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Robotic assisted common bile duct exploration for management of complex gallstone disease

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Background: Minimally invasive cholecystectomy and common bile duct exploration offers single-stage management for complex gallstone disease (cholelithiasis and choledocholithiasis). The Robotic platform presents benefits in improving operative precision, which has not been extensively evaluated in the acute setting of managing complex gallstone disease, as well as in performing transcholedochal or postcholecystectomy common bile duct exploration. The authors report an early series of emergent and expedited robotic-assisted cholecystectomy with common bile duct exploration (RC-CBDE) or robotic common bile duct exploration (R-CBDE) alone.

Material and Methods: A retrospective analysis from a specialist unit in the United Kingdom was undertaken from April 2022 to September 2023, inclusive. All patients who underwent RC-CBDE or R-CBDE were included. Data was collated on patient demographics, perioperative investigations, intraoperative approach, and postoperative outcomes.

Results: Twenty-three consecutive patients were identified. The median (IQR) age was 51 (33–66) years. Median (IQR) Charlson Comorbidity Index (CCI) was 1 (0–4). Five patients underwent operative intervention as an emergency and 18 on an expedited basis. Two patients underwent postcholecystectomy R-CBDE. Fourteen (61%) were transcholedochal and nine were transcystic (39%) CBDE. Median (IQR) bilirubin was 51 (34–253). Median (IQR) operative time was 176 (124–222) minutes. Median (IQR) postoperative length of stay was 2 (0–4) days. There were no bile leaks requiring intervention. The clearance rate of CBDS was 100%. No patients developed postoperative pancreatitis. One patient required intervention for port site hernia following RC-CBDE. One patient developed subhepatic collection postoperatively and required laparoscopic washout and placement of drains. No patients had retained stones after a 3-month follow-up.

Conclusion: Early experience confirms that RC-CBDE and R-CBDE in feasible, safe, and effective treatment for complex gallstone disease. Integrated adjuncts (intraoperative robotic ultrasound – IORUS and Firefly – fluorescence guided surgery – FGS) and superior ergonomics of the robotic platform may assist in reducing the learning curve and increase wider uptake of this complex procedure.

Keywords: biliary, common bile duct exploration, gallstones, robotic surgery

Introduction

In patients with symptomatic cholelithiasis, the prevalence of concomitant common bile duct stones (CBDS) is between 10 and 20%[1]. Current intervention strategies for CBDS include endoscopic retrograde cholangio-pancreatography (ERCP) and cholecystectomy with common bile duct exploration (CBDE), which can be performed by either open or with minimally invasive (laparoscopic or robotic) techniques[2–5].

Laparoscopic common bile duct exploration (LCBDE) is established as a safe and effective intervention for CBDS[6,7]; however, studies investigating outcomes in the robotic approach are limited, especially in both the emergent and post-cholecystectomy setting[8]. Transcystic or transcholedochal methods can be used to extract CBDS[4,9].

HIGHLIGHTS

- Robotic-assisted cholecystectomy with common bile duct exploration (RC-CBDE) or robotic common bile duct exploration (R-CBDE) alone is a feasible, safe, and effective treatment for complex gallstone disease.
- RC-CBDE and R-CBDE in feasible, safe, and effective treatment for complex gallstone disease.
- Integrated robotic platform adjuncts (intraoperative robotic ultrasound – IORUS and Firefly – fluorescence guided surgery – FGS) and superior ergonomics may assist in reducing the learning curve and increase wider uptake of this complex procedure.

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The transcystic approach can be successful in select cases (low volume, small stones in the CBD) but is limited when large stones are encountered and the size of CBDS is greater than the width of the cystic duct (CD). Anatomical variation of the CD should be considered and difficulty to remove CBDS is often encountered in long convoluted ducts and those inserting low, at an acute angle and to the left of the CBD. Large stones can be fragmented with lithotripsy (laser or electrohydraulic) via the transcystic route although proximal migration of fragments into the common hepatic duct (CHD) is a recognised risk. This can result in retained stones, which could lead to complications (cholangitis and pancreatitis) and the need for further interventions with ERCP. Furthermore, it is technically challenging to address stones in the CHD where the 3 mm or fine choledochoscope, due to anatomical variations of the CD often cannot be manipulated to enter the proximal system.

