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ORIGINAL ARTICLE

A New Era of Bile Duct Repair: Robotic-Assisted Versus Laparoscopic Hepaticojejunostomy

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Abstract

Background Despite scientific evidence of the safety, efficacy, and in some cases superiority of minimally invasive surgery in hepato-pancreato-biliary procedures, there are scarce publications about bile duct repairs. The aim of this study was to compare the outcomes of robotic-assisted surgery versus laparoscopic surgery on bile duct repair in patients with post-cholecystectomy bile duct injury.

Methods This is a retrospective comparative study of our prospectively collected database of patients with bile duct injury who underwent robotic or laparoscopic hepaticojejunostomy.

Results Seventy-five bile duct repairs (40 by laparoscopic and 35 by robotic-assisted surgery) were treated from 2012 to 2018. Injury types were as follows: E1 (7.5% vs. 14.3%), E2 (22.5% vs. 14.3%), E3 (40% vs. 42.9%), E4 (22.5% vs. 28.6%), and E5 (7.5% vs. 0), for laparoscopic hepaticojejunostomy (LHJ) and robotic-assisted hepaticojejunostomy (RHJ) respectively. The overall morbidity rate was similar (LHJ 27.5% vs. RHJ 22.8%, $P = 0.644$), during an overall median follow-up of 28 (14–50) months. In the LHJ group, the actuarial primary patency rate was 92.5% during a median follow-up of 49 (43.2–56.8) months. While in the RHJ group, the actuarial primary patency rate was 100%, during a median follow-up of 16 (12-22) months. The overall primary patency rate was 96% (LHJ 92.5% vs. RHJ 100%, log-rank $P = 0.617$).

Conclusion Our results showed that the robotic approach is similar to the laparoscopic regarding safety and efficacy in attaining primary patency for bile duct repair.

Keywords Bile duct injury · Bile duct repair · Cholecystectomy complication · Laparoscopic surgery · Robotic surgery

Introduction

The fundamental principles for long-term success of bile duct repairs (BDR) are tension free, mucosa-to-mucosa, widely patent, precisely constructed anastomosis, using well-vascularized ducts, with complete drainage of all liver segments.[1] All of these six ideals of biliary-enteric anastomosis are achievable with laparoscopic and robotic-assisted surgery.[2,3]

Although bile duct injury (BDI) is a devastating costly problem 4] and plenty of information for prevention and culture of safe cholecystectomy is available,[5,6] the problem persists. Even more, a recent publication described an increased rate of BDI in patients with and without cholangiogram.[7] In 2011, we initiated a protocol to treat patients by laparoscopic surgery and a few years later, we incorporated the robotic platform to our procedure in order to provide a high-quality bile duct repair plus the benefits of the minimally invasive surgical approach. Despite an increasing number of procedures and scientific evidence of the safety, efficacy, and in some cases superiority of minimally invasive surgery in hepato-pancreato-biliary procedures, there are scarce publications about bile duct repairs.

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Based on the greatest previous studies of Hepp,[8,9] Couinaud,[10,11] Strasberg et al.,[12–15] Lillemoe et al.,[16–19] and Mercado et al.,[20–24] we adapted meticulously each of their technical pearls to our minimally invasive surgical (MIS) repairs.[2,3]

The aim of this study was to compare the outcomes of robotic-assisted surgery versus laparoscopic surgery on bile duct repair in patients with iatrogenic post-cholecystectomy bile duct injury.

Materials and Methods

Study Population and Database

This is a retrospective comparative study of our prospectively collected database of patients with major bile duct injury who underwent either laparoscopic or robotic-assisted Roux-en-Y hepaticojejunostomy (HJ) at Hospital General Dr. Manuel Gea González in Mexico City, Mexico, between June 2012 and February 2018. All bile duct injuries included in this study were produced during cholecystectomy. This study was approved by the institutional research and ethical board of our hospital. Patients provided written informed consent for both approaches.

Since June 2012, we started treating all referred patients with BDI by laparoscopic hepaticojejunostomy (LHJ). Robotic-assisted surgery program started in our hospital at the beginning of 2015. After November 2015, patients that were referred to our hospital underwent robotic-assisted hepaticojejunostomy (RHJ). Some patients were treated by laparoscopic surgery during this time period (after 2015) due to the occasional lack of availability of robotic supplies.

