

Robotic Surgery for Pediatric Choledochal Cysts: Advancing the Minimally Invasive Frontier. First Italian series.

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Abstract

Introduction:

Choledochal cyst is a congenital dilatation of the biliary tract, most frequently involving the extrahepatic bile ducts, and presents with symptoms such as jaundice and abdominal pain. Minimally invasive surgery offers advantages in improved intraoperative visualization, reduced postoperative pain, and better cosmetic outcomes. Due to the technical challenges associated with biliary reconstruction and the anatomical features of pediatric patients, robot-assisted surgery has emerged as a valuable alternative. This study aims to analyze the robotic surgical experience of our center in the treatment of choledochal cysts.

Materials and methods

This retrospective study analyzes the robotic experience from 2016 to 2024. Collected data included age, sex, weight at the time of surgery, presence of symptoms and/or associated comorbidities, type of surgical procedure performed, operative time, intraoperative complications, length of postoperative hospital stay, duration of parenteral nutrition, postoperative complications, and follow-up.

Results

Three female patients were included, all of whom underwent choledochal cyst resection and hepaticojejunostomy using a robot-assisted approach. The mean age at surgery was 22.6 months (range: 14–40), with a mean weight of 11.1 kg (range: 10–15). In two cases, the diagnosis was made postnatally by ultrasound in the presence of clinical symptoms (abdominal pain and jaundice); in the third case, the diagnosis had been established prenatally. According to the Todani classification, two patients had type Ia cysts and one patient had a type Ic cyst. The mean operative time was 413 minutes (range: 340–500). No intraoperative complications occurred, and no conversion to laparoscopic or open surgery was required. The mean postoperative hospital stay was 10.5 days (range: 9–15). The mean follow-up was 24 months (range: 18–36), during which a single complication was recorded: a *Clostridium difficile* infection that occurred approximately 1 month after surgery.

Conclusions

Robot-assisted surgery appears to be a safe and effective option for the management of choledochal cysts in pediatric patients, even in centers with lower case volumes but with established expertise in minimally invasive surgery. The robotic approach provides enhanced visualization and greater precision of movements, proving particularly advantageous during the reconstructive phase, where conventional laparoscopy presents greater technical limitations.

Introduction

Choledochal cysts (CCs) are congenital anomalies characterized by cystic or fusiform dilatation of the biliary tree. Their incidence varies geographically and shows a strong female predominance [1–3]. Although the pathogenesis remains incompletely understood, an abnormal pancreaticobiliary junction with pancreatic juice reflux is considered a major etiological factor [4].

Clinical presentation in children is variable and often age-dependent. While older children may present with abdominal pain or jaundice, infants frequently show nonspecific symptoms, and an increasing number of cases are diagnosed prenatally through routine ultrasonography [5, 6]. Complete cyst excision with biliary reconstruction is recommended to prevent severe complications such as cholangitis, biliary cirrhosis, portal hypertension, and malignant degeneration [7–9].

Minimally invasive surgery has progressively replaced open approaches in pediatric CC management, offering reduced postoperative pain, shorter hospitalization, and improved cosmetic outcomes [10]. Nevertheless, laparoscopic CC excision remains technically demanding, particularly during hepaticojejunostomy, due to limited instrument articulation and two-dimensional visualization, challenges that are accentuated in small pediatric patients [11, 12].

Robotic-assisted surgery offers three-dimensional visualization, enhanced dexterity, and improved ergonomics, which can potentially facilitate precise biliary dissection and reconstruction [13, 14]. Although increasing evidence supports its use in pediatric CC surgery, data from low-volume centers remain limited. This study reports the first Italian single-center experience with robot-assisted CC excision in children.

Materials and Methods

This retrospective observational study was conducted at the Department of Pediatric Surgery, Ospedale Salesi, Ancona, Italy. All pediatric patients undergoing robot-assisted choledochal cyst excision between January 2016 and December 2024 were included in this study.

Collected data included age, sex, weight at surgery, clinical presentation, diagnostic investigations performed, cyst type (Todani classification), operative time, intraoperative complications, conversion rate, postoperative hospital stay, postoperative complications, and duration of follow-up.

Primary outcomes included feasibility, operative time, conversion rate, and postoperative complications. Secondary outcomes included length of hospital stay and follow-up results.

Surgical Technique

All procedures were performed under general anesthesia using the Da Vinci robotic surgical platform (Si in the first case, Xi in the other two cases).