Of the two approaches, transcholedochal CBDE is necessary in cases with large (>1 cm) stones, impacted stones in the distal CBD and CHD stones. The most technically challenging and critical part of the procedure remains to be choledochotomy followed by its primary closure. This requires sufficient training, experience, and advanced laparoscopic technical skills. Although less evaluated, surgical assistance with robotic platform and its adjuncts (IORUS and Firefly - FGS) may provide a solution in performing technically challenging aspects of the CBDE with superior ergonomics and precision[10].

This study reports the early experience of RC-CBDE and R-CBDE alone in the management of complex gallstone disease from a single, high-volume specialist benign pancreaticobiliary unit in the United Kingdom (UK).

Material and methods

This is a retrospective observational study of patients that underwent emergent and expedited RC-CBDE and R-CBDE at a single, high-volume benign pancreaticobiliary centre from April 2022–September 2023 inclusive. The medical records were reviewed, and data was extracted into an anonymised database.

The following parameters were collected: demographic data (age, sex, BMI, American Association of Anaesthesiology (ASA) grade, Acute Physiology and Chronic Health Evaluation II (APACHE-II), and Charlson Comorbidity Index (CCI)), clinical characteristics of CBDS (magnetic resonance cholangiopancreatography - MRCP), operative approach to CBDE, method of choledochotomy closure and outcomes following intervention (operative time, morbidity, bile leak, reintervention, length of stay from date of intervention (LOS), pancreatitis, retained stones, and mortality). Complications were categorised according to Clavien–Dindo (C-D) classification.

All cases were undertaken either on an emergent or expedited basis. Emergent cases were defined as patients undergoing procedure during index admission with evidence of acute biliary obstruction confirmed with biochemical tests (persistent derangement of liver function tests) and/or imaging (MRCP) investigations. Expedited cases included those who underwent intervention within 2 weeks following discharge and had spontaneous improvement of liver function tests.

Inclusion criteria

Patients fit for general anaesthesia and laparoscopic surgery. MRCP confirming CBD stones. No previous major laparotomy. CBD diameter of ≥ 8 mm when considering transcholedochal approach. Transcystic approach considered when a low volume of small, nonimpacted stones in the distal CBD.

Exclusion criteria

Patients with clinical evidence of cholangitis, moderately severe or severe pancreatitis and Parkland severity grade of cholecystitis ≥ 4 were excluded[11,12].

Intervention strategy

The narrated operative procedure can be viewed in the Supplementary Section (Supplemental Digital Content 1, http://links.lww.com/JS9/C802).

Initial set-up and port placement

All procedures were undertaken by two specialist pancreaticobiliary surgeons. The Da Vinci X Robotic Platform (Intuitive) was utilised in all cases. Initial abdominal entry was undertaken with a combination of Veress needle (Locamed, UK) insufflation at Palmers point followed by 12 mm optical port insertion at infraumbilical location (Airseal, Lawmed, UK-assistant port). Four 8 mm robotic ports were inserted under direct vision, with initial entry 15 cm below the xiphisternum (right of midline) and the remaining robotic ports inserted in an oblique line as shown in Figure 1. Before docking, the patient was placed in a 30° reverse Trendelenburg position. Robotic arms 1 and 3 were working ports, robotic arm 2 was the endoscopic port and robotic arm 4 was used for retraction. The assistant Airseal port (Lawmed, UK) was utilised to maintain pneumoperitoneum and allow insertion of a laparoscopic aspirator (Kebomed, UK), adjuncts (laparoscopic swabs, clip applicator – for ligation of CD and artery and sutures) and IORUS (Hitachi, Japan). A 5 mm laparoscopic port was inserted either in the epigastrium or right upper quadrant (RUQ) for transcholedochal (5 mm video choledochoscope (Karl Storz, Germany)) or transcystic (3 mm video choledochoscope with reducer (Karl Storz, Germany)) CBDE. When performing an RC-CBDE, dissection of the hepatocystic triangle was undertaken to achieve the critical view of safety (CVS). Ligaclips (Johnson & Johnson, UK) was applied to the cystic artery prior to division. Laparo-clips (Medtronic, UK) were applied to the CD and was divided following CBDE.

