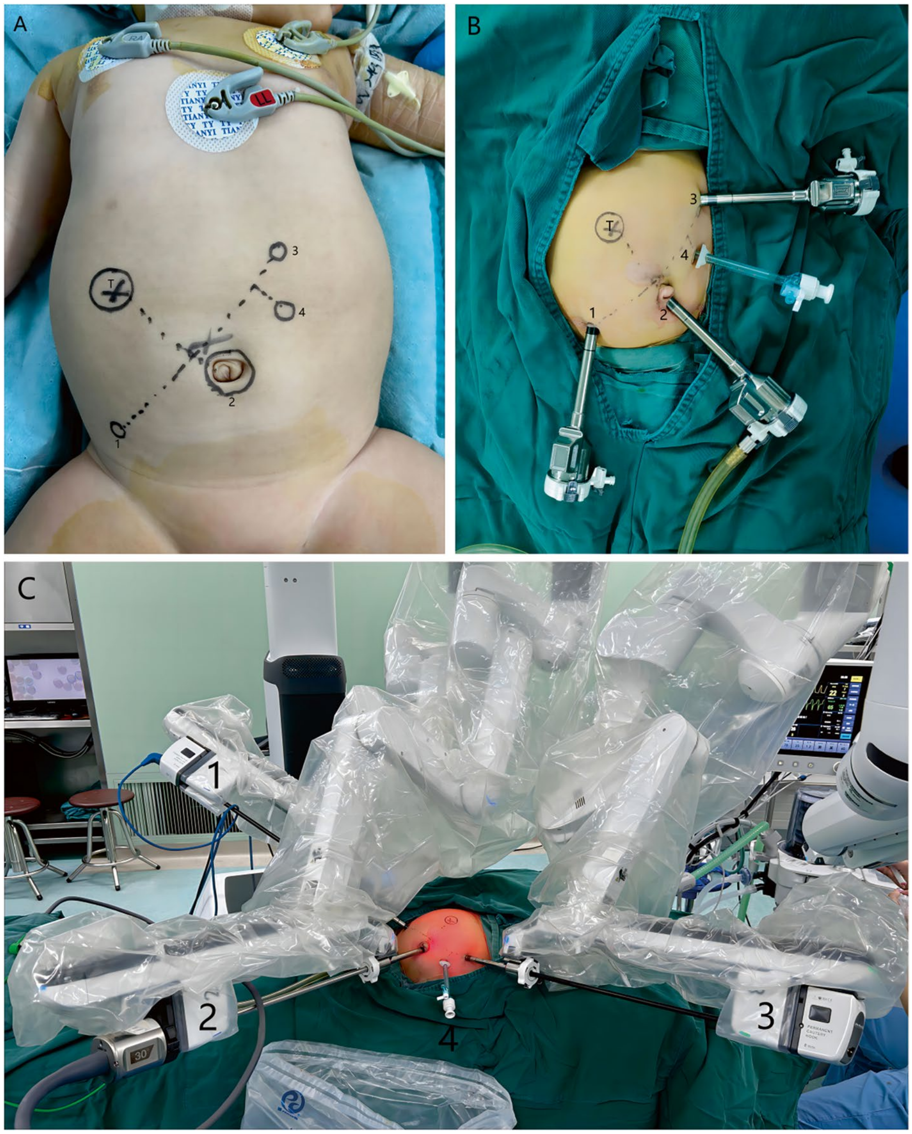

Fig. 1 **A** Trocar position of Da Vinci XI robot-assisted nephrectomy: 1. Da Vinci port, 2. Camera port, 3. Da Vinci port, 4. Assistant port. **B** Completing the placement of Da Vinci trocar. **C** Da Vinci XI robot docked for right robotic nephrectomy: 1. Fenestrated bipolar forceps, 2. Camera, 3. Permanent cautery hook

drainage was non-bloody or non- urinary within 48 h. Then the tumor along with the kidney was placed in a plastic bag and removed through the enlarged umbilicus incision.

For partial nephrectomy (PN), the renal artery was first dissected, followed by freeing the kidney to expose the tumor. After the artery was clamped, the renal parenchyma was resected at least 0.5 cm from the edge of the tumor, and then the tumor was removed from the kidney. The kidney wound was sutured using 3–0 sutures. The clamps were then released.

Laparoscopic surgery

Patient's position was the same as RAS. Four ports were used to perform the surgery. A 10-mm incision was made through umbilicus for the 30° laparoscope. Another three 5-mm ports were placed at the ipsilateral lower abdomen, midline below xiphoid and contralateral upper abdomen, respectively. The procedure of tumor resection was similar to the RAS.

