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The First Single-Port Robotic-Assisted Excision of Choledochal Cyst and Hepaticojejunostomy in Children

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ABSTRACT

Background: Choledochal cysts are congenital anomalies requiring surgical intervention, typical excision and hepaticojejunostomy. The da Vinci single-port (SP) robotic system offers a minimally invasive approach with potential benefits for paediatric patients.

Methods: This study describes the SP robotic-assisted resection of choledochal cysts and hepaticojejunostomy in two paediatric patients. Surgical techniques, system description, and procedural outcomes were detailed.

Results: Both surgeries were successfully completed with minimal blood loss and no intraoperative complications. Patients transitioned to a soft diet by postoperative day 3 and were discharged by day 6 without complications. Follow-up at 6 months showed normal sonography and laboratory findings.

Conclusions: The da Vinci SP system facilitated precise single-incision surgery with improved manoeuvrability and visualisation, demonstrating safety and feasibility for paediatric choledochal cyst excision and hepaticojejunostomy. Further studies are warranted to confirm these findings across larger paediatric populations.

1 | Introduction

Choledochal cysts represent a congenital anomaly of the extra- and intrahepatic biliary systems, which are predominantly diagnosed during childhood or even prenatally and predominantly occur in individuals of Asian descent, with the incidence in Japan reaching as high as 1 in 10,000 [1]. These cysts are associated with significant pancreaticobiliary complications, including cholangitis, pancreatitis, liver cirrhosis, and cholangiocarcinomas, requiring surgical intervention. Traditionally, the standard treatment has involved the complete resection of the choledochal cyst followed by Roux-en-Y hepaticojejunostomy (HJ). Recent trends in management emphasise minimally invasive techniques, with laparoscopic surgery remaining a prevalent choice. Because of the inaugural report in 2006, robotic-assisted surgery has emerged as a viable option [2], demonstrating safe procedures with excellent functional outcomes. However, conventional robotic trocars, which are 8–12 mm in diameter, produce relatively larger scars in paediatric patients compared with those from laparoscopic procedures, despite similar surgical outcomes.

The da Vinci single-port (SP) system (Intuitive Surgical, Sunnyvale, CA, USA) has recently been introduced, offering a substantially different surgical experience compared with traditional single-port laparoscopic surgery. Unlike laparoscopy, the SP system features multi-jointed wristed instruments and a three-dimensional, high-definition articulating scope, which facilitates ideal triangulation. This system is also gaining traction in paediatric urology due to its success in a recent

surgical case involving an infant, underscoring its expanding utility [3].

This study aimed to describe the robotic SP technique for choledochal cyst excision and Roux-en-Y HJ in paediatric patients and assess its safety and feasibility. Our study included a detailed overview of the procedure and the benefits of the SP system.

2 | Methods

2.1 | Participant and Ethical Considerations

The same surgeon performed all robotic SP surgeries in this study, ensuring consistency in the surgical technique and outcomes. Before participation, parents of all patients were fully briefed on the innovative nature of the da Vinci SP system and its potential benefits and risks. All parents provided informed consent following these discussions (Supporting Information S1 and S2). The Institutional Review Board at Dongsan Medical Centre approved our study (IRB File No. 2024-05-043).

2.2 | SP Robotic System Description

The da Vinci SP system shares a similar surgeon console with its predecessors, which is multiport the da Vinci X or Xi systems. However, distinct from the multiport robotic system, the SP system is specifically designed for SP entry, incorporating one camera and three instruments through a single incision (Figure 1). Unlike SP laparoscopy, each instrument and camera possess two joints, enhancing manoeuvrability within a limited space, such as the abdominal cavity, in children. These articulated joints mimic the bending of a human elbow, which provides effective surgical manipulation in constrained fields. Additionally, the camera can be adjusted to various angles (upside, downside, and multiple directions), securing diverse and comprehensive surgical views. The SP system's integrated navigation system allows the surgeon to monitor the spatial arrangement, articulation, and any potential instrument conflicts in real-time without significant assistant intervention. An access port kit was used for the floating docking technique to accommodate the limited abdominal space in paediatric patients (Figure 2).