An 8-mm camera port is placed through the umbilicus by an open approach. The 8-mm operating port I is placed in the left upper of the umbilicus, and the 8-mm operating port II is placed right of the umbilicus, and the 5 mm port for assistance is between port I and the umbilical port.

The procedure began with careful identification and progressive isolation of the cyst (Fig. 1A). The distal portion of the common bile duct was then exposed and dissected following the placement of Hem-o-lock clips (Fig. 1B). The cystic artery and cystic duct were subsequently isolated and transected between clips. The cyst was mobilized up to the level of the hepatic duct.

At this stage, the da Vinci robotic system was undocked to prepare a Roux-en-Y jejunal loop approximately 20 cm from the ligament of Treitz, with a total length of about 30 cm. A termino-lateral jejunojejunostomy was performed in a double layer using separate stitches of Vicryl Rapid 5 – 0 and Vicryl 4 – 0. The robotic system was then redocked, and the Roux loop was passed transmesocolically and anchored to the transverse mesocolon.

The hepatic duct was then transected, and the cyst was excised (Fig. 1C). An enterotomy was created on the Roux loop to facilitate a termino-lateral hepaticojejunal anastomosis, which was performed with interrupted Monosyn 5 – 0 sutures (Fig. 1D). Hemostasis was carefully reviewed and ensured. A cholecystectomy was performed, and both the cyst and the gallbladder were extracted through the umbilical incision.

Results

Three female patients were included. Mean age at surgery was 22.6 months (range: 14–40 months), and mean weight was 11.1 kg (range: 10–15 kg).

During hospitalization, two pediatric patients were diagnosed with choledochal cysts following distinct symptomatic presentations. The first patient, a 14-month-old infant, was admitted due to progressive cholestatic jaundice. Laboratory evaluation revealed a direct bilirubin of 6 mg/dL, gamma-glutamyl transferase (GGT) of 977 U/L, alanine aminotransferase (ALT) of 152 U/L, and aspartate aminotransferase (AST) of 122 U/L. Abdominal ultrasonography identified a fluid-filled structure with fine particulate content measuring 36 × 23 × 39 mm, in continuity with the cystic duct at the hepatic hilum, strongly suggestive of a choledochal cyst.

The second patient, a 40-month-old child, presented with an acute and severe episode of pancreatitis. Laboratory testing demonstrated markedly elevated pancreatic and hepatic enzymes: amylase 1314 U/L, lipase 1602 U/L, AST 211 U/L, ALT 320 U/L, alkaline phosphatase 408 U/L, and GGT 244 U/L. Ultrasound examination revealed dilation of the extrahepatic bile ducts but did not yield a definitive diagnosis.

Both patients subsequently underwent magnetic resonance cholangiopancreatography (MRCP) under anesthesia, which confirmed the presence of choledochal cysts. According to Todani's classification, the

14-month-old patient harbored a type Ia cyst (Fig. 2), whereas the 40-month-old patient had a type Ic cyst (Fig. 3).

In the third case, a choledochal cyst was suspected prenatally in a 15-month-old patient. Routine prenatal ultrasonography identified dilation of the extrahepatic bile ducts, prompting further evaluation with fetal magnetic resonance imaging (MRI). The MRI demonstrated a cystic dilation of the common bile duct measuring $1.5 \times 1.3 \times 1.0$ cm, without involvement of the hepatic ducts, cystic duct, or intrahepatic bile ducts, findings suggestive of a choledochal cyst.

The patient was delivered at our center with unremarkable perinatal outcomes. Postnatal follow-up included MRI at three months of age under anesthesia, which confirmed the presence of a type Ia choledochal cyst according to Todani's classification (Fig. 4). The patient was closely monitored through routine outpatient visits and ultimately underwent definitive surgical management at 15 months of age.

All patients underwent complete cyst excision with subsequent Roux-en-Y hepaticojejunostomy using a robotic-assisted approach, as previously described. The mean operative time was 413 minutes (range, 340–500 minutes), and no intraoperative complications were encountered. Notably, none of the procedures required conversion to either laparoscopic or open surgery, highlighting the feasibility of the robotic-assisted technique in this patient cohort.

Postoperatively, the mean hospital stay was 10.5 days (range, 9–15 days). During a mean follow-up of 24 months (range, 18–36 months), one patient experienced a *Clostridium difficile* infection approximately one month after surgery, which resolved with conservative management. Importantly, no biliary complications or anastomotic strictures were observed, underscoring the safety and durability of the procedure.