Statistical analysis

For statistical analysis, the IBM SPSS software (Version 26.0.0; Armonk, NY, IBM Corp.) was used. Continuous

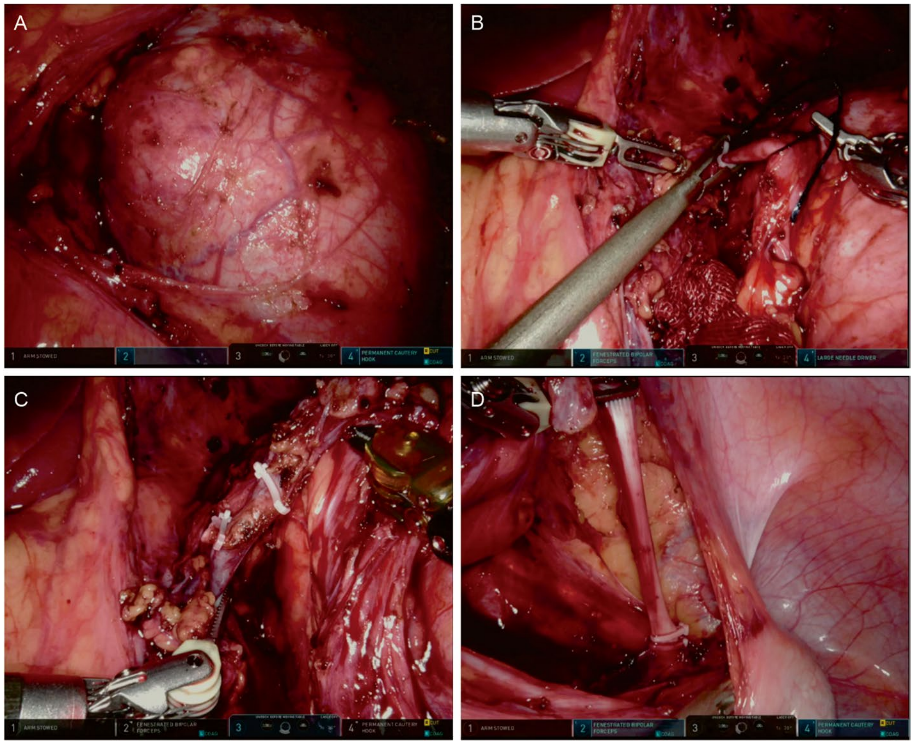

Fig. 2 Robot-assisted laparoscopic nephrectomy procedures. **A** Three-dimensional visualization of renal tumor with robotic image magnification. **B-D** Ligation of renal artery, renal vein and ureter with hemoclips

variables were reported as median and range, and Mann–Whitney U test was used to compare data from the two groups. Categorical variables were expressed by counts and percentage, and the comparison between the two groups used Pearson's $\chi2$ and Fisher's exact tests. $P < 0.05$ was considered statistically significant.

Results

Robot-assisted surgery

Seventeen patients including 9 males and 8 females received RAS. The median age was 64 months (range, 9–156) with a median weight of 19.48 kg (range, 8.4–46.5). The tumors were located in the right kidney in 10 cases and the left kidney in 7 cases. The maximum tumor diameter at operation was 55.65 mm (range, 22–88). Histological patterns were WT in 9 cases, RCC in 5 cases, and MA in 3 cases. The operation time was 188.8 min (range, 120–210), the intraoperative blood loss was 20 ml (range, 5–50), and the length of postoperative hospital stay was 4 days (range 1–9).

Laparoscopic surgery

Six patients including 4 males and 2 females received LAS. The median age was 51 months (range, 9–128) with a median weight of 18.07 kg (range, 8.9–36.5). The tumors were located in the right kidney in 4 cases and the left kidney in 2 cases. The maximum tumor diameter at operation was 50.83 mm (range, 27–90). Histological patterns were WT in 4 cases, RCC in 1 case, and MA in 1 case. The operation time was 214 min (range, 180–300), the intraoperative blood loss was 37.5 ml (range, 20–50), and the length of postoperative hospital stay was 7.33 days (range 3–10).

Comparison of two groups

All patients in the RAS group completed procedure successfully without conversion, but two cases in the laparoscopic group were converted to laparotomy because of slowly blood oozing resulting in an unclear surgical field ($P > 0.05$). Surgical margins were negative in all cases.