2.3 | Surgical Techniques

The patients were positioned in the supine position with a reverse Trendelenburg tilt. The procedure was performed according to traditional laparoscopic choledochal cyst excision with Roux-en-Y HJ [4], adapted to the capabilities of the da Vinci SP system. A 2.7-cm incision was made at the umbilicus where the access port kit for small incisions was inserted to establish a pneumoperitoneum at 10 mmHg pressure (Figure 2). The da Vinci SP surgical cart was positioned at the right side of the patient's bed and docked to the operating port. Through this port, the Endowrist SP camera with an above view, 6-mm Maryland bipolar forceps, 6-mm Cardiere forceps, and a 6-mm

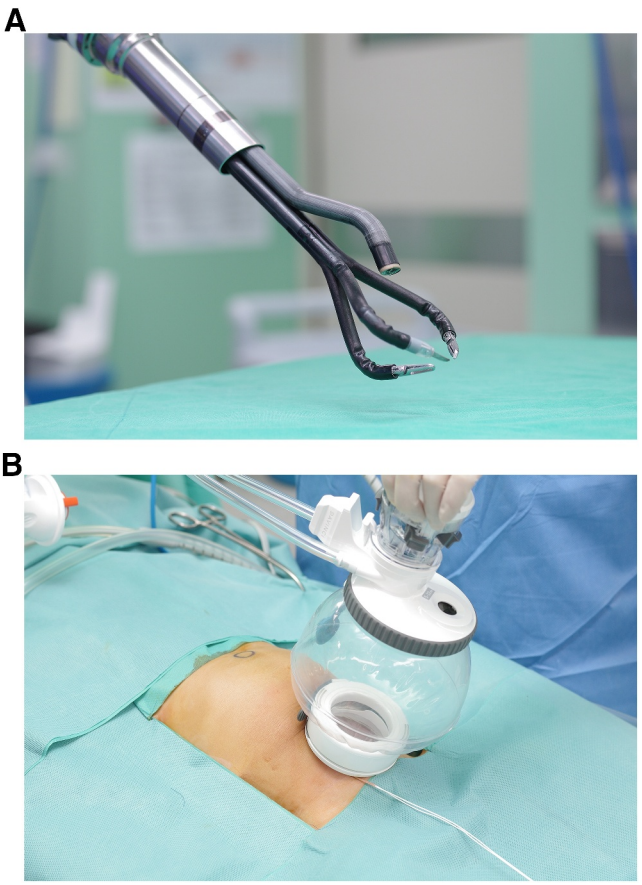

FIGURE 1 | (A) Three instruments and an endoscope through a single port. Each instrument, including an endoscope, can achieve triangulation and move easily with multiple joints. (B) The access port kit for small incisions was inserted through an umbilical incision.

Needle driver were introduced into the abdominal cavity. To enhance the surgical field visibility, falciform and gallbladder tenting was performed using the first and third robotic arms, respectively. Subsequently, the third arm was swapped for monopolar curved scissors, and the duodenum was tractioned downward using the Cardiere forceps to facilitate a top–down approach for distal common bile duct (CBD) dissection. Throughout this process, the real-time status of the camera and instrument articulation was continuously displayed on the navigation bar positioned centrally below the main screen (Figure 3A). An advantage of SP robot surgery is the third arm traction because it does not require a surgical assistant, allowing the operator to control position, orientation, and force. The distal portion of the choledochal cyst was sharply tapered to a normal duct, which was ligated using a Weck Hem-o-lok medium–large polymer clip and divided (Figure 3B).

The following procedure was performed in cases where preoperative magnetic resonance cholangiopancreatography (MRCP) revealed protein plugs or sludge in the distal CBD or common channel: After completing the distal CBD dissection, an incision was made into the dilated CBD, and an 8-Fr Levin tube was inserted to pass through the common channel, facilitating obstruction removal. Subsequently, operative cholangiography was performed to confirm the removal of any plugs or sludge

