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ORIGINAL ARTICLE

Robotic-assisted choledochal cyst excision with Roux-en-Y hepaticojejunostomy in children: does age matter?

Liying Rong[1] · Yibo Li[1] · Jingfeng Tang[2] · Guoqing Cao[1] · Li Wan[1] · Xiangyang Li[1] · Xi Zhang[1] · Shuiqing Chi[1] · Shaotao Tang[1]

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Abstract

Background Robotic-assisted surgery (RAS) is being increasingly used in pediatric choledochal cysts (CCs), but is most commonly performed in older children and adolescents. The outcomes in young infants remain to be explored. The purpose of this study is to compare outcomes in infants aged ≤ 1 year with an older cohort.

Methods From July 2015 to January 2020, a retrospective study was conducted to evaluate the RAS in patients with CCs at our institution. Patients were divided into two groups (group A ≤ 1 year old and group B > 1 year old). Demographics, intraoperative details, complications, and outcomes were analyzed.

Results A total of 79 patients were included in the study (28 patients in group A and 51patients in group B). The median age of patients at the surgery in group A was 4.9 months (IQR: 3.1–9.1), compared with 46.8 months (IQR: 28.5–86.5) in group B. Three patients in group A were neonates. No conversion to open surgery was required. No significant differences were found between the two groups including sex, Todani type, or diameter of the cysts. The diameter of the common hepatic duct was smaller in group A (6.0 ± 1.7 vs. 9.0 ± 3.0 mm; $p < 0.001$). Group A had the longer hepaticojejunostomy time [51(44–58) vs. 42(38–53) min; $p = 0.013$], while Group B had the longer cyst excision time [43(41–59) vs. 50(43–60) min; $p = 0.005$]. However, their total operative time and console time were similar. There were no statistical differences in length of hospital stay and complications between the two groups.

Conclusions Robot-assisted cyst resection and hepaticojejunostomy are feasible and safe in infants ≤ 1 year old. Age cannot be considered an absolute contraindication for robotic surgery in patients with CCs.

Keywords Infant · Robotic-assisted surgery · Choledochal cyst · Clinical outcomes

Over the past few years, robotic surgical systems have been used to help overcome the limitations of human physiology and laparoscopic instruments associated with surgery. In 2006, the first report on robotic operation for a 5-year-old patient with a choledochal cyst (CC) was published [1]. Since then, robotic surgery has been the preferred treatment for pediatric CCs at some centers, with several reports of innovative techniques. Its safety and efficacy among children were generally praised [2–4]. However, the robotic operation still is not attractive enough for some pediatric surgeons, as they consider the implementation of robotic procedures to be very technically challenging, especially in infants [5].

More patients with CCs are being diagnosed prenatally due to advances in prenatal ultrasound screening [6, 7]. Furthermore, early surgery is recommended to avoid unnecessary complications [8, 9]. This may result in a significant downward shift in the age of surgery. Unfortunately, the reports of RAS in infants with CCs are confined to limited case series [10–12], and its effectiveness has not been verified definitely. Therefore, in this study, we evaluated the applicability of RAS for CCs in infants aged ≤ 1 year and compared surgical outcomes with patients aged > 1 year.

Liying Rong, Yibo Li, and Jingfeng Tang have contributed equally to this work.

✉ Shaotao Tang
tshaotao83@hust.edu.cn

[1] Department of Pediatric Surgery, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

[2] Department of Hepatobiliary Surgery, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