Choledochotomy and closure of CBD

For transcholedochal robotic CBDE, a vertical choledochotomy was performed using robotic scissors. Stay sutures (4/0 Vicryl – Ethicon, Johnson & Johnson, UK) were utilised in cases where a lax CBD was encountered to create tension and avoid injury to the posterior wall of the CBD. Once CBDE was completed, primary closure of the choledochotomy was undertaken with 4/0 Vicryl (Ethicon, Johnson & Johnson, UK) suture in a continuous fashion.

Primary closure of the CBD has been our preferred approach in closing the choledochotomy. This practice is taken from experience of a low bile leak (0.5%) and stricture rate (0%) in previous laparoscopic series of >400 patients. T-tube insertion is

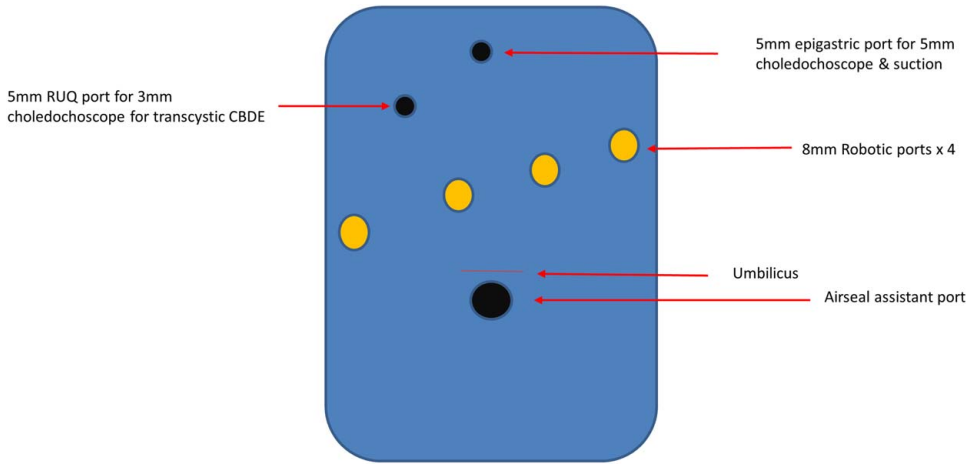

Figure 1. Port placement for robotic cholecystectomy and common bile duct exploration.

considered in patients with suspicion of a retained stone and lack of endoscopic access to the papilla from an altered GI anatomy (e.g. Billroth II gastrectomy or gastric bypass). Despite the effective role of the T-tube in such cases, they can still be associated with delayed bile leak after interval removal[13,14].

Transcystic CBD

During transcystic R-CBDE, a ligaclip was applied at the gallbladder end (close to Hartmann's pouch) of the CD and an incision made below the clip to allow entry of a 3 mm choledochoscope.

Once CBDE was successfully completed, a Laparo-clip was applied distal to the incision on the CD (towards the CBD) and divided between clips. Cholecystectomy was then completed. Two 18F Robinsons drains (PFM Medical, UK) were placed in the subhepatic space in patients that had undergone a transcholedochal CBDE. No drains were placed in patients that underwent transcystic CBDE.

Indication of transcystic vs transcholedochal approach (Table 3)

Transcystic: Low volume/number and wide CD with favourable anatomical course.
Transductal: CBD width ≥ 8 mm, CBDS larger than CD diameter, impacted CBDS and intrahepatic duct stones (IHDS).

Adjuncts for intraoperative identification of CBD and CBDS

IORUS was performed to delineate anatomical structures in the hepatoduodenal ligament and to confirm presence of CBDS (Fig. 2). Indocyanine green (ICG) (Verdye, Kimmel) was injected intravenously, to assist with FGS using Firefly technology (Inituitive) (Fig. 3). Three ml ICG dye (Verdye – 2.5 mg/ml, Kimmel) was administered as a bolus at induction (30 min prior to surgical incision), which allowed sufficient time for ICG excretion into the bile duct to assist with fluorescence identification of biliary anatomy. For identification of vascular anatomy (cystic artery and hepatic artery) and its relation to the bile duct, a further bolus of ICG (Verdye, Kimmel) was administered intraoperatively during dissection of hepatoduodenal ligament to expose the CBD prior to choledochotomy.