Preoperative Management

A multidisciplinary team approach was advocated in all cases. All patients were studied preoperatively with computed tomography (CT) for abscess and collection. Evaluation of biliary anatomy was made by magnetic resonance cholangiography (MRC) or endoscopic retrograde cholangiography (ERCP). Patients with suspected vascular injury were assessed by contrast enhanced CT and by CT angiography. Revision of the video recording of the surgery was performed when available. Classification of the BDI was done according to Strasberg et al.,[12] and also we classified injuries with a new severity grading system.[29] This system employs three severity grades (SG): SG1 (lateral injuries which do not result in discontinuity of the biliary tract), SG2 (axial injuries which result in single discontinuity of the biliary tree), and SG3 (axial injuries which result in two or more discontinuities of the biliary tree).[29] Once the initial work-up was finished, all patients were scheduled for repair. BDR was termed "early" (within 7 days of injury), "intermediate" (between 8 days and 6 weeks), or "late" (after 6 weeks).[25] We decided to perform "late" repairs if the general and nutritional status of the patients were suboptimal, if the patients underwent previous attempts of repairs at referral center, and if the patients had associated vascular injury.

Surgical Technique

In all cases, we placed the patient in French position. For LHJ, a trans-umbilical 12-mm port was employed for a 30° laparoscopic lens. Three working ports were placed: 12-mm left para-median subcostal port and 5-mm sub-xiphoid and right subcostal ports. For RHJ, a 12-mm port was employed at the right para-umbilical area for the camera arm, a 12-mm port in the left flank for robotic arm no. 1, and an 8-mm port in right flank for robotic arm no. 2. One additional port was placed in the right side (between robotic arm no. 2 and camera arm) for laparoscopic assistant. Robotic surgery was performed with the da Vinci Si robotic platform (Intuitive Surgical Inc., Sunnyvale, CA).[2,3,26]

The initial step was to perform a diagnostic laparoscopy to inspect the peritoneal cavity, drain bile collections, and take-down adhesions.

Common Steps

The technique involved a laparoscopic Roux-en-Y loop construction. The distal limb was placed close to the hilum in an antecolic position, with no tension, and ensuring adequate length (70 cm between the hepaticojejunostomy and the jejunojejunostomy).

The inferior surface of the liver and porta hepatis were exposed in all cases. We proceeded with an intraoperative cholangiography (IOC) in order to define all segments of the intrahepatic biliary tree, identify possible intrahepatic stenosis and hepatolithiasis, and corroborate the class of the injury and in some cases to define the fistulous tract. The IOC was done with a cholangiography catheter, introducing the tip of the catheter through the site of transection, after dissecting the scarring and fibrous tissue. In cases with chronic obstruction, and suspected or confirmed hepatolithiasis, we performed cholangioscopy. For this step, we employed a flexible gastroscope (Olympus GIF-H 180).[27,28]

We advocated partial resection of segment IV and/or segment V to adequately expose the ducts. All bile duct remnants were fully inspected, and ischemic or fibrotic edges were excised until viable mucosa was found (high repair), then the hilar plate was lowered to obtain adequate length of the ducts.

E1 and E2 Injuries

In cases of E1 and E2 injuries, the common hepatic duct was opened longitudinally on its anterior surface and extended onto the anterior surface of the left hepatic duct or both the left and right hepatic ducts.

E3 Injuries

For E3 injuries, an anterior longitudinal ductotomy was performed in order to expose the confluence and part of the left (Hepp-Couinaud or "the French connection") and right ("the American connection") hepatic ducts.

E4 and E5 Injuries

For E4 injuries, we built a neo-confluence in order to perform a single biliary-enteric anastomosis. Neo-confluences were built with interrupted stitches of 4, 5, or 6–0 monofilament absorbable suture, based on caliber of the ducts.

Construction of Anastomosis

The technique of repair consisted in a wide, side-to-side, single-layer Roux-en-Y hepaticojejunostomy. Anastomoses between the jejunal loop and the previously dissected bile ducts were constructed with two 4–0 monofilament absorbable barbed sutures in the case of robotic approach, and 3–0 or 4–0 monofilament absorbable sutures in the case of laparoscopic approach. Transhepatic stents were never employed. For robotic, the first step was to place a posterior row of running suture, beginning in the lateral corner and tying it in the medial corner. Then, the anterior row was completed with another suture, beginning from medial and tying it in the lateral corner. For laparoscopy, separated sutures with extracorporeal sliding knots were employed, starting with the posterior row and finishing with the anterior row.