Patients and methods

Patients

This was a retrospective study approved by the ethics committees of Wuhan Union Hospital, Tongji Medical College, Huazhong University of Science and Technology (2016-LSZ-S180). Patients who underwent robot-assisted choledochal cyst excision with Roux-en-Y hepaticojejunostomy were reviewed between July 2015 and January 2020. Before surgery, all children who had clinical symptoms or suspected CCs on abdominal ultrasonography were diagnosed using either magnetic resonance cholangiography or computed tomography. The CCs were classified with reference to the Todani modification [13] (Fig. 1). Patients were divided into two groups based on their ages (Fig. 2). Patients with age ≤ 1 year constituted group A. And patients older than 1 year were distributed in group B. The robotic procedures were approved by the patients' parents (guardians). And informed consent was obtained from parents or guardians before the surgery. The operation was performed by the same team of experienced pediatric surgeons in our center. All patients were followed up postoperatively at 1, 3, 6, and 12 months, including medical history inquiry and ultrasonic examination. Further follow-up was conducted every 6 months to evaluate the postoperative complications. Demographics, type of choledochal cyst, operative details, length of hospital stay, and postoperative complications were retrospectively analyzed. Patients with incomplete data or loss follow-up were excluded from the statistical analysis.

Operative techniques

Our surgical technique in robot-assisted choledochal cyst excision with Roux-en-Y hepaticojejunostomy was performed as previously described [2]. Briefly, the operation was performed with the da Vinci Surgical system Si (Intuitive Surgical, Sunnyvale, CA) using the "3+1" mode in which four ports were placed, including three ports for the robotic arm (two 8-mm working ports and one 12-mm camera ports) and one 5-mm port for laparoscopic assistance (Fig. 3). Traction sutures to the gallbladder and round ligament were first performed laparoscopically for better exposure of the cyst and hilum. For huge cysts, it was necessary to decompress the cyst to facilitate the dissection. The Roux-en-Y limb was fashioned extracorporeally using an Echelon Flex™ powered plus stapler (Ethicon Endo-Surgery, Cincinnati, OH, USA). The anastomosed jejunum was then placed back into the abdominal cavity, and the Roux limb was brought without tension through the retrocolic window to the porta hepatis using the laparoscope. After docking the robotic system, the choledochal cyst was removed and hepaticojejunostomy was performed. The diameter of the remaining common hepatic duct after cyst resection was