Follow-up

Retained stones were defined as CBDS detected within 3 months postprocedure. Liver function tests were performed (6 weeks), and an abnormality led to performing MRCP. Follow-up was arranged 6–12 weeks postoperatively via telephone consultation. No patient was lost to follow-up.

Statistical analysis

Data was recorded using Microsoft Excel 2007–2019 (Microsoft, Inc.) and analysed with STATA 16. Descriptive statistics for continuous data included median (with interquartile

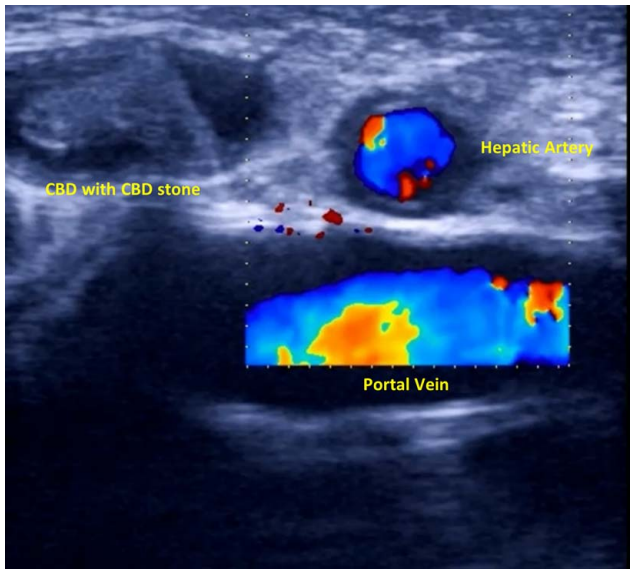

Figure 2. Intraoperative robotic ultrasound demonstrating common bile duct (CBD), hepatic artery and portal vein.

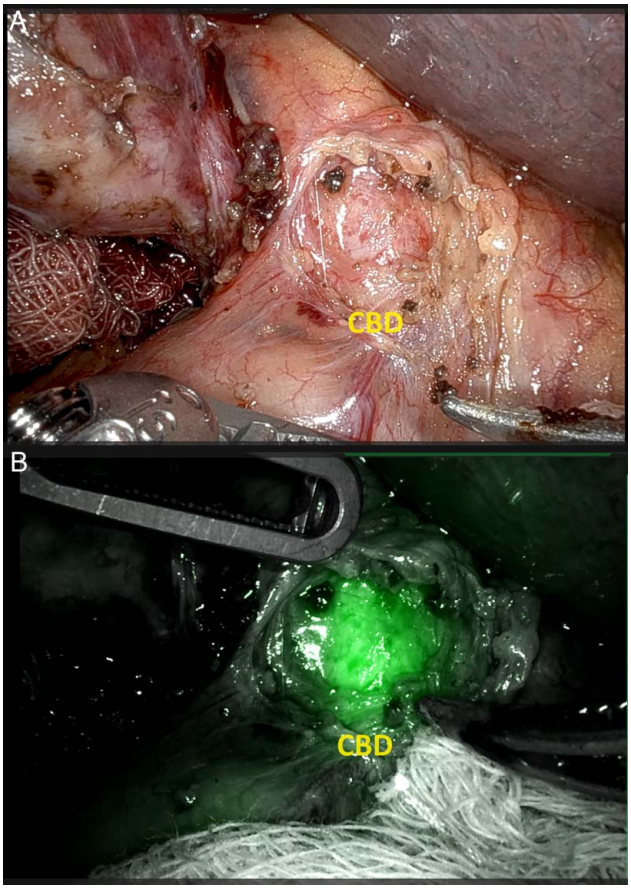

Figure 3. A - Intraoperative image of common bile duct without Firefly mode. B–Intraoperative image of common bile duct fluorescence with Firefly mode.

range, IQR); median was chosen due to nonparametric distribution of dataset. Categorical data was expressed as numbers and percentages.

Results

Twenty-one RC-CBDE and two R-CBDE alone were undertaken between April 2022–September 2023 by two specialist pancreaticobiliary surgeons. Eighteen cases (78%) were expedited referrals for CBDS, and five cases (22%) were emergent.