Discussion

The surgical management of choledochal cysts in pediatric patients has undergone substantial evolution over the past decades, moving from open procedures to minimally invasive techniques that are now widely adopted in specialized centers. Laparoscopic excision with biliary reconstruction is currently considered the standard of care; however, it remains one of the most technically demanding procedures in pediatric minimally invasive surgery, particularly during complete cyst excision and hepaticojejunostomy. The intrinsic limitations of conventional laparoscopy—restricted degrees of freedom, amplification of tremor, and challenging intracorporeal suturing—are especially relevant in children, where anatomical structures are small and delicate. Following initial evidence of safety and efficacy in pediatric urology and abdominal surgery (15, 16), also in this setting, robotic-assisted surgery has emerged as a promising technological advancement.

In the present series, robotic-assisted excision of choledochal cysts proved to be feasible and safe, even in young children with low body weight. Although the cohort size is limited, the absence of intraoperative complications and conversions supports the technical reliability of the robotic platform when employed

by surgeons with established expertise in pediatric minimally invasive surgery. Operative times were relatively prolonged, reflecting both the inherent complexity of the procedure and the learning curve associated with robotic surgery. This finding is consistent with previous reports demonstrating a progressive reduction in operative time as experience increases [17, 18], suggesting that initial time-related drawbacks may be mitigated with structured training and case accumulation.

Comparative studies between robotic and laparoscopic approaches have shown largely comparable perioperative outcomes, with some potential advantages favoring robotic surgery. Zhang et al. reported similar complication rates between the two techniques, alongside shorter postoperative fasting time and faster recovery in the robotic group [17]. Similarly, Koga et al. emphasized the enhanced precision afforded by the robotic system during distal bile duct dissection and hepaticojejunostomy, which may contribute to a lower risk of incomplete cyst excision and anastomotic stricture [18]. These technical advantages are particularly meaningful in pediatric patients, where accurate suturing of small-caliber bile ducts is critical to ensure long-term biliary patency and to minimize late complications.

Our postoperative outcomes were favorable, with only one complication that was unrelated to the biliary reconstruction. The length of hospital stay was comparable to that reported in other robotic series and slightly longer than that described in some laparoscopic studies [19]. This difference is likely influenced by institutional postoperative management protocols rather than by surgical morbidity itself. Importantly, no anastomotic complications or biliary strictures were observed during follow-up. Nevertheless, longer-term surveillance is essential, as late biliary complications may develop years after surgery and remain a key determinant of long-term success.

The role of robotic surgery in low-volume centers remains a matter of debate. While excellent outcomes have been consistently reported by high-volume institutions, concerns persist regarding reproducibility and cost-effectiveness in smaller centers. Our experience suggests that robotic-assisted choledochal cyst surgery can be safely implemented even in centers with a limited annual caseload, provided there is substantial expertise in pediatric minimally invasive surgery and appropriate training in robotic techniques. This observation aligns with emerging evidence indicating that surgeon experience and structured training pathways may partially offset the influence of institutional volume on outcomes [20].

Several limitations of this study must be acknowledged. Its retrospective design and small sample size limit the strength of the conclusions that can be drawn. In addition, a formal cost analysis was not performed, despite the well-recognized higher costs associated with robotic systems. Economic considerations remain a critical issue, particularly in healthcare systems with limited resources. Future multicenter prospective studies and registry-based analyses are warranted to better define patient selection criteria, assess cost-effectiveness, and evaluate long-term outcomes, including biliary function and quality of life.

Overall, our findings support the growing body of evidence suggesting that robotic-assisted surgery represents a valuable tool in the management of pediatric choledochal cysts, offering enhanced dexterity and precision during complex biliary reconstruction.

Conclusion

Robot-assisted excision of choledochal cysts with biliary reconstruction is feasible and safe in pediatric patients. The robotic platform offers technical advantages during hepaticojejunostomy and may be particularly valuable in centers with established minimally invasive experience.

Declarations

Data Availability Statement

The datasets generated for this study are available from the corresponding author upon reasonable request.

Ethics Statement

This study was conducted in accordance with institutional standards and the principles of the Declaration of Helsinki. Due to the retrospective nature of the study, formal ethical approval was not required. Informed consent for surgical treatment was obtained from all patients' legal guardians.

Author Contributions

EB and GC conceptualized the study. EB, DDF, and CR collected data. IT and EB analyzed the data. EB drafted the manuscript. EB and GC critically revised the manuscript. All authors approved the final version.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Ethics approval and consent to participate

The study was reviewed by the Hospital Ethics Committee, which determined that, given the nature of the data collected and analyzed, formal ethical approval through the full review process was not required. The Committee considered the study eligible to proceed based on the written informed consent routinely signed by all patients before undergoing surgery.