We created an enteropexy of the blind segment of the jejunal biliary limb beneath sub-xiphoid region (so called access loop).[2,3] A closed suction drain was placed routinely to drain the perianastomotic area.

Postoperative Management

Patients were discharged home once a full normal diet was tolerated, pain was adequately controlled with oral analgesics, no signs of sepsis were presented, and parenteral antibiotic regime was completed. Closed suction drains were removed after resumption of oral feeding and before discharge, except in those patients with detected bile drainage. Patients were followed postoperatively through direct clinic encounters scheduled at 1, 3, 6, and 12 months and at 1 year thereafter. In each appointment, clinical and biochemical evaluations (liver function tests) were performed. An annual MRC was part of the evaluation.

Outcomes and Follow-up

Complications were divided as those occurred within the first 90 days after BDR and those occurred more than 90 days after BDR.[29] Postoperative complications and mortality were recorded and classified using the Clavien-Dindo classification of surgical complications.[30]

Acute cholangitis was defined according to the Tokyo 2018 guidelines.[31] Cholestasis and jaundice were evaluated with clinical assessment and biochemical analysis (liver function tests). Evaluation protocol and medical treatment were done following Tokyo guidelines. Events of suspected biliary-enteric anastomotic stricture were examined with MRC.

Report of outcomes was based on the standard tabular reporting.[32] Definition of patency, index treatment periods, grading of patency, and *actuarial primary patency rate* were based on recently published standards for reporting outcomes.[29] The total treatment period in which primary patency could be obtained was fixed at 90 days. The follow-up period for duration of primary patency started at 90 days after the operative repair.[29]

Statistical Analysis

The data were summarized as means (standard deviation), medians (interquartile range), or number of patients (percentages). The chi-square test or Fisher's exact test was used for categorical variables, and Student's t test or Mann-Whitney U two-sample tests were used for continuous variables depending on the distribution. We estimated actuarial primary patency rate using the Kaplan-Meier curves. The curves were compared using the log-rank test. In this study, two-sided P values of < 0.05 were considered statistically significant. Analyses were conducted using SPSS version 22.0 for Windows (SPSS Inc. Chicago, IL, USA).

Results

Patient Baseline Characteristics

After revision of all minimally invasive bile duct repairs performed from June 2012 to February 2018, we included a total of 75 HJ (40 laparoscopic and 35 robotic-assisted HJ) to our study. Nine patients (22.5%) in the LHJ underwent repair after 2015. The groups were similar for age, gender, body mass index, comorbidities, type of cholecystectomy, presenting symptoms after injury, and injury type (see Tables 1 and 2)

Index Operation (Cholecystectomy)

Cholecystectomies were performed open (LHJ 37.5% vs. RHJ 54.3%, $P = 0.145$), laparoscopic (LHJ 52.5% vs. RHJ 37.1%,

Table 1 Comparison of laparoscopic versus robotic groups: demographics and preoperative data of patients with bile duct injury

Variables	Overall ($n = 75$)	LHJ ($n = 40$)	RHJ ($n = 35$)	$P < 0.05$
Age (years), mean (SD)	43.1 (15.7)	42.9 (15.2)	43.3 (16.5)	0.915
Sex, no. (%)				0.745
Female	57 (76)	31 (77.5)	26 (74.3)	
Male	18 (24)	9 (22.5)	9 (25.7)	
BMI (kg/m^2), mean (SD)	25.3 (3.1)	25.9 (3.3)	24.6 (2.9)	0.075
Patient comorbidities, no. (%)				0.918
Yes	21 (28)	11 (27.5)	10 (28.6)	
No	54 (72)	29 (72.5)	25 (71.4)	
Diabetes	11 (14.7)	5 (12.5)	6 (17.1)	
Hypertension	5 (6.7)	3 (7.5)	2 (5.7)	
Other	5 (6.7)	3 (7.5)	2 (5.7)	
Indication for cholecystectomy, no. (%)				0.685
Acute cholecystitis	41 (54.6)	20 (50)	21 (60)	
Symptomatic cholelithiasis	30 (40)	17 (42.5)	12 (34.3)	
Unknown	4 (5.4)	3 (7.5)	2 (5.7)	
Type of cholecystectomy, no. (%)				0.338
Open	34 (45.3)	15 (37.5)	19 (54.3)	
Laparoscopic	34 (45.3)	21 (52.5)	13 (37.1)	
Converted to open	7 (9.3)	4 (10)	3 (8.6)	
Injury recognized during cholecystectomy, no. (%)				0.824
Yes	29 (38.7)	15 (37.5)	14 (40)	
No	46 (61.3)	25 (62.5)	21 (60)	
Management of injury before referral, no. (%)				
Drainage only	17 (22.7)	11 (27.5)	6 (17.1)	0.285
Repair attempt	12 (16)	4 (10)	8 (22.8)	0.129
Type of repair attempt, no. (%)				
Open HJ	8 (10.7)	2 (5)	6 (17.1)	0.089
Open CD	1 (1.3)	0	1 (2.8)	0.466
Duct-to-duct repair	3 (4)	2 (5)	1 (2.8)	0.636