Demographic data is shown in Table 1. The median (IQR) age was 51 (33–66) years. The median (IQR) BMI was 26 (22–32) kg/m^2. The median (IQR) ASA grade was 1 (1–2) and median (IQR) CCI was 1 (0–4).

The clinical and biochemical characteristics of CBDS are shown in Table 1. All patients underwent preoperative US and MRCP. Median (IQR) CBD diameter was 11 (9–14) mm. Two patients had preoperative ERCP which failed to clear CBDS and had biliary stent placed prior to R-CBDE. Median (IQR) bilirubin was 51 (34–253) μmol, median (IQR) ALP was 323 (201–593), median WCC was 5 (5–6), and median CRP was 4 (2–14).

The operative details are shown in Table 2. Twenty-one patients with intact gallbladder had a concomitant cholecystectomy. Nine patients (39%) underwent transcystic and 14 patients (61%) underwent transcholedochal CBDE. Two cases

Table 1

Demographic data and clinical/biochemical characteristics

Parameter	Median	IQR
Age (Years)	51	33–66
BMI (kg/m^2)	26	22–32
ASA grade	1	1–2
CCI	1	0–4
Parameter	n (%)	
Preoperative imaging		
US	23 (100%)	
MRCP	23 (100%)	
	Median	IQR
CBDD (mm)	11	9–14
Bilirubin	51	34–253
ALP	323	201–593
WCC	5	5–6
CRP	4	2–14

that had R-CBDE alone were performed via a transcholedochal approach. Primary closure was performed for all patients that had choledochotomy. No procedures were converted to open. One case was converted from transcystic to transcholedochal approach. Median (IQR) operative time was 176 (124–222) min.

Postoperative outcomes are shown in Table 2. The median C-D was 0. No patients developed postoperative pancreatitis. There was successful clearance of CBDS in all cases. When performing the transcholedochal approach, drains were removed 48 h postoperatively in 13 (93%) patients. A patient developed postoperative cholangitis, treated with intravenous antibiotics (C-D II). One patient required intervention postoperatively due to

Table 2

Operative and postoperative characteristics

Parameter	*n* (%)	
Referral type		
Urgent elective	18 (78%)	
Emergent	5 (22%)	
Procedure		
RC-CBDE	21 (92%)	
R-CBDE	2 (8%)	
Approach		
Transcystic	9 (39%)	
Transcholedochal	14 (61%)	
Intraoperative imaging		
IOUS	23 (100%)	
ICG	23 (100%)	
Conversion to open	0 (0%)	
	Median	IQR
Operative time (Minutes)	176	124–222
Parameter	n (%)	
Clavien–Dindo		
0	15 (65%)	
I	4 (17%)	
II	2 (9%)	
IIIb	2 (9%)	
Pancreatitis	0 (0%)	
Retained stones	0 (0%)	
	Median	IQR
Time		
Length of stay (Days)	2	0–4

port site hernia and underwent laparoscopic suture repair of hernial defect and repositioning of drains (drains were removed 1 week following discharge – C-D IIIb). One patient developed subhepatic collection and required laparoscopy, washout, and insertion of drains, which were removed 1 week postdischarge (C-D IIIb). Median (IQR) LOS 2 (0–4) days.

Discussion

The choice of approach in treating CBDS operatively is influenced by several factors, including technical expertise, availability of instrumentation, operative scheduling, and financial reimbursement. LCBDE offers the advantage of a single staged intervention for complex gallstone disease, reducing both an economic burden and the risk of post-ERCP pancreatitis[1]. Recommendations by the British Society of Gastroenterology (BSG) state that LCBDE should be performed and coached to surgical trainees wherever possible[1]. The current problem worldwide is that few transductal CBDEs are performed, confirming a lack of experience and, thus, deficiency in training opportunities for residents[15]. The implications of errors made during a choledochotomy, and closure are serious and could be life-changing in the event of biliary stricture/injury with or without concomitant vascular injury. Therefore, structured training pathways by way of specialist fellowships and dedicated courses would be necessary to achieve a foundation to build on competence.