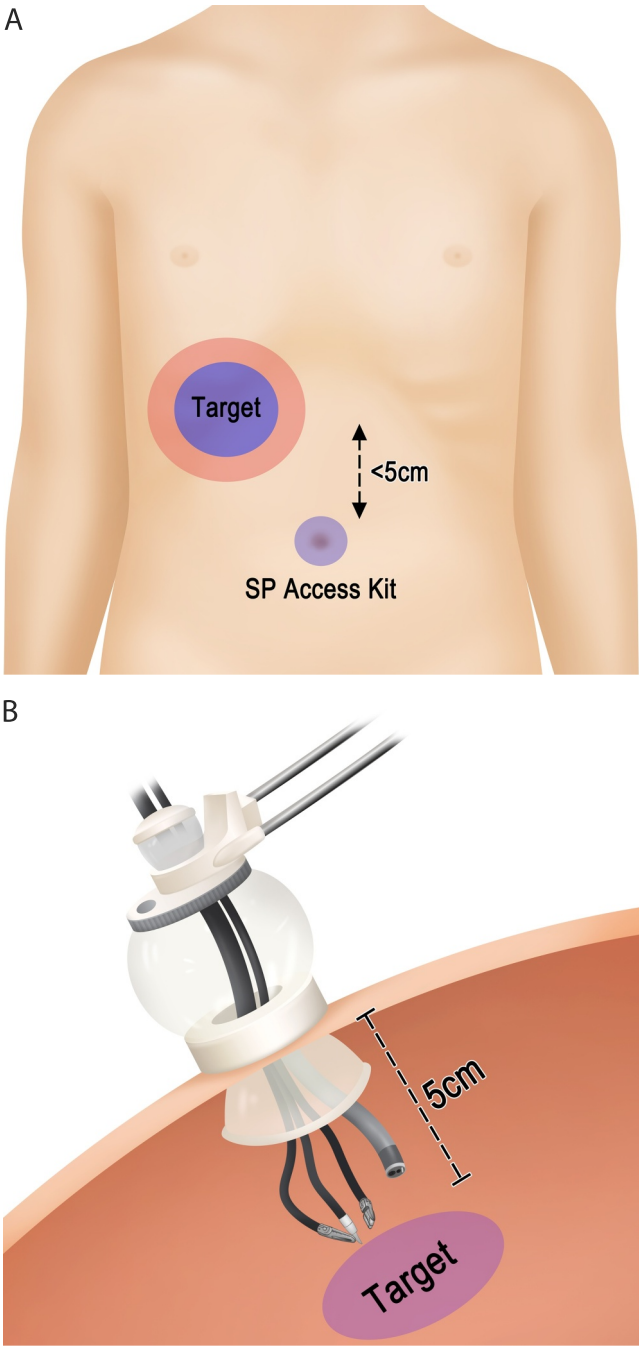

FIGURE 2 | (A) Location of the umbilical port and the target within a short distance. (B) This specialised port allows for whole robotic articulation with a minimum distance of 5 cm.