There was no significant difference in patients' gender, age, weight, location, tumor size, histological pattern and operation time between the two groups ($P > 0.05$). The RAS group had a significantly less intraoperative blood

Table 1 Clinical parameters of the patients

Group	n	Gender (male/female)	Age [month, M(range)]	Wight [kg, M(range)]	Side (right/left)	MTD [cm, M(range)]	Operational style (RN/PN)	Operation time [min, M(range)]	IBL [ml, M(range)]	LOPS [days, M(range)]	Histological patterns (WT/RCC/MA)	Conversion
RS	17	9/8	64.2(9–156)	19.5(8.4–46.5)	10/7	55.7(22–88)	14/3	188.8(120–210)	20(5–50)	4(1–9)	9/5/3	0
LS	6	4/2	51.7(9–128)	18.1(8.9–36.5)	4/2	50.8(27–90)	5/1	214(180–300)	37.5(20–50)	7.33(3–10)	4/1/1	2
t/X^2	-	0.34	0.628	0.31	0.115	0.487	0.003	-0.875	-2.403	-3.009	0.426	-
p	-	0.56	0.537	0.76	0.735	0.631	0.957	0.391	*0.026*	*0.007*	0.808	-

Abbreviations: *MTD* Maximum tumor diameter, *RN* Radical nephrectomy, *PN* Partial nephrectomy, *IBL* Intraoperative blood loss, *LOPS* Length of postoperative stay, *WT* Wilms tumor, *RCC* Renal cell carcinoma, *MA* Metanephric adenoma, *RS* Robot-assisted surgery, *LS* Laparoscopic surgery

Table 2 Clinical parameters of the patients underwent PN

Patient No	Sex	Age(Mon)	Wight (Kg)	Side	MTD (mm)	Operation time (hour)	Clamp time (min)	IBL (ml)	PHS (day)	Histological patterns	Local Recurrence
#1	M	70	25	R	60	240	38	50	9	MA	No
#2	M	115	23	R	84	168	25	20	4	MA	No
#3	F	72	16.2	L	58	150	20	50	6	WT	No
#4	F	9	8.9	R	27	180	28	50	10	MA	No

Abbreviations: *PN* Partial nephrectomies, *MTD* Maximum tumor diameter, *IBL* Intraoperative blood loss, *PHS* Postoperative hospital stay, *WT* Wilms tumor, *MA* Metanephric adenoma; maximum tumor diameter

loss and less length of postoperative stay ($P<0.05$) as seen in Table 1.

Fourteen patients underwent radical nephrectomy (RN), and three patients underwent PN in the RAS group. In the LAS group, five patients had RN, and one patient had PN, no significant difference was observed between two groups ($P=0.957$). Clinical parameters of the patients underwent PN was shown in Table 2.

In the RAS group, only one patient complicated with lymphatic leakage after surgery, who recovered after 2 weeks of conservative treatment. The remaining patients in both groups had no complications.

The median follow-up time was 29 months in RAS group and 31mouths in LAS group. One patient with WT of stage II in the RAS group who underwent radical nephrectomy relapsed in situ 6 months after surgery and was in a stable condition under chemotherapy, while in the LAS group, one case with RCC of T1N0M0 who underwent radical nephrectomy relapsed in situ and lung metastasis 13 months after surgery and died as refusing further treatment. The other patients in both groups were disease-free.

Discussion

With the improvements in MIS techniques, application of robotic or laparoscopic surgical procedure in selected pediatric tumor is gaining popularity in recent years [12]. In this report, among patients with nonmetastatic renal tumor undergoing MIS, treatment with RAS resulted in a statistically significant decrease in intraoperative blood loss and length of postoperative stay, without conversion and serious complication. Our initial experience suggested that RAS in pediatric renal tumor was feasible and safe, and it reduced surgical trauma and accelerate postoperative recovery for the patients. Due to the limitations of sample size and study quality, the clinical importance of these findings still needs to be further verified.

Although the 2016 UMBRELLA protocol did not specify the indications for MIS or laparoscopic surgery, these techniques will be acceptable in selected circumstances, including small, central tumors with a rim of nonmalignant renal tissue [11]. Different from renal carcinoma, pediatric WT usually presents with a large tumor at the time of diagnosis. Preoperative chemotherapy could reduce tumor size and extend MIS opportunities, and the criteria for LN were gradually being expanded [13, 14]. Robotic surgical system which has overcome the limitations of conventional laparoscopic technology can provide surgeons with enhanced visual control and favorable surgeon ergonomics [15]. It allows for significant benefits including three-dimensional magnification, tremor filtering, precision and flexibility [16], all of which play significant roles in the success of MIS for renal tumors. According to our experience, RAS has the following advantages compared to laparoscopic surgery: (1) safer ligation or clamping of renal vessels; (2) more reliable of lymph node sampling; (3) faster and more reliable suture of renal parenchyma in PN; and (4) quicker postoperative recovery and shorter length of stay.