In our experience, the selection criterion for transcystic and transductal exploration differ, and therefore, outcomes are difficult to compare (Table 3). We limit transcystic exploration (20% of cases) for small CBD stones (stones less in width compared to CD) and nondilated (< 8 mm) CBD (Table 3). Performing a choledochotomy when CBD is <8 mm would increase risk of postoperative biliary stricture. Access into the proximal system is limited to cases where there is a short wide CD. Therefore, migrated stones or fragments into the proximal system in cases with long convoluted CD cannot be addressed. As mentioned, it would be challenging to offer transcystic exploration with lithotripsy in cases with large CBD stones due to a higher risk of retained stones and associated complications. Adjuncts can be used to address larger stones via the transcystic route, such as balloon dilation of the CD and ductotomy extension onto the CBD. Both approaches may increase the risk of duct perforations leading to bile leak and potential biliary strictures by severing the blood supply to the CBD (usually found at the 3 and 9 o'clock position). The transductal approach by performing a vertical choledochotomy offers flexibility in addressing large CBD or CHD stones (Table 3). Either lithotripsy can be performed to fragment large stones, or the stone can be captured in a basket, bringing it to the choledochotomy, allowing for extension of the incision over the stone, followed by complete extraction. It is our view that due to the complexity of CBDS presentation and serious implications of complications (biliary injury/stricture, vascular injury, bile leak needing further intervention, and retained CBDS increasing risk of cholangitis and pancreatitis), a surgeon should have the expertise to use either approach that best fits the clinical case and not take the approach of 'one size fits all'. Each approach has its own advantages, dependent on the presentation (Table 3).

Table 3

Indications and advantages of transcystic vs transductal CBDE

Indications	
Transcystic	Transductal
Low volume of stone load in CBD	Large CBD stone
Small stones (< width of CD)	CHD stones
CBD <8 mm	Impacted distal CBD stone
	CBD ≥ 8 mm
Advantages	
Transcystic	Transductal
Daycase	Address large stones
Low risk of bile leak when adjuncts such as balloon dilation or ductotomy avoided	Address CHD stones which often can't be accessed by transcystic route
	Low risk of CBD stricture when CBD diameter ≥ 8 mm

Preoperative MRCP was performed to confirm the presence of a CBD stone. This was necessary to plan the length of the procedure and confirm its suitability for the use of the robotic platform. MRCP also delineated anatomy, size, position of stones in the biliary tree, and other complications (severity of cholecystitis, posterior gallbladder perforations, and Mirizzi syndrome) that would preclude a CBDE, as well as the size and anatomical course of the CD. Large or impacted stones increased the likelihood of lithotripsy. This would predict the need for an extended time to clear the duct and therefore assist in decisions pertaining to theatre efficiency. Judicious use of the robotic platform where the maximum number of cases could be completed in each operative list helped justify the economic argument of its use in complex benign cases.

With the rapid uptake of robotic-assisted surgery (RAS), the benefits of the robotic platform (integrated technologies – IORUS, FGS, enhanced 3D vision, and articulated instruments) alongside appropriate training may compensate and bridge the gap in the technical expertise required to perform transcholedochal CBDE. RC-CBDE has been reported as early as 2003 by Roeyan *et al*.[16], and subsequently by Jayaraman *et al*.[17] in 2008. Both were single case reports and were undertaken on earlier versions (Si) of Da Vinci robotic platform. Ji *et al*.[2] published their experience of 5 RC-CBDE and Alkhamesi *et al*.[8] reported outcomes from a series of 19 RC-CBDE over a 5-year period, with a 21% conversion rate to open. Almamar *et al*.[18] evaluated clinical outcomes and cost-effectiveness of 50 consecutive RC-CBDE with the closure of choledochotomy over T-tube in 52% of cases and retained stone rate of 6%. Their indication for T-tube placement was the size of the bile duct, cholangitis, and failed cannulation at ERCP. We report satisfactory outcomes from our robotic series for primary closure in all patients who underwent choledochotomy. The outcomes noted were based on two reasons: 1) we selected a group of patients without cholangitis or severe inflammation of the gallbladder, and 2) the unit has extensive experience in LCBDE with over 400 cases performed in the last decade. Authors reported improved ergonomics and increased precision with the robotic platform, particularly when suturing the choledochotomy, which is the most critical step and where precision is an absolute necessity to mitigate postoperative biliary complications[8,16,17]. A limitation of RAS is a lack of haptic feedback, and therefore, its use requires sufficient training to allow for safe tissue handling to reduce the risk of inadvertent injury.