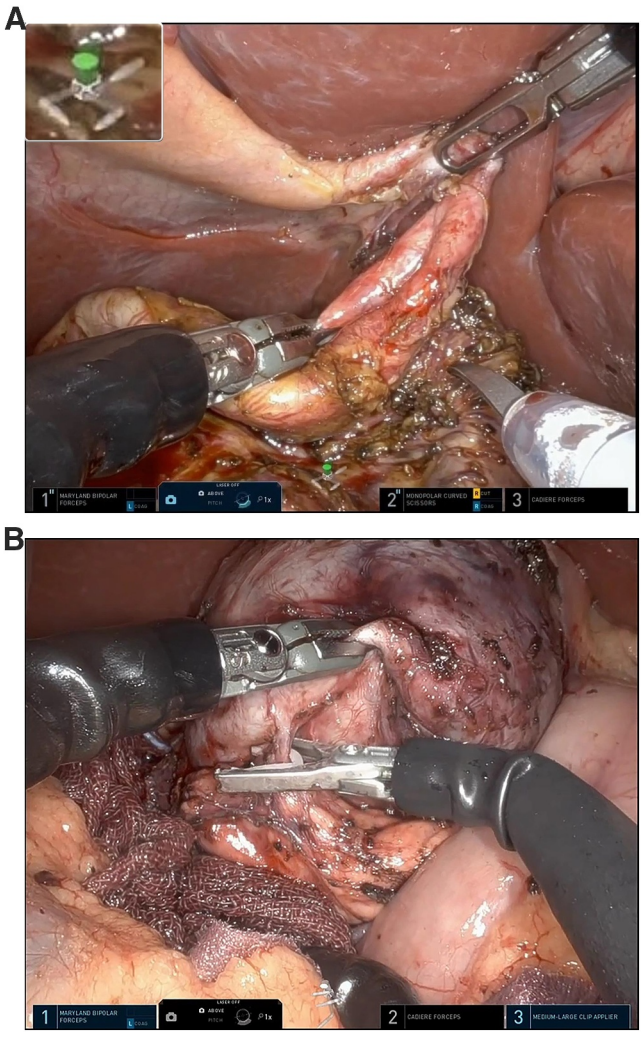

FIGURE 3 | (A) A navigation bar below the centre shows the camera location (green), and the location and the status of each arm's location in real-time. The instrument spatial orientation can be seen in this bar. (B) Transition between the dilated distal common bile duct (CBD) and normal CBD. A 5-mm Weck Hem-o-lok medium–large polymer clip was used for ligation.

(Figure 4). Following confirmation, the distal CBD was clipped using the same method.

Subsequent manoeuvres involved the use of the divided stump to retract the cyst cephalad, allowing posterior dissection off the portal vein. Proximal dissection was continued up to the level of the common hepatic duct with cyst excision at the hepatic ducts' confluence. Unlike multiport surgery, stable traction was achieved by lifting the liver's hilum with the Cardiere forceps attached to the third arm. Additionally, this method also facilitates easy transection of the proximal common hepatic duct.

The ligament of Treitz was identified, and a Roux limb was marked 20 cm distally. Subsequently, the robotic system was undocked, and the small bowel was exteriorised through the umbilical wound to create a 50-cm Roux limb and jejuno-jejunostomy extracorporeally. An enterotomy was performed on the antimesenteric side of the Roux limb tip to aid in its later intracorporeal identification. Subsequently, the small bowel was returned to the abdomen, where the SP robotic system was redocked, and the Roux limb was brought retrocolic to the hilum. The previously created enterotomy was tailored, and continuous 5-0 Monosyn suture was used to construct the HJ (Figure 5).

After anastomosis completion, a JP drain was placed posterior to the anastomosis site, and the Roux limb and jejunojejunostomy