Experience of RAS with renal tumor in children and adolescents is still limited and based on case reports and small case series. Blanc T et al. reported the largest number of 24 cases with renal tumors in a pediatric oncology study, however, they did not provide precise surgical or prognostic information [17]. Li P et al. reported their experience and the medium-term outcomes of utilizing RAS in 12 patients with WT, and demonstrated promise RAS as feasible and safe modalities for the surgical management of WT [18].

The intraoperative blood loss and length of postoperative stay of RAS from our study were similar to previous single and retrospective studies [18–20]. These data suggested that the results might be generalizable, reflecting the advantages of RAS. Intraoperative bleeding was statistically lower in the RAS group; however, the clinical consequences were not obvious since no patient received a transfusion either during or after surgery. The length of hospital stay was significantly longer in the LAS group in the current study and also a little longer than that in some previous reports [21, 22], which may be heavily impacted by the 2 conversion cases and the small size of this group. Therefore, multi-center and large sample size studies are needed to further confirm.

Open partial nephrectomy for bilateral and syndromic unilateral WT has long been widely accepted, however, there is very limited experience with robotic PN [23–25]. Della Corte M et al. successfully performed transperitoneal robotic-assisted PN for localized WT in a four-year-old patient and no tumor recurrence during a 28-month follow-up period [26]. The use of 3D virtual magnification allows for selective arterial clamping, preventing tumor rupture and avoiding complete kidney ischemia. It has become the standard approach for PN in patients with RCC in many centers, however, care must be exercised when generalizing results of the experience with RAS to patients with un-syndromic WT, recognizing how distinct WT and RCC are from a biology, lymph nodes dissemination, risk of rupture, and other surgical treatment perspectives is paramount [27–30].

The uptake of three-dimensional virtual models is increasing in the urological community, especially for minimally invasive PN [31]. New technologies now offer 3D tumor reconstructions and image overlapping in the robotic console, as well as preoperative planning [32]. Using these models, the surgeons are able to evaluate the technical feasibility of the proposed strategy in a 3D virtual environment, avoid the risks of inaccurate maneuvers during interventions, and decide on a preferred surgical strategy a priori [33].

It is always too early for rigorous assessment of a new surgical technique, until, unfortunately, it is suddenly too late [34]. Randomized controlled studies are challenging to conduct once a new technology has proven beneficial because patients typically select the newest and most advanced models. The evaluation of prognosis and long-term renal function should be the main focus of future research. It's been 10 years since the first report of RAS for pediatric renal tumor was published in 2015 [7], it's time to get started.

This study presented some limitations. First and foremost was the retrospective study design with subsequent risk of selection bias, and confounding factors. Second, cohorts were not perfectly balanced in terms of caseload, patient, and tumor characteristics, and the small number of patients did not allow generalization of the results. Third, due to the short follow-up period, long term oncologic outcomes should be further evaluated after a longer follow-up time.

In conclusion, among patients with nonmetastatic renal tumor undergoing MIS, treatment with RAS resulted in a statistically significant decrease in intraoperative blood loss and length of postoperative stay. Our initial experience suggested that RAS in pediatric renal tumor was feasible and safe, and it reduced surgical trauma and accelerate postoperative recovery for the patients. Due to the limitations of sample size and study quality, the clinical importance of these findings still needs to be further verified.

Abbreviations

MIS	Minimally invasive surgery
RAS	Robot-assisted surgery
LAS	Laparoscopic surgery
WT	Wilms tumor
RCC	Renal cell carcinoma
MA	Metanephric adenoma
LN	Laparoscopic nephrectomy
RN	Radical nephrectomy
PN	Partial nephrectomy

Authors' contributions

MH and SAL contributed equally to this work and should be considered co-first authors. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by MH, SAL, ZQH and JHW. The first draft of the manuscript was written by MH, TT, and XY. All authors read and approved the final manuscript.

Clinical trial number

Not applicable.

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Data availability

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Children's Hospital, Zhejiang University School of Medicine (2023-IRB-0178). Informed consent was obtained from the parent/guardian of all participants involved in the study.

Competing interests

The authors declare no competing interests.

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