Consent to publish declaration: Written informed consent for publication of anonymized radiological and intraoperative images was obtained from the parents or legal guardians of all participants. All images were fully anonymized, and no identifying information is included. According to our institutional policy, no additional approval is required for the publication of anonymized images.

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Figures

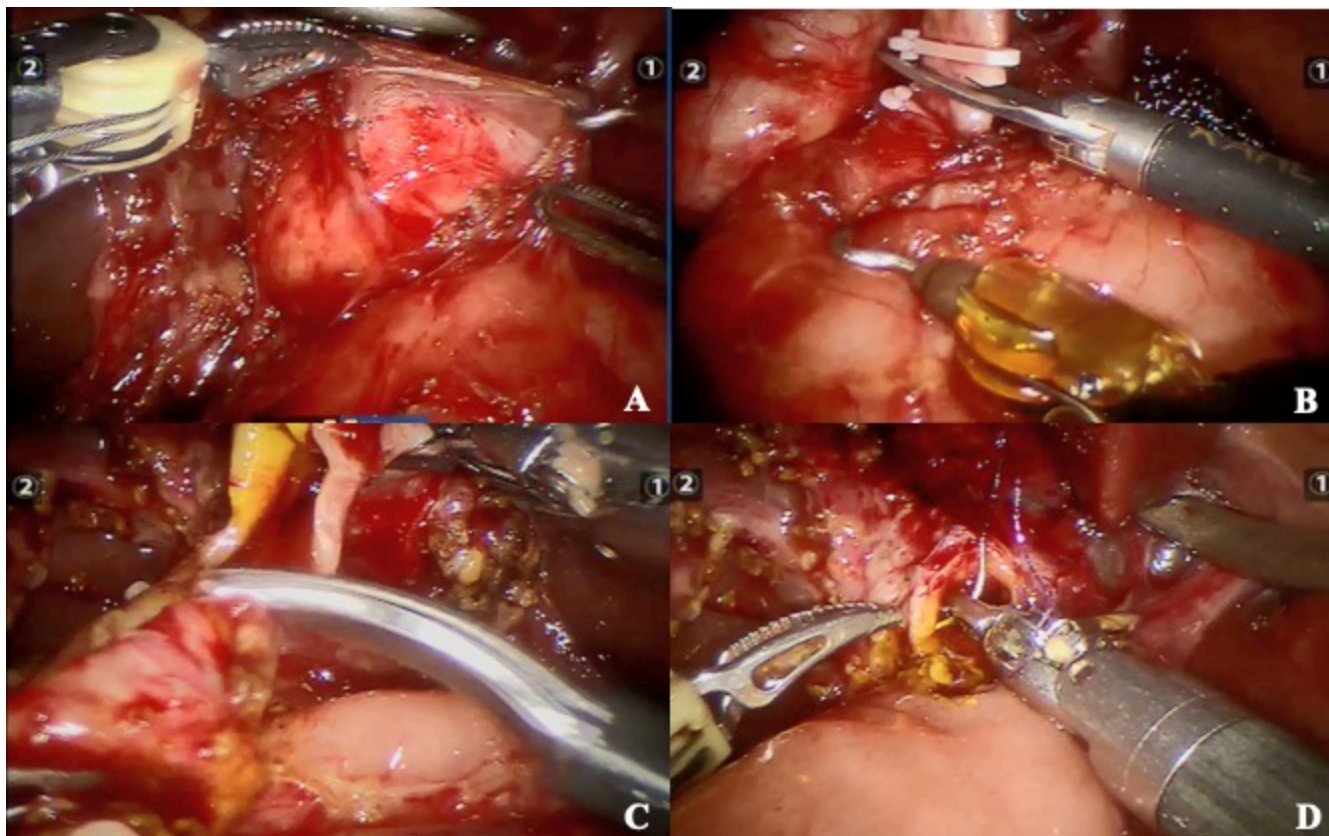


Figure 1

Main steps of the surgical procedure of cyst excision with subsequent Roux-en-Y hepaticojejunostomy using a robotic-assisted approach.