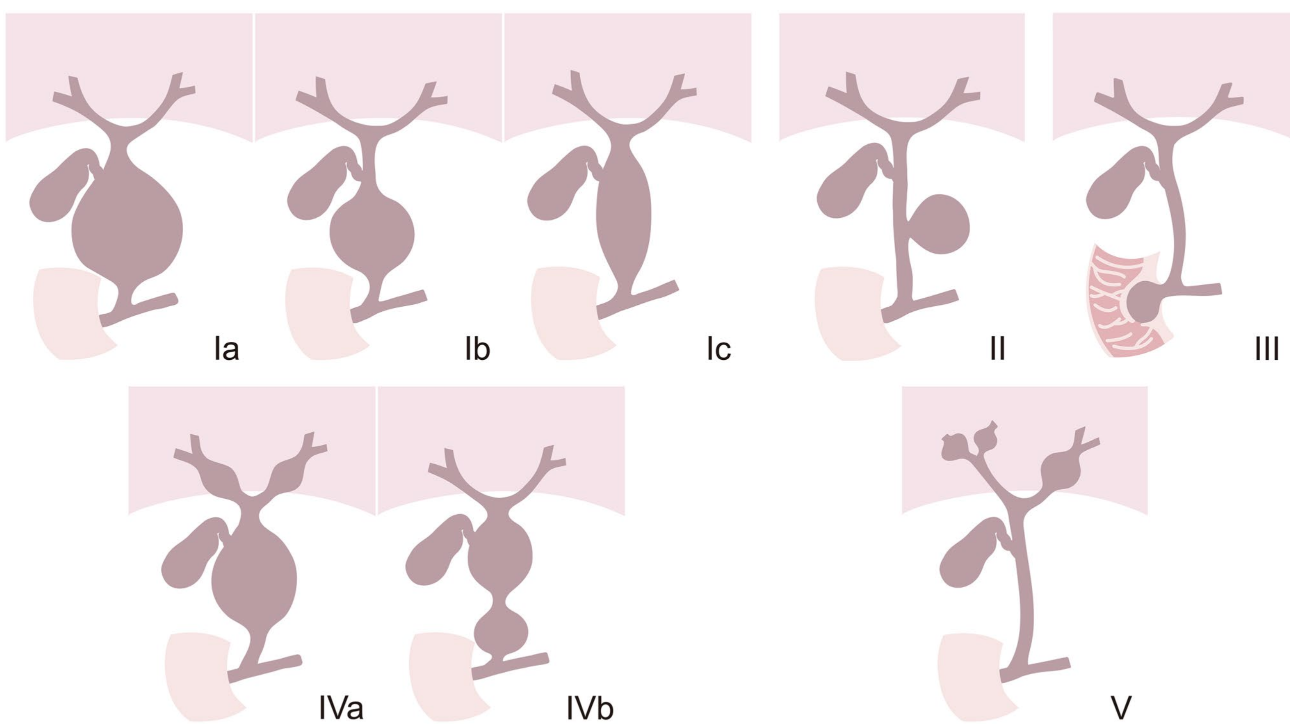

Fig. 1 Todani modification of the Alonso-Lej et al. classification of choledochal cysts