LHJ laparoscopic hepaticojejunostomy, *RHJ* robotic hepaticojejunostomy, *BMI* body mass index, *HJ* hepaticojejunostomy, *CD* choledochoduodenostomy

$P = 0.182$), and laparoscopic converted to open (LHJ 10% vs. RHJ 8.6%, $P = 0.831$).

There was no statistically significant difference in the rate of detection of injury during cholecystectomy between the laparoscopic (37.5%) and robotic (40%) groups ($P = 0.824$).

Repair Attempts Previous to Referral

A total of four (10%) patients in the LHJ group and eight (22.8%) patients in the RHJ underwent an attempted repair before referral ($P = 0.129$). The type of repair attempted was open hepaticojejunostomy (LHJ $n = 2$ vs. RHJ $n = 6$, $P = 0.089$); open choledochoduodenostomy (LHJ $n = 0$ vs. RHJ $n = 1$, $P = 0.466$), and duct-to-duct repair (LHJ $n = 2$ vs. RHJ $n = 1$, $P = 0.636$). All patients with previous attempts experienced repeated bouts of cholangitis due to strictured anastomosis. These patients experienced multiple failed endoscopic therapies previous to referral to our institution.

Clinical Presentation of Injury

In 62.5% of patients in the LHJ group and in 60% of patients in the RHJ group ($P = 0.824$), their injury was not recognized during cholecystectomy. This was reflected on the median time from cholecystectomy to diagnosis of injury (LHJ 4.5 vs. RHJ 5 days, $P = 0.948$). This also influenced the median time from diagnosis of injury to bile duct repair (LHJ 15 vs. RHJ 30 days, $P = 0.081$).

Referred patients (see Table 2) presented with jaundice (LHJ 45% vs. RHJ 57%, $P = 0.294$); intra-abdominal sepsis (LHJ 25% vs. RHJ 25.7%, $P = 0.943$); biliary fistula (LHJ 22.5% vs. RHJ 14.3%, $P = 0.362$); cholangitis (LHJ 42.5% vs. RHJ 40%, $P = 0.826$); and/or biloma (LHJ 7.5% vs. RHJ 5.7%, $P = 0.757$).

Grading of Severity of Biliary Injury and Timing of Repair

Based on the grade of severity,[29] we classified patients as being SG2 (LHJ 70% ($n = 28$; E1: 3, E2: 9, E3: 16) vs. RHJ 71.5% ($n = 25$; E1: 5, E2: 5, E3: 15)) and SG3 (LHJ 30% ($n = 12$; E4: 9, E5: 3) vs. RHJ 28.5% ($n = 10$; E4: 10)), with no statistically significant difference between both groups ($P = 0.892$) (see Table 2).

Associated vascular injury was detected in 6 (8%) patients in total (LHJ $n = 4$ vs. RHJ $n = 2$ patients, $P = 0.494$). Patients with associated vascular injury were scheduled for late repair

Table 2 Comparison of laparoscopic versus robotic groups: Presentation of patients and staging of injury