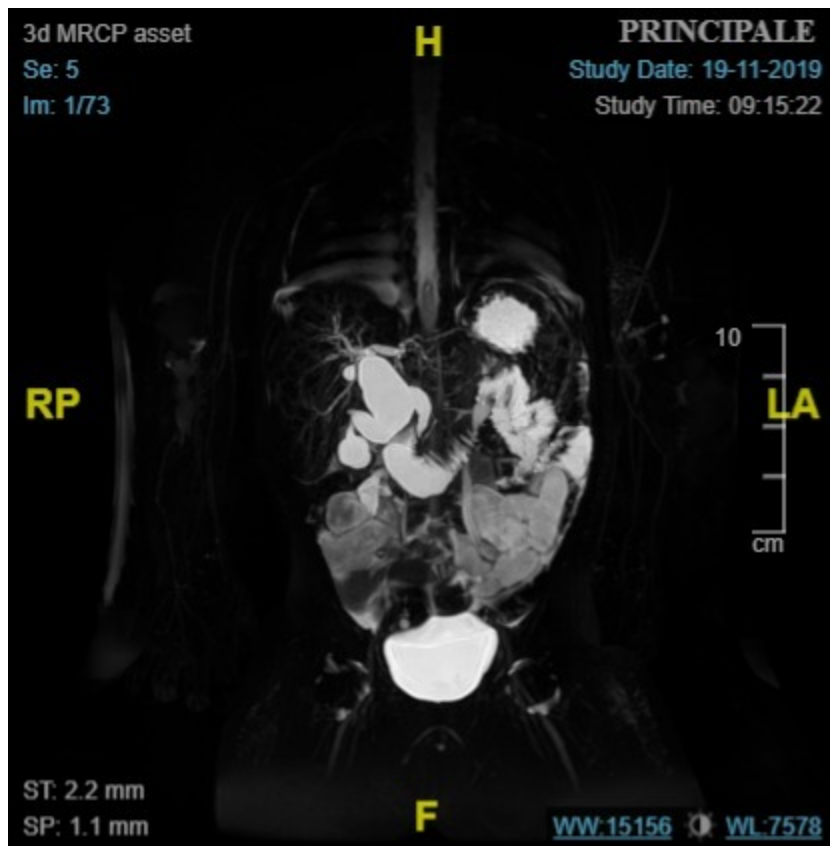


Figure 2

14-month-old patient: MR cholangiography showing dilation of the extrahepatic bile duct, consistent with a type Ia choledochal cyst according to Todani's classification.

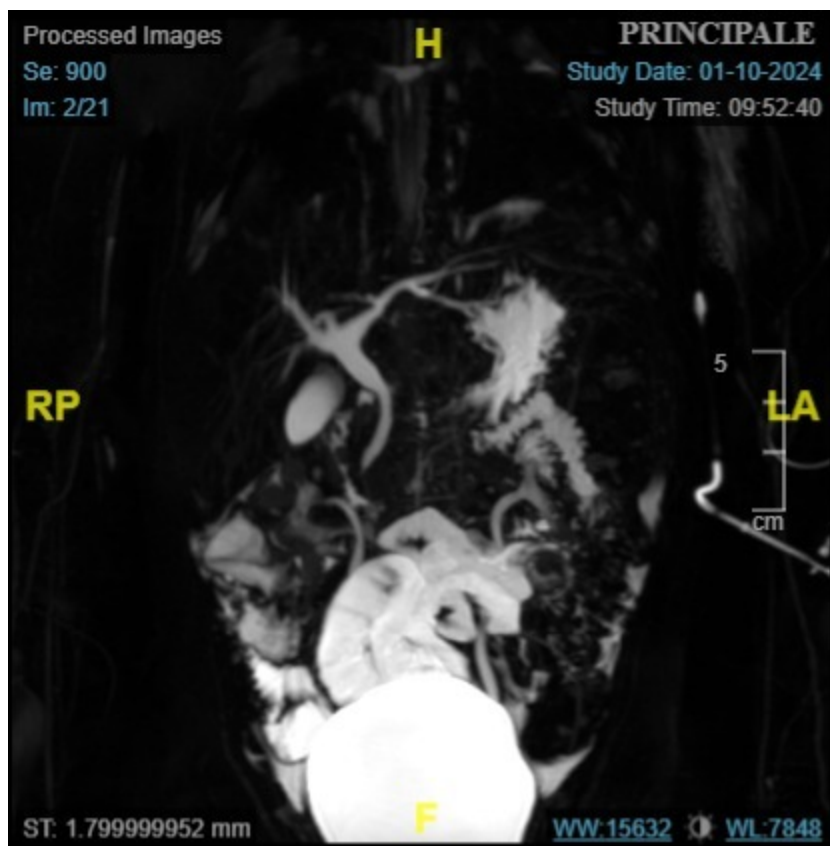


Figure 3

40-month-old patient: MR cholangiography showing a fusiform dilation of the extrahepatic bile duct, consistent with a type Ic choledochal cyst according to Todani's classification.