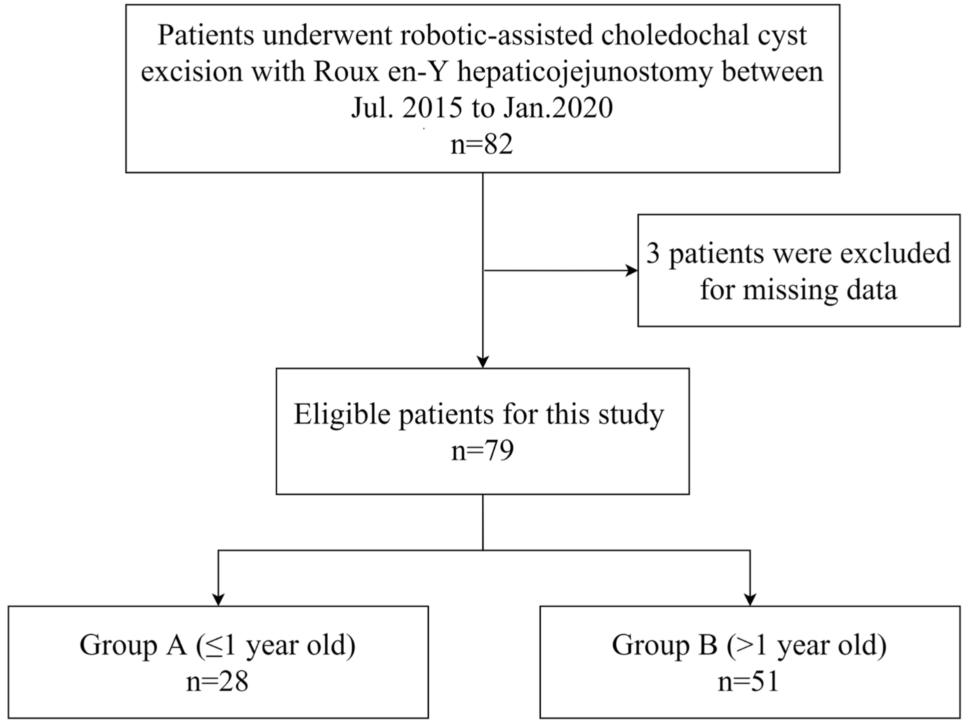

Fig. 2 Flowchart of patient selection

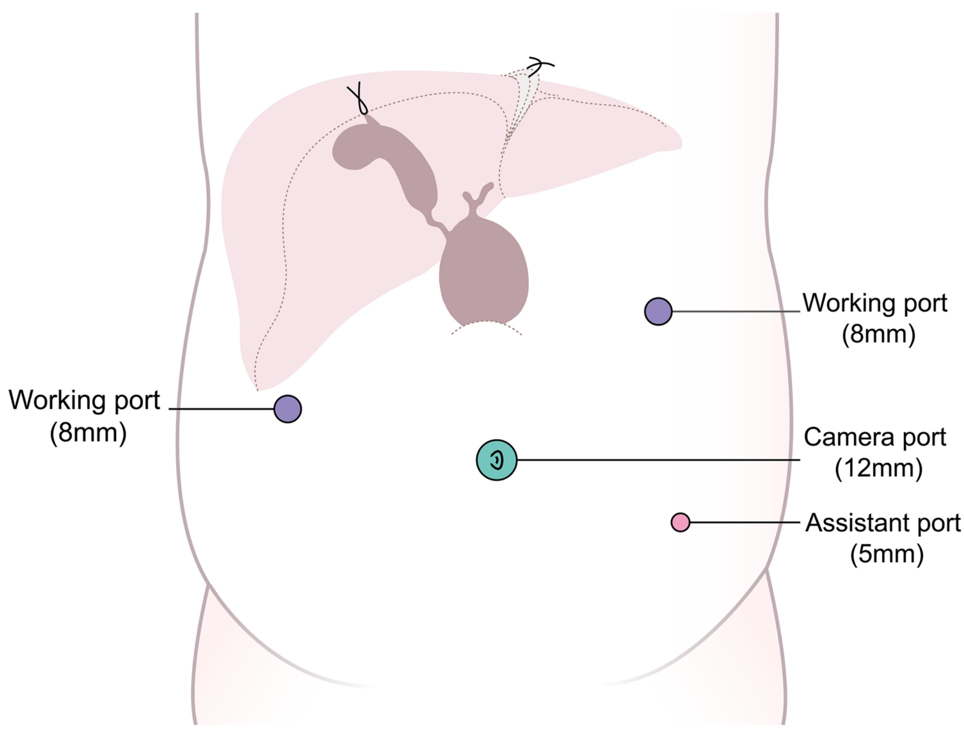

Fig. 3 Port placement in robotic-assisted surgery for choledochal cysts. One 12-mm port for the robotic camera, two 8-mm ports for robotic working arms, and one 5-mm port for laparoscopic assistance

evaluated, and for the bile ducts less than 6 mm in diameter (Fig. 4a), a modified anastomosis method was adopted to prevent anastomotic stricture, which was based on the previously reported laparoscopic ductoplasty plus widened portoenterostomy [14]. The common hepatic duct was split upward to the junction of the left and right hepatic ducts (Fig. 4b). The distal edge of the portal bile duct was then everted circumferentially and secured to the surrounding hepatic parenchyma or the seromuscular layer of the proximal bile duct (Fig. 4c), thus forming a papilla (Fig. 4d). The