Variables	Overall ($n = 75$)	LHJ ($n = 40$)	RHJ ($n = 35$)	$P < 0.05$
Indication for referral for repair, no. (%)				
Jaundice	38 (50.6)	18 (45)	20 (57.1)	0.294
Intra-abdominal sepsis	19 (25.3)	10 (25)	9 (25.7)	0.943
Biliary fistula	14 (18.7)	9 (22.5)	5 (14.3)	0.362
Cholangitis	31 (41.3)	17 (42.5)	14 (40)	0.826
Biloma	5 (6.7)	3 (7.5)	2 (5.7)	0.757
ERCP previous to referral, no. (%)	37 (49.3)	22 (55)	15 (42.9)	0.294
Time from cholecystectomy to diagnosis of BDI (days), median (IQR)	5 (0–20)	4.5 (0–18.7)	5 (0–20)	0.948
Time from diagnosis to repair (days), median (IQR)	20 (7–80)	15 (3–36.5)	30 (10–97)	0.081
Injury type (Strasberg), no. (%)				0.353
E1	8 (10.7)	3 (7.5)	5 (14.3)	
E2	14 (18.7)	9 (22.5)	5 (14.3)	
E3	31 (41.3)	16 (40)	15 (42.9)	
E4	19 (25.3)	9 (22.5)	10 (28.6)	
E5	3 (4)	3 (7.5)	0	
Associated vascular arterial injury, no (%)				0.494
None	69 (92)	36 (90)	33 (94.3)	
Right hepatic artery	6 (8)	4 (10)	2 (5.7)	
Preoperative laboratory values, mean (SD)				
Hemoglobin (g/dL)	11.5 (1.1)	11.5 (1.1)	11.4 (1.2)	0.712
WBC, $\times 10^9$/L	10.8 (4.8)	10.3 (4.1)	11.4 (5.5)	0.382
Platelet count, $\times 10^3/\mu$L	341.7 (104.1)	342.2 (105.7)	341.1 (103.7)	0.966
Total bilirubin (mg/dL)	3.5 (9.8)	6.7 (11.8)	6.5 (7.5)	0.942
Direct bilirubin	3.4 (4.3)	2.9 (3.6)	3.9 (4.9)	0.292
AP, U/L	386.3 (324.7)	318.5 (248.1)	458.1 (380.6)	0.072
GGT	312.3 (223.3)	302.5 (207.6)	322.9 (241.9)	0.701
Aspartate aminotransferase	77.3 (56.6)	68.7 (55.2)	87.2 (57.4)	0.185
Alanine aminotransferase	83.4 (71.7)	81.6 (74.8)	85.4 (69.4)	0.829
Albumin (g/dL)	3.08 (0.7)	2.88 (0.83)	3.25 (0.66)	0.045

LHJ laparoscopic hepaticojejunostomy, *RHJ* robotic hepaticojejunostomy, *ERCP* endoscopic retrograde cholangiopancreatography, *IQR* interquartile rate, *WBC* white blood cell count, *AP* alkaline phosphatase, *GGT* Gamma-glutamyl transpeptidase

(> 6 weeks). No cases of extreme vascular injury were referred to our center.

In regard to the timing of repair, patients were classified as early (LHJ 35% vs. RHJ 17.1%), intermediate (LHJ 42.5% vs. RHJ 40%), and late (LHJ 22.5% vs. RHJ 42.9%), with no statistically significant difference between both groups ($P = 0.096$).

Intraoperative Outcomes

In regard to the intraoperative outcomes, the median operative time and the median estimated blood loss are shown in Table 3. One patient (2.5%) in the LHJ group required conversion to open surgery (RHJ group $n = 0$, $P = 1.000$). Conversion was required because of dense adhesions and lack of adequate identification of the biliary duct anatomy with laparoscopic surgery.

We found six patients with spontaneous biliary-enteric fistula at the level of the duodenum [LHJ $n =$ 1 (2.5%) and RHJ $n =$ 5 (14.3%)], one at colon (2.5%, LHJ group), and one at pylorus (2.8%, RHJ group), all of them with history of several bouts of cholangitis. In all cases, we took down the fistulous tract with blunt and sharp dissection. The bile duct remnant was excised until viable mucosa was found. In all cases, we performed primary closure of the enteric defect with separate monofilament absorbable 2–0 sutures.[26]

Postoperative Complications

The overall morbidity rate was 27.5% in the LHJ group and 22.8% in the RHJ group, with no statistically significant difference between both groups ($P = 0.644$) (see Table 4).

Similar rates of early postoperative bile leaks were found ($P = 0.637$). These bile leaks were conservatively managed with closed suction drain (Table 4).