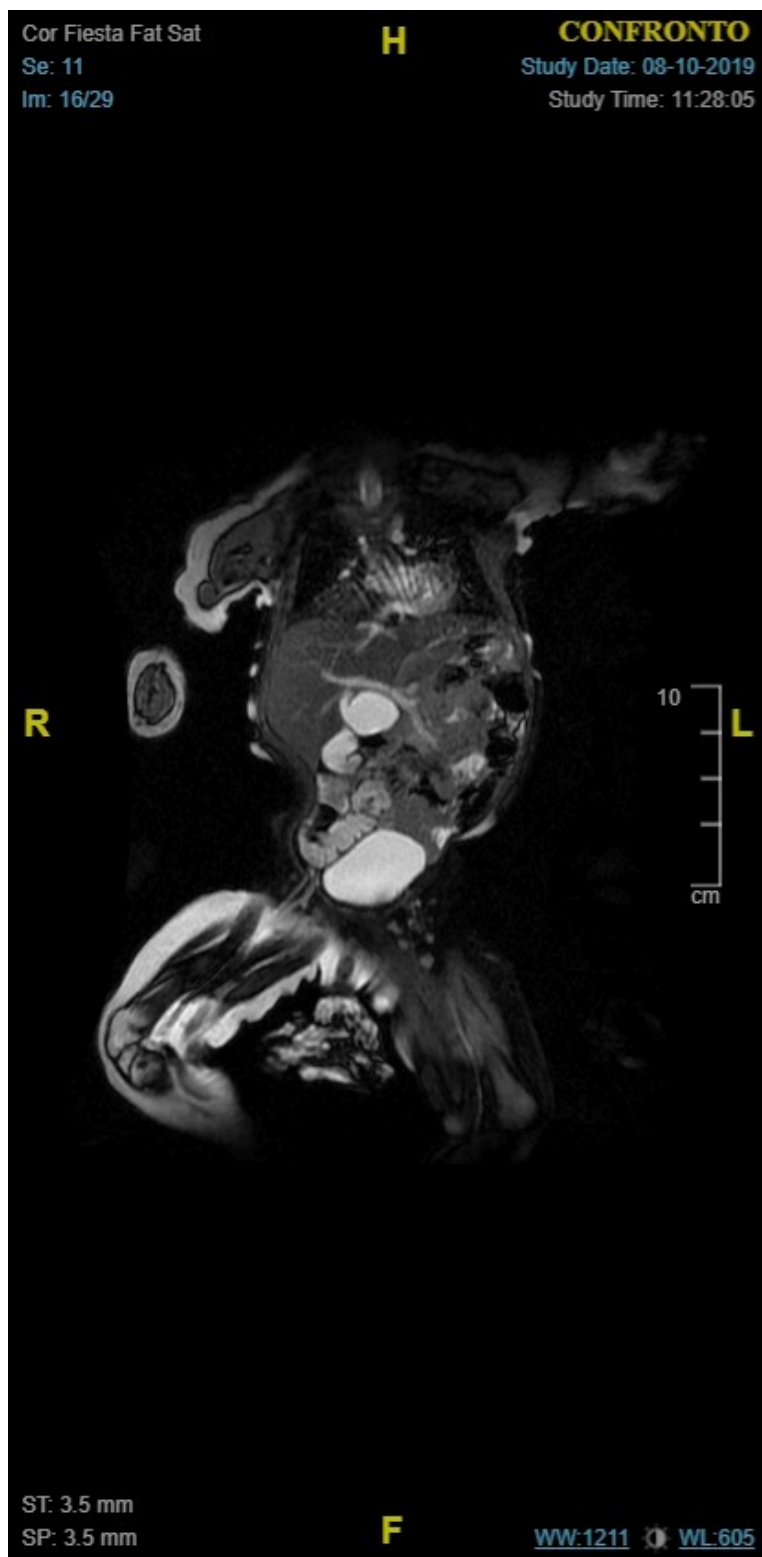


Figure 4

3-month-old patient: MR cholangiography showing dilation of the extrahepatic bile duct, consistent with a type Ia choledochal cyst according to Todani's classification.