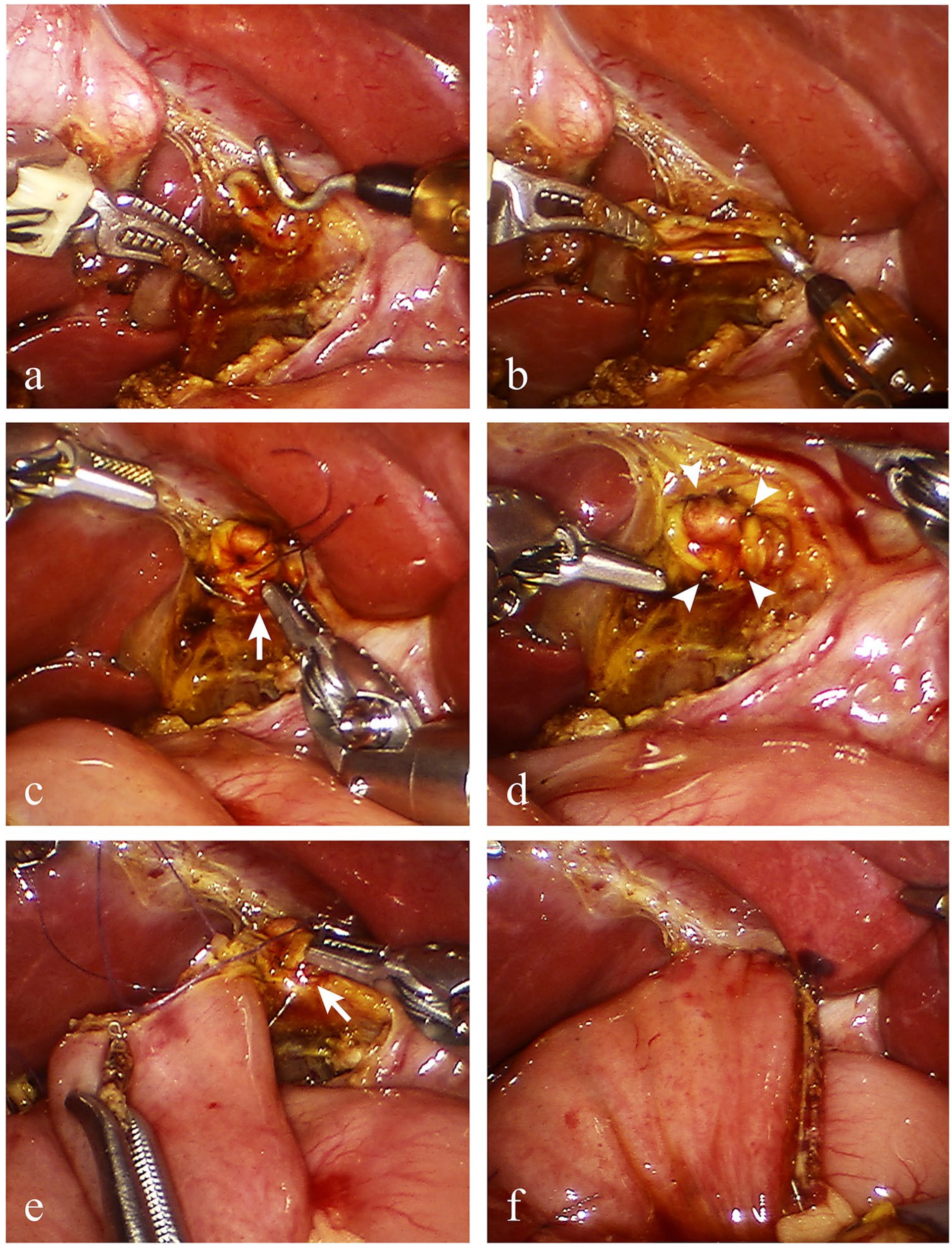

Fig. 4 Intraoperative pictures of robotic-assisted ductoplasty plus widened portoenterostomy: **a** Narrow common hepatic duct of 4 mm diameter versus electric hook; **b** Widening of the opening by splitting upward; **c** Everting of the distal end of the bile duct by securing to its proximal seromuscular layer (arrow); **d** Papillary appearance after four sutures (arrowhead); **e** Anastomosis of the jejunum and the Glisson capsule (arrow); **f** Overall appearance after anastomosis

full-thickness wall of the intestine was sutured continuously to the peripheral capsule (Glisson capsule) or the hepatic parenchyma around the papillary end of the portal bile duct (Fig. 4e), creating a wide anastomotic stoma (10–15 mm) and wrapping the portal bile duct in the intestinal lumen (Fig. 4f). A drain tube was placed under the liver, and the incision was closed.

Statistical analysis

Continuous variables in this study were presented as median (interquartile range) or mean ± standard deviation (SD). To compare the differences between the two groups, discrete variables were analyzed using the χ^2 test and continuous variables using the Student *t* test or Mann–Whitney *U* test. All the data and analyses were performed by SPSS 26.0, and the *p* value of < 0.05 was considered statistically significant.

Results

A total of 79 patients who underwent robot-assisted choledochal cyst excision with Roux-en-Y hepaticojejunostomy were enrolled in our study. Of them, 28 patients aged ≤ 12 months (range: 0.8–12.0 months) were located in group A, including three neonates. And 51 patients who were older than 1 year old (range: 13.2–150.2 months) constituted group B. The youngest patient was 24 days old and weighed only 4.2 kg in group A. There was no significant difference in sex, Todani type, the diameter of the cysts, or follow-up time between the two groups (Table 1).