Two HJ leaks required reoperation, 1 (2.5%) patient in the LHJ group and in 1 (2.8%) patient in the RHJ group ($P =$ 1.000) within 90 days after surgery. These leaks required reoperation to drain biloma and a new closed drain was collocated near the leak. No intervention of the biliary tree was required in these patients, all leaks ceased within the 90-day period, and all patients attained primary patency.

The rest of complications (according to the Clavien-Dindo) are shown in Table 4. No mortality was registered in the first 90 days after surgery. One patient in the LHJ group died of pancreatic cancer, after 90 days of surgery. All morbidity (< 90 days and > 90 days) and specially HJ-related complications

Table 3 Comparison of laparoscopic versus robotic groups: intraoperative characteristics

Intraoperative variables	Overall ($n = 75$)	LHJ ($n = 40$)	RHJ ($n = 35$)	$P < 0.05$
Time of repair, no. (%)				
Early (< 7 days)	20 (26.7)	14 (35)	6 (17.1)	0.096
Intermediate (8 days to 6 weeks)	31 (41.3)	17 (42.5)	14 (40)	
Late (> 6 weeks)	24 (32)	9 (22.5)	15 (42.9)	
Neo-confluence construction, no. (%)	22 (29.3)	12 (30)	10 (28.6)	0.892
The Hepp-Couinaud-like reconstruction, no. (%)	53 (70.7)	28 (70)	25 (71.4)	0.892
Segment IV and/or segment V partial resection, no. (%)	43 (57.3)	23 (57.5)	20 (57.1)	0.975
Conversion to open procedure, no. (%)	1 (1.3)	1 (2.5)	0	1.000
Operative time (min), median (IQR)	240 (210–310)	240 (200–330)	270 (240–300)	0.316
Estimated blood loss (mL), median (IQR)	200 (100–300)	215 (157.5–322.5)	150 (100–250)	0.055

LHJ laparoscopic hepaticojejunostomy, *RHJ* robotic hepaticojejunostomy, *IQR* interquartile rate

were registered during the median 28 months (IQR 14–50) of follow-up.

Anastomotic Outcomes (Patency)

All patients (100%, in both groups) attained primary patency within the 90-day index treatment period. In the LHJ group, the actuarial primary patency rate was 92.5% during a median follow-up of 49 (IQR 43.2–56.8) months. While in the RHJ group, the actuarial primary patency rate was 100%, during a median follow-up of 16 (IQR 12–22) months. There was no statistically significant difference between both groups ($P = 0.617$). The primary patency curve is shown in Fig. 1.

Three patients (7.5%) in the LHJ group lost primary patency in the first year. These patients were classified as grade C result. These patients had biliary-enteric anastomotic stenosis and presented with cholangitis ($n = 2$) and persistent jaundice ($n = 1$). Two patients underwent one successful endoscopic dilation, reaching the HJ through the access loop. No recurrence of stenosis was registered during follow-up. Reoperation was required in one patient (secondary surgical reconstruction), following unsuccessful endoscopic dilation. The previous HJ was dismantled, intrahepatic ducts were assessed by cholangioscopy, and a new HJ was performed by robotic surgery. Thus, for the LHJ group, the establishment of secondary patency was eventually achieved in all patients.

Table 4 Comparison of laparoscopic versus robotic groups: postoperative results and follow-up

Postoperative variables	Overall ($n = 75$)	LHJ ($n = 40$)	RHJ ($n = 35$)	$P < 0.05$
Time to resume diet (days), median (IQR)	2 (1–2)	2 (1.25–3)	2 (1–2)	0.011
Hospital length of stay (days), median (IQR)	7 (5–10)	7 (6–11)	6 (5–8)	0.015
Overall morbidity rate, no. (%)	19 (25.3)	11 (27.5)	8 (22.8)	0.644
Clavien-Dindo class, no. (%)				
Grade I (< 90 days)				
Seroma	4 (5.3)	2 (5)	2 (5.7)	0.890
Wound hematoma	1 (1.3)	1 (2.5)	0	1.000
Grade II (< 90 days)				
Blood transfusion	1 (1.3)	0	1 (2.8)	0.466
TIA	1 (1.3)	0	1 (2.8)	0.466
Pneumonia	1 (1.3)	0	1 (2.8)	0.466
Atelectasis	1 (1.3)	1 (2.5)	0	1.000
Bile leaks	3 (4)	2 (5)	1 (2.8)	0.637
Grade III-b (< 90 days)				
HJ leaks	2 (2.7)	1 (2.5)	1 (2.8)	1.000
Petersen hernia	1 (1.3)	1 (2.5)	0	1.000
Site port bleed	1 (1.3)	0	1 (2.8)	0.466
Grade III-b (> 90 days)				
HJ stenosis (primary patency lost)	3 (4)	3 (7.5)	0	0.243
Overall mortality, no. (%)	1 (1.3)	1 (2.5)	0	1.000
Length of follow-up (months), median (IQR)	28 (14–50)	49 (43.2–56.8)	16 (12–22)	< 0.001
Patients with > 12 months of follow-up, no. (%)	67 (89.3)	38 (95)	29 (82.8)	0.089