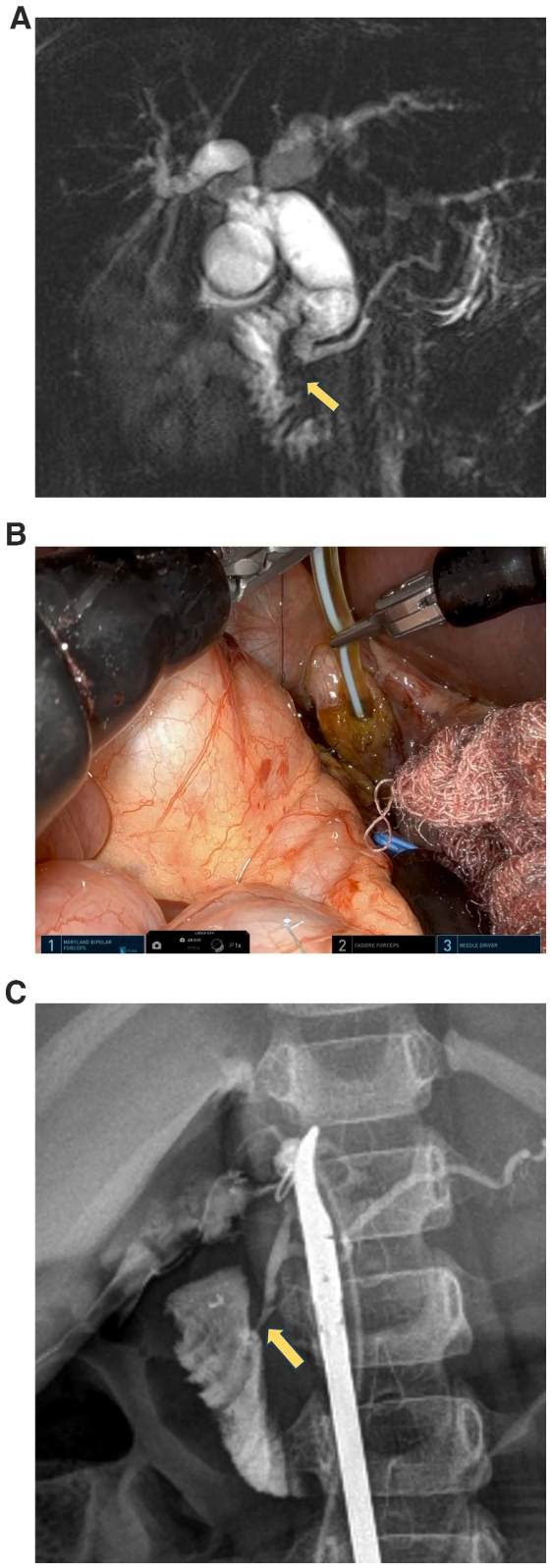

FIGURE 4 | (A) Preoperative MRCP image from a patient with cholangitis. The protein plug was identified in the common channel (arrow). (B) After incision of the common bile duct (CBD), an 8-Fr. Neonatal nasogastric tube was inserted and pushed towards the distal CBD to remove the protein plug in the common channel. (C) Intraoperative cholangiography was performed to confirm the disappearance of the protein plug in the common channel.

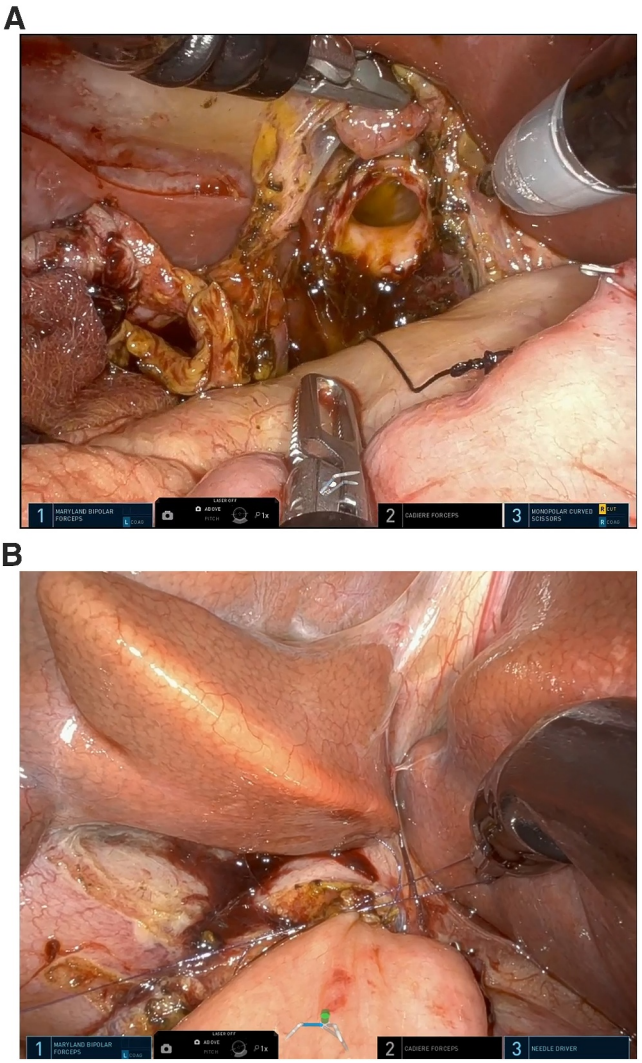

FIGURE 5 | (A) Transected proximal common hepatic duct. (B) Hepaticojejunostomy with a continuous running suture.

were reexamined to confirm their proper positioning without torsion, bleeding, or bile leak. Cholecystectomy was completed, and the specimen was removed using an endo-bag. Fascial and skin incisions were closed using absorbable sutures.

3 | Results

Table 1 presents the patient characteristics.

Both surgical interventions were successfully performed with no intraoperative complications. In each case, the estimated blood loss was minimal. No transfusion was necessary perioperatively. Each surgery was performed using two to three robotic dockings. Table 2 shows the details of the operative characteristics, including docking and console times. On the third and fourth postoperative days, the patients progressed to a soft diet, and the JP drain was removed on the fifth postoperative day. The patients were discharged on postoperative days 5 and 6 without complications. Both patients were followed up at 6 months, and

TABLE 1 | Patient characteristics.

Case	Age (months)	Sex	Height (cm)	Weight (kg)	Symptom[a]	Cholangitis	Pancreatitis	Todani type	Protein plugs in the common channel
1	48	M	102	18	No	No	No	IVa	No
2	50	F	101	15	Yes[a]	Yes	Yes	IVa	Yes

[a]Abdominal pain, jaundice, and leukocytosis.