Robotic procedures in all patients were completed successfully without conversion to open surgery or intraoperative complications. The diameter of the common hepatic duct in group A was smaller than that in group B (6.0 ± 1.7 vs. 9.0 ± 3.0 mm; $p < 0.001$), and a higher proportion of patients in Group A received ductoplasty plus widened portoenterostomy (39.3% vs. 15.7%; $p = 0.028$). The two groups had a similar median total operative time (204 vs. 208 min; $p = 0.747$) and console time (116 vs. 125 min; $p = 0.403$). For the detailed operative times, the hepaticojejunostomy time was longer in Group A (51 vs. 42 min; $p = 0.013$), but the cyst excision time was longer in group B (43 vs. 50 min; $p = 0.005$). The postoperative enteral feeding time was comparable between the two groups (3.6 ± 1.0 vs. 4.0 ± 1.0; $p = 0.146$). Both groups also had similar postoperative lengths of stay (6.9 ± 1.6 vs. 7.3 ± 1.8 days; $p = 0.428$). (Table 1).

Postoperative complications of the two groups are shown in Table 2. There were no statistically significant differences in the overall complication rate between the two groups (3.6% vs.5.9%; $p = 1$). Specifically, one patient in group A experienced intestinal obstruction but recovered from conservative treatment. One patient developed an anastomotic stricture in Group B. This patient had not undergone hilar ductoplasty because of the 8 mm diameter of the hepatic duct, a reoperation was performed by the same surgeon, and the surgical procedures included adopted ductoplasty plus widened portoenterostomy and Roux-en-Y hepaticojejunostomy. Two patients had cholangitis in Group B. They were treated with medical treatment including intravenous antibiotics and recovered finally.

Table 2 Postoperative complications in two groups

Complications	Group A ($n = 28$)	Group B ($n = 51$)	p value
Bile leakage	0	0	–
Bleeding	0	0	–
Anastomotic stricture	0	1	1
Cholangitis	0	2	0.537
Intestinal obstruction	1	0	0.354
Total	1	3	1

Discussion

To our knowledge, this is the first report of surgical outcomes of RAS comparing CCs in infants aged ≤ 1 year and those in children aged > 1 year performed on a series of patients. We implemented optimized and standardized surgical procedures to overcome the confined space in infants. The segmental operative time was presented in this study as

Table 1 Patient demographics and perioperative characteristics in two groups

	Group A ($n = 28$)	Group B ($n = 51$)	p value
Sex (male: female)	6:22	13:38	0.686
Age at operation (months)	4.9 (3.1–9.1)	46.8 (28.5–86.5)	< 0.001*
Weight at operation (kg)	7.5 (5.7–8.5)	15.5 (12.0–23.7)	< 0.001*
Todani modification of the Alonso-Lej classifications (Ia:Ib:Ic:IVa:IVb)	16:1:8:2:1	32:0:12:7:0	0.345
Diameter of the cysts(cm)	3.6(2.2–4.9)	3.1(2.1–4.0)	0.242
Operative time (minutes)			
Total operative time	204 (185–225)	208 (180–221)	0.747
Console time	116 (107–130)	125 (107–134)	0.403
Cyst excision time	43 (41–59)	50 (43–60)	0.005*
Hepaticojejunostomy time	51 (44–58)	42 (38–53)	0.013*
Diameter of the common hepatic duct (mm)	6.0 ± 1.7	9.0 ± 3.0	< 0.001*
Implementation of ductoplasty plus widened portoenterostomy	11	8	0.028*
Conversion to open	0	0	–
Intraoperative Complications	0	0	–
Time to enteral feeding (days)	3.6 ± 1.0	4.0 ± 1.0	0.146
Postoperative length of stay (days)	6.9 ± 1.6	7.3 ± 1.8	0.428
Follow-up time (years)	3.0 ± 1.6	3.2 ± 1.8	0.560

*$p < 0.05$

the surrogate for the difficulty of the procedure. All operations in both groups were completed without conversion to open surgery. It is demonstrated that RAS for CCs in infants aged ≤ 1 year was technical feasibility, safety, and efficacy, without increasing operative time or complications compared with older patients.