LHJ laparoscopic hepaticojejunostomy, *RHJ* robotic hepaticojejunostomy, *IQR* interquartile rate, *TIA* transient ischemic attack, *HJ* hepaticojejunostomy

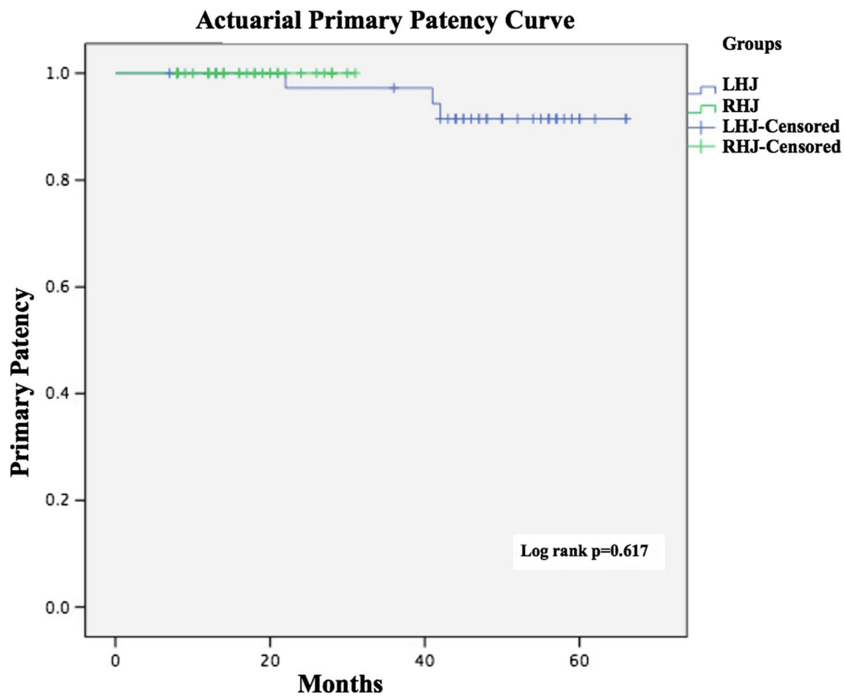

Figure 1 Actuarial primary patency curve. Seventy-five patients had surgical bile duct repair (LHJ $n = 40$ and RHJ $n = 35$). All patients (100%) achieved primary patency within the 90-day index treatment period. Therefore, the per cent of patients attaining primary patency was 100%. Three patients lost primary patency in the first year (from the LHJ group) and none thereafter. The overall primary patency rate was 96% (LHJ 92.5% vs. RHJ 100%, log-rank $P = 0.617$). Important: difference in length to follow-up between groups should be noticed

Discussion

The standard approach for bile duct reconstruction is a side-to-side Roux-en-Y hepaticojejunostomy.[1] Using a side-to-side anastomosis obviates the need for extensive and potentially devascularizing dissection of the duct and permit wider anastomoses.[1] The Hepp-Couinaud approach to the left hepatic duct is ideal for E3 injuries.[1,8,9] To approach the right-sided component of E4 and E5 injuries, "The American Connection" is employed.[13] In cases of separated right and left ducts, construction of a neo-confluence is useful.[24] For the greatest exposure of the left duct, partial resection of segment IV or V is sometimes necessary.[20,23] We have demonstrated in previous reports the safe, feasibility, and reproducibility of these techniques with MIS.[2,3] We believe that applying these fundamental principles of open bile duct reconstruction in laparoscopic and robotic repairs will provide the same long-term outcomes, plus the advantage of providing the well-known benefits of minimally invasive surgery.[2]