TABLE 2 | Details of operative characteristics.

Case	EBL[a] (mL)	Total OP[b] time (min)	Docking no.	Docking time (min)	Console time (min)	Instrument active (min)	Instrument count	Instrument exchange	SOW[c]	Discharge	Cx[d]
1	20	485	3	21	434	314	5	23	4	6	No
2	< 10	433	4	17	387	244	5	26	3	5	No

[a]EBL: Estimated blood loss.
[b]OP: Operation.
[c]SOW: Sips of water.
[d]Cx: Complications.

follow-up sonography and laboratory findings were also normal (Figure 6).

4 | Discussion

Although robotic systems operate smoothly in adult thoracic and abdominal surgeries, their efficacy across varying paediatric age groups and sizes—from neonates to adolescents—has not been conclusively determined. Prior research suggests that robotic arms function most effectively within a 7-cm cubic space, encountering significant collisions at 4–4.5 cm and tolerable collisions at 5–6-cm cubic spaces [5]. However, recent studies have shown that robot-assisted surgery on small infants is feasible, and the time and safety of the procedure are not different from those of paediatric patients older than 12-month-old [6–8]. Moreover, these findings are specific to multiport systems, and multiport robot-assisted surgery is frequently used in paediatric settings because of its precision and superior visualisation.

Introduced in 2018, the da Vinci SP system was developed to enhance the capabilities of single-site robot-assisted surgeries, which were previously limited to cholecystectomies and gynaecological procedures. However, these initial systems did not fully leverage the robotics' potential due to technical shortcomings, such as external collisions and limited joint mobility [9]. Single-site robot-assisted surgeries in children typically require an additional port, which complicates the procedure [10]. Unlike the earlier systems, the SP allows for greater freedom of movement for the robotic arms within the abdominal cavity. However, the joints require a minimum amount of space for proper unfolding. The instruments and camera should be inserted at a minimum distance of 12.5 cm into the body to ensure that the elbows clear the metal cannula tip, with the port ideally placed 10–25 cm from the surgical field's edges for optimal instrument separation and triangulation [11, 12].

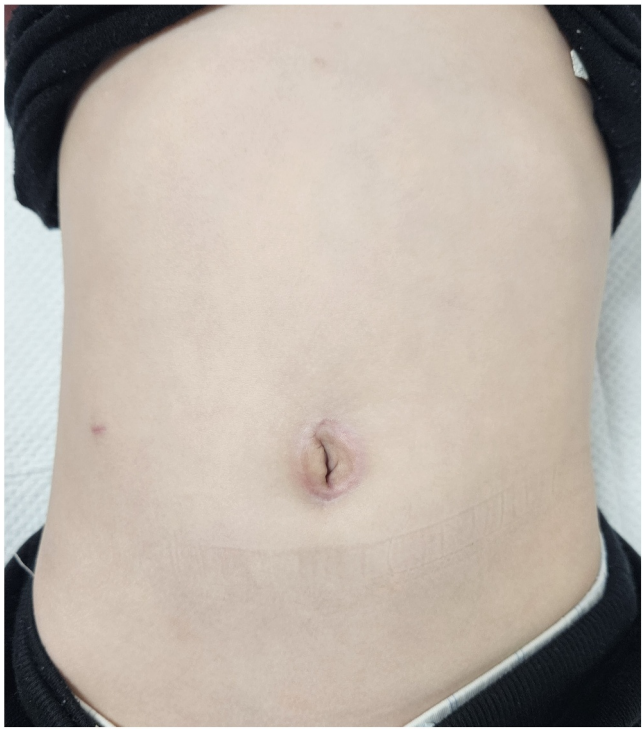

FIGURE 6 | Postoperative periumbilical scar 6 months postoperatively.