RAS for small pediatric patients is a challenging procedure and remains controversial. One of the major reasons is the size constraints of the da Vinci Surgical System. Collisions can occur and inhibit the proper use of the instruments [5]. Previous research suggested that RAS was limited to patients older than 2 years and with a weight > 15 kg [15]. However, some argued that, through certain adjustments, RAS is feasible in children under 15 kg, but with a minimum limit of 3 kg. [16]. Similar age or weight restrictions, such as 6 months or 8 kg, have also been mentioned in studies of RAS for CCs [3, 11]. Few studies have focused on applying RAS for the treatment of CCs in small children (Table 3). In 2010, Dawrant et al. first presented their successful experience with RAS in 5 children weighing less than 10 kg who underwent robotic resections of CCs and hepaticojejunostomy [10]. They began by docking the robotic system to excise the cyst, then created the Roux loop outside the abdominal cavity, and finally re-docked and performed the biliary-enteric anastomosis. Another recent case series on RAS for CCs reported 10 patients under the age of 1 [11]. As described in this report, the extracorporeal end-to-side anastomosis of the jejunum was performed first, followed by the cyst resection and the hepaticojejunostomy, thus avoiding the re-docking of the robotic system. A subsequent study adopted a similar surgical sequence, including a subset analysis of 27 patients weighing less than 10 kg [12].

The difference from these studies was that we enhanced the assistance of conventional laparoscopy. First, the gallbladder and the round ligament were suspended under laparoscopy to expose the cyst and hilar. Then, the Roux loop was fashioned extracorporeally as in prior studies. Before docking the robotic system, the Roux limb was also pre-positioned to the hilar region laparoscopically. Laparoscopic instruments are more favorable in size for large movement within the abdominal cavity, so they are used for less difficult but wide-ranging procedures. In contrast, the application of robotic instruments is mainly limited to complex procedures around the hilar region, avoiding the wide movement of the robotic arms. The superb efficiency was attributed to the adjustment of the operating sequence, the combined surgical approach, and the help of a linear stapler device. Therefore, our mean operative time was shorter than that of other centers (Table 3). Depending on the main operating area of the robotic system, we triangulate the position of ports to achieve better ergonomics and to distance the ports as far apart as possible. The ports can be 6–8 cm apart in older children and around 4.5–6 cm in infants. Although the recommended distance for port placement in RAS is 8–10 cm, we did not suffer from instrument collisions during operations through our strategic optimization.

Other reasons for limiting RAS in infants include the risks of anesthesia and the respiratory effects of pneumoperitoneum [17]. Thanks to the improved surgical efficiency, our operative time of RAS is approaching that of laparoscopic surgery [2], with a corresponding reduction in anesthetic and pneumoperitoneum time. The pneumoperitoneum pressure could also be controlled at 6–12 mmHg. This may reduce the risk of RAS for infants to an acceptable level.

The minimum age of the patients in previous studies was 6 months [10, 11]. The number of infants included in our study was greater and the age at the time of surgery was younger. Eight infants were younger than 6 months, and three of them were even newborns. This may suggest that a cut-off age for RAS to be unsafe or technically unfeasible is not absolute.

Besides, we have found that families of infant patients are more concerned about the postoperative cosmetic outcome than those of older children. Our center has been using the da Vinci Si system with a camera size of 12 mm. Although the new fourth-generation da Vinci Xi system offers a smaller camera of 8 mm [17], we believe that the camera size has little impact on the cosmetic appearance. Because the camera

Table 3 Review of the literature on surgical outcomes of robot-assisted choledochal cyst excision with Roux-en-Y hepaticojejunostomy for small children