The advantages of primary closure of choledochotomy in the laparoscopic experience are a shorter operative time, reduced postoperative complications, and shorter LOS[15,19,20]. In our

series, we adopted an identical approach to our laparoscopic series with primary closure of choledochotomy. Authors subjectively noted enduring less physical and cognitive stress when compared to the laparoscopic approach. These factors may help increase safety in performing complex biliary procedures. An additional benefit was the surgeon's ability to control the endoscope, which meant a precise and stable operative field of view. The disadvantage noted in laparoscopy likely takes place from the endoscope being held by the assistant. Poor views of the operative field are often noted due to assistant fatigue, frequently evident in more complex and time-consuming procedures[21].

It is our routine practice to close all 12 mm ports at the end of minimally invasive surgical procedures. RAS dominantly utilises 8 mm ports, which theoretically may reduce risk of port site herniation. In our series, there was a patient that presented with acute small bowel obstruction from a port site hernia 2 days following discharge from hospital. The patient required emergency laparoscopic reduction of small bowel without need for resection and closure of defect with trans-fascial suture (0 Vicryl – Ethicon, Johnson & Johnson, UK). We believe that the patient's thin and lax abdominal wall may have contributed to an increased risk of port site herniation. It is now our routine practice to close 8 mm port sites in such patients to avoid acute robotic port site hernia.

Eighteen of the CBDEs were undertaken as expedited cases, and 5 five were emergent. No patients had preoperative evidence (clinical and/or biochemical) of cholangitis. However, it is reported in the literature that a higher degree of obstructive jaundice can increase postoperative complications following CBDE[20,21]. This is thought to be due to an increased pressure in the biliary system and dilation of the peripheral/aberrant biliary ducts, which, although more visible, may not be anticipated and, therefore, be more readily injured. Although there were limited numbers in this study, a patient that underwent emergent transcholedochal RC-CBDE had repeat laparoscopy, washout and drains for localised subhepatic collection (day 2 postoperatively). At laparoscopy, no obvious bile leak was identified from choledochotomy site, and the patient recovered following washout and placement of drains (removed on day 7).

When performing RC-CBDE and R-CBDE, the use of IOC can be cumbersome with the requirement to undock the robot to allow for entry of C-arm to undertake IOC. Robotic platform integrated technologies (IORUS – Fig. 2 and FGS) provide an alternative approach, in defining CBDS and both biliary and vascular anatomy. IORUS not only locates and confirms the position of the CBD in relation to vascular structures but also identifies the presence of CBDS. FGS using Firefly mode during CBDE compliments IORUS by visually delineating biliary and vascular anatomy. ICG fluorescence can be detected in the biliary tree as early as 15 min from administration[22,23]. By adhering to the local ICG administering protocol, we were able to identify fluorescence in the bile duct in all cases that underwent CBDE. In 10% of cases, the right hepatic artery travels in front of the CBD and, therefore, is crucial to identify before performing the choledochotomy[24]. FGS allows visualisation of vascular anatomy (hepatic artery and tributaries) in real-time, thereby in our opinion its application whilst undertaking choledochotomy supplements operative safety. Fluorescence may be less than optimal in patients with high BMI (significant adipose tissue covering and obscuring CBD) and impaired excretion from liver (CBD obstruction or liver cirrhosis). Near-infrared light ideally can only penetrate tissue with a thickness 5–10 mm[25]. Dissection of adipose tissue on the anterior aspect of the CBD would be a key technical step in improving the tissue penetration and, thereby, fluorescent detection of CBD. In addition, the placement of a laparoscopic swab under the liver immediately above the bile duct mitigates fluorescence dispersion from the liver, thereby enhancing the CBD.