This case used a floating technique to overcome the smaller paediatric abdominal spaces. Floating allows the cannula to operate effectively when the surgical target-to-cannula distance is < 10 cm, enabling the use of the robotic system in smaller cavities [12, 13]. This approach facilitated the surgery after deploying the 5-cm joints. Another advantage of the SP system is its ability to simultaneously use three arms and a scope, significantly improving manoeuvrability and visualisation intraoperatively. Thus, we were able to perform surgery on a 15-kg patient with small abdominal cavities without any significant difficulties. Moreover, it could also be effectively used in even smaller

patients. Kang et al. [14] reported that the instrumental replacement time for the SP robotic system was longer than the multiport system, and the use of the floating technique increased the difficulty of the surgery. This is due to the surgeon re-adjusting the entire remote centre to re-align the pivot point of the instrument, which is called the remote centre. In our study, we tried to avoid replacing the instruments as much as possible. Recently, the DaVinci SP system has updated its software to add a custom remote centre (CRC) allowing the surgeon to adjust the remote centre arbitrarily when floating, and with the help of CRC, the surgeon can easily replace the instrument even when floating, so the longer instrumental replacement time compared with multiport can be overcome. However, more case studies are needed to confirm its applicability in such scenarios in the future.

Our cases replicated traditional laparoscopic procedures, except for the routine use of intraoperative cholangiography. Routine intraoperative cholangiography was not performed because all paediatric patients with choledochal cysts underwent preoperative MRCP [15]. However, intraoperative cholangiography was performed as needed in cases with associated biliary symptoms due to bile duct sludge or protein plugs, which was shown in this case of cholangitis. Unlike laparoscopic surgery requiring an assistant for traction, traction was performed independently without assistance, utilising the robotic camera's flexibility and dual 3D-viewing capabilities. In a patient with a history of cholangitis, the protein plug in the common channel was removed using an 8-Fr nasogastric tube, and the freedom of movement of the robot's joints made this manoeuvre easier than laparoscopic surgery. Furthermore, the SP system permitted the insertion of the necessary ports through a single incision made for the Roux-en-Y, unlike most multiport robotic and laparoscopic surgeries that require an umbilical site extension.

Robotic joints have greater precision than laparoscopy, enhancing surgical outcomes. However, a potential drawback of the SP surgery is the need for assistance in emergencies, such as sudden bleeding, where additional ports may be necessary. Future strategies might include the precreation of the Roux limb to save docking time, similar to approaches in multiport robot-assisted surgery. However, more cases are needed to validate the efficiency of such adaptations.

The SP robotic system represents a promising advance in paediatric surgery, mirroring its success in adult general surgery [16]. Research on multiport surgeries has highlighted the superiority of robotic systems in terms of visualisation and handling. The SP system incorporates all reported advantages for patients with similar size to adults. In our cases, the procedure was successfully performed on a patient weighing approximately 15 kg without postoperative complications, demonstrating the system's effectiveness and potential for broader paediatric applications.

Despite these strengths, some areas warrant further improvement and consideration. The high cost of the SP system remains a significant barrier to widespread adoption. Additionally, technical challenges, such as “fighting” between the deployed robotic arms intraoperatively due to the relatively small operating space in paediatric patients should be addressed to enhance the system's functionality and safety.

Although further research is necessary, the use of the da Vinci SP system for choledochal cyst excision and HJ is a safe surgical method that enables precise operations with smaller scars.

Although the da Vinci SP system has considerable potential for broader application in paediatric surgery, further studies and case evaluations are essential to fully establish its effectiveness and optimise its design and functionality for paediatric use. This will ensure that the benefits can be consistently realized across a wider range of surgical scenarios and patient demographics.

5 | Conclusion

The da Vinci SP system showed several significant advantages that underscore its potential for complex paediatric surgeries. First, intricate surgical procedures can be performed by using only a single incision, which facilitates precision while minimising surgical trauma and improving cosmetic outcomes. Second, the simplicity and speed of port insertion and docking processes enhanced the efficiency of the surgical workflow. Moreover, the capability to operate three arms and a camera from a single port effectively replicated the benefits of a traditional four-port multiport setup, allowing this arrangement for solo surgery with smoother dissection processes because of the ability to perform traction with one of the arms.

HJ was performed due to the precision of the robotic system, making it more feasible and stable, significantly contributing to surgical precision and patient safety, and potentially improving recovery times and outcomes.

Ethics Statement

The Institutional Review Board at Dongsan Medical Centre approved our study (Approval No. 2024-05-043).

Consent

Informed consent was obtained from all parents following these discussions.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability Statement

The author has nothing to report.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.