Open bile duct repair is the preferred surgical method for BDI; however, it is associated with increased morbidity.[33–36] In the USA, single-center experiences have reported morbidity rates ranging from 10 to 42.9%.[36] Our study found a 25.3% overall morbidity rate (27.5% in LHJ and 22.8% in RHJ). In regard to HJ stenosis, in a 2009 publication after combination of multiple series (with an entire population of 1642 patients), the restricture rate was 12.8%, during mean follow-up of 60.4 months.[1] We found in our series an overall 4% of HJ stenosis, during an overall median follow-up of 28 (IQR 14–50) months.

Our results showed similar rates of estimated blood loss and operative times between laparoscopic and robotic surgery. Both procedures demonstrated comparable rates of return to normal diet and hospital length of stay. We consider one of the most important findings of our study the fact that both procedures attained primary patency within the 90-day index treatment period. Because difference between the groups regarding follow-up time exists, we could not draw conclusions about long-term actuarial primary patency rates, and this represents an important limitation of the study. Further studies are required to confirm these findings and identify additional benefits and risks from laparoscopic and robotic bile duct repair.

Robotic-assisted surgery allows easily improved range of motion in a small and deep space, ease of suturing and ambidextrous handling for precise dissection, three-dimensional perception with up to 10× magnification for optimal evaluation of the ducts, precision and stability of movement by eliminating the surgeon's tremor, and better ergonomics for the operating surgeon,[37,38] while laparoscopic surgery allows high-definition imaging and magnified views.[13]

To our knowledge, this study represents the largest series of patients with major bile duct injury treated by minimally invasive surgery and the first study that compare robotic-assisted to laparoscopic bile duct reconstruction.[39,40] BDI is still a big problem in Mexico despite multiple efforts to prevent it. As stated by Dominguez-Rosado et al.,[25] state of health care in Mexico results in advanced disease presentations, variable quality of care, and inadequate processes to assure patient safety. All of this was reflected in our series in the rate of open cholecystectomies, the rate of injuries recognized during cholecystectomy, and the time from diagnosis to repair (which reflects referral times). Thus, we advocated in our country early referral to a specialized center with placement of an intra-abdominal drain once BDI is suspected.

This study has limitations due to its retrospective nature. Also, patients were treated either with laparoscopic or robotic surgery based on the availability of the equipment. Therefore, patients were not randomized or case-controlled and this could represent a selection bias. Although 89.3% of patients (LHJ = 95% vs. RHJ = 82.8%) had more than 12 months of follow-up, this time is insufficient to draw conclusions about long-term outcomes (3, 5, and 10 years). Importantly, although we achieved acceptable short-term results, our results are only applicable to surgeons with experience in *complex* hepatobiliary laparoscopic and robotic surgical procedures. Based on this limitation, minimally invasive bile duct repair should be treated by experienced surgeons and at referral centers.

The cost is a concern for the use of the robot in gastrointestinal procedures.[41] Undoubtedly, it adds cost to an already costly disease.[4,42] Nevertheless, these additional costs may be offset by the fact that minimally invasive techniques had a major impact on postoperative recovery, thus contributing to a reduction in length of stay and cost, although this is not yet proven on bile duct repairs.[43] It would have been optimal to perform a cost-effective analysis between laparoscopic and robotic-assisted surgery. Unfortunately, this analysis is very difficult to perform in our institution, due to the fact that funding comes from different sources (government, patient fees, and private donations).

The authors recognized as a major limitation of the study the fact that we were not comparing our techniques with the standard of care that is open bile duct repair. The best way to test if MIS is superior or at least non-inferior to open surgery and which of the two minimally invasive approaches (robotic vs. laparoscopic) is the best is to perform a large prospective randomized clinical trial. So right now, we could not recommend it as the approach of choice.

Conclusion

Our results showed that the robotic approach is similar to the laparoscopic regarding safety and efficacy in attaining primary patency for bile duct repair. The fact that all patients attained primary patency and that the actuarial primary patency rate was 96% positions the minimally invasive bile duct repair as an attractive option to offer to patients who suffer this condition. However, we recommend further investigation with longer follow-up time and randomized clinical trials to evaluate the benefits and establish the role of laparoscopic and robotic surgery in patients with iatrogenic bile duct injury.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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