Access to the robotic platforms remains a challenge in NHS. We anticipate access to the robot for complex benign surgery to be limited whilst priority remains on addressing patients with malignancy and long benign waiting lists. In such a climate, there is little appetite to nurture surgeons through their initial learning curve. Nevertheless, once proficiency is obtained, both precision (enhanced 3D vision and wristed instruments) and safety adjuncts (Firefly and IORUS) with robotic surgery may improve a surgeon's ability to perform complex operations that previously could not be performed with minimally invasive techniques, in turn improving patient experience and outcomes. To successfully implement R-CBDE in NHS practice, the key would be the development of a comprehensive robotic CBDE curriculum and training by way of dedicated fellowship programs.

A direct cost analysis was not undertaken for this study. Currently, robotic surgery is in its early phase of growth within the general surgical specialty in the UK, and therefore, an increased cost implication would be expected. Over time, we would expect costs to fall with both increased competition from other robotic platform competitors and a natural reduction in the cost of instruments as economies of scale are reached. Overall, we did not note a significant difference in the length of postoperative stay between our laparoscopic and robotic series, however, we expect that from the obvious ergonomic and visual advantages, there will be a reduced learning curve and increased uptake for those surgeons interested in dedicating themselves to treating patients with complex CBDS.

There are some limitations to the study. We have presented an early series and therefore the time taken to perform the procedure was prolonged. This improved as the surgeons became familiar with the nuances of using the robotic platform for robotic CBDE. Intraoperative cholangiogram could not be performed due to the difficulty in positioning the X ray C-arm between the robotic arms. Hence, IORUS was used to define biliary and CBDS. A nuance that should be mentioned is the placement of an additional 5 mm port to perform the choledochoscopy by the surgeon between the robotic arms. It would add significant time to remove an instrument and undock one of the ports. This would also hinder the view as the instruments are used to retract the gallbladder and liver to optimise the view of the choledochotomy. This was needed to effectively perform the choledochoscopy and stone retrieval. The postoperative follow-up was limited to 3 months. Biliary strictures were not expected given that transductal CBDE was carried out in patients with a dilated CBD ($\geq$ 8 mm), which is consistent with our laparoscopic experience. Although we have presented a limited number of patients it certainly proves feasibility by way of confirming satisfactory outcomes when compared to our laparoscopic series. We would expect the outcome measures, particularly the duration of the procedure, to improve with increased experience. The unit specializes in performing laparoscopic CBDE ($>$ 400 cases), and the skills needed for this complex procedure are transferrable. Therefore, the outcomes reported may not be applicable to those initiating their training pathway for CBDE. Nevertheless, such

outcomes would still be achievable in those surgeons appropriately trained in treating this complex condition.

RAS offers more independence to the operating surgeon without the definite requirement of a skilled bedside assistant. The robot allows the instruments to stay in a fixed position whilst the operating surgeon can go to the bedside to undertake choledochoscopy and duct clearance before returning to the console to complete the operation (choledochotomy closure +/– cholecystectomy). Furthermore, as demonstrated by the Genesis Staffing Optimisation team (Intuitive), the need for circulating personnel is reduced in robotic surgery when compared with laparoscopic theatre. These advantages could contribute to the long-term economic viability of performing RC-CBDE or R-CBDE alone.

Conclusion

Results from our early experience of RC-CBDE and R-CBDE show that this approach is feasible, safe, and effective for treatment of emergent and expedited cases with complex gallstone disease. Benefits of RAS include enhanced visualisation (IORUS and FGS) of key biliary structures and superior ergonomics, aiding precise execution and closure of choledochotomy, which may allow for an acceptable biliary complication rate and, in turn, promote safe but also a wider uptake of CBDE.

Ethical approval

Not applicable.

Consent

Not applicable.

Source of funding

Not applicable.

Author contribution

J.L.: contributed to study design, data collection, data analysis or interpretation, writing the paper, and final review; P.M.: contributed to data collection and editing and voiceover of supplementary media file; H.L.: contributed to study design, data collection, and data analysis or interpretation; I.B.: contributed to study design, writing the paper, and final review; A.A.: contributed to study design, writing the paper, and final review.

Conflicts of interest disclosure

Altaf Awan is a proctor for intuitive surgical.

Research registration unique identifying number (UIN)

Not required as no human subjects used in this study.

Guarantor

Javed Latif, Imran Bhatti, and Altaf Awan accept full responsibility for the work submitted.

Data availability statement

Data is available upon reasonable request.

Provenance and peer review

Not applicable.

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