Author	Year	Number of cases	Mean age in months (range)	Mean weight in kg (range)	Mean operative time, mins	Conversion to open surgery	Mean length of stay, days	Mean follow-up time, years	Postoperative complication
Dawrant et al. [10]	2010	5	11.5 (6.0–16.8)	8.5 (7.6–9.5)	482	0	6	0.5	0
Xie et al. [11]	2021	10	8.8 (6.0–11.0)	9.11 (8.3–9.9)	219.5	0	7.6	2	1
Ihn et al. [12]	2021	27	NA	NA (6.3-NA)[a]	371.3	0	7.3	NA	1
Current study		28	5.8 (0.8–12.0)	7.4(4.2–9.9)	206	0	6.9	3.0	1

[a]All patients weighed under 10 kg (the minimum body weight was 6.3 kg and seven patients weighed less than 7 kg)

was inserted through the umbilical incision, cosmetically the scar here did not present a significant difference.

Similar total operative time and console time for infants and older children in this study may indicate that both age groups had similar levels of surgical difficulty. We also recorded the time spent on cyst excision and hepaticojejunostomy, which is the emphasis and difficulty in RAS for CCs. The time of hepaticojejunostomy in the infant group was significantly longer than in the older child counterparts. Two reasons could explain this result. On the one hand, the size of the common hepatic duct was small and the tissue was friable in infants, which may increase the difficulty and prolong the operative time. On the other hand, most patients in Group A required ductoplasty plus widened portoenterostomy due to the narrow common hepatic duct, leading to a longer time of anastomosis. Interestingly, the time of cyst excision in group A is shorter than in group B. This may relate to the shorter course in infants, which means much milder inflammation, less tissue adherence, and easier dissection [18, 19]. Overall, although patients in Group A required more delicate and complex handling due to their young age, they also benefited from early surgery, making the overall difficulty of the procedure comparable to that of Group B.

Indeed, we believe that RAS in infants requires greater patience than in older children. Just as summarized by literature [11], we have gained some experience with older children before applying the RAS to infants. Moreover, the robotic system has been of great help in complex hepatobiliary operations on infants. The camera can provide 3D visualization with high magnification. Robotic arms have instrumentation articulations with improved degrees of freedom, tremor filtration, and motion scaling [20]. These features make dissection, suturing, and knot tying easier within the narrow operational workspaces.

Our findings showed that postoperative complications and outcomes did not differ significantly between the two groups. The total postoperative complications were encountered by one child (3.6%) in the lower age group, which was comparable to previously reported results [12]. In patients with narrow common hepatic duct, biliary stent implantation [21, 22] or hilar ductoplasty [23, 24] was performed to prevent anastomotic stenosis. This was especially important in infants, who had a smaller common hepatic duct diameter. Instead of placing biliary stents, our center has addressed this problem by adopting ductoplasty plus widened portoenterostomy during RAS. This approach, initially used in laparoscopic surgery [14], is now performed by RAS. In addition to reducing the difficulty greatly, the robotic technology with higher dexterity and precision also allows improvement of the original procedure. We have continued the previous anastomosis of the jejunum and the Glisson capsule around the hilar duct, thus avoiding the contraction of circular scarring. Besides, we folded the end of the hepatic duct outwards, which was difficult to achieve laparoscopically, to prevent the opening from collapsing and closing. As a result, no anastomotic stenosis occurred in patients with narrow common hepatic ducts during the follow-up period.

The limitations of our study include single-center experience, retrospective data, and a small sample size. These may have introduced selection bias and rendered the study underpowered in detecting small differences between the results of the two groups. Notwithstanding, the information provided may be useful for pediatric surgeons with consideration of applying RAS to infants with CCs.

Conclusions

In conclusion, our study proved that robot-assisted laparoscopic CC resection and hepaticojejunostomy for children under 1 year old achieved equally effective as older children, which was feasible and safe. However, more cases and long-term follow-ups are needed to demonstrate the real benefits of robotic surgery in young children with CCs.

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Declarations

Disclosures Li-ying Rong, Yi-bo Li, Jing-feng Tang, Guo-qing Cao, Li Wan, Xiang-yang Li, Xi Zhang, Shui-qing Chi, and Shao-tao Tang have no conflicts of interest or financial ties to disclose.

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