Reply to the reviewers' comments

Dear Editor-in-Chief,

We thank you for your decision letter for our manuscript entitled "**Minimally invasive surgery for post cholecystectomy biliary stricture: current evidence and future perspectives"** We have considered the reviewer's comments and provide below a point-by-point answer to each of them. Changes have been incorporated and highlighted in the revised manuscript. We are grateful to the reviewers for their comments which have helped us improve the manuscript. We hope that you will find this revised version suitable for publication in your esteemed journal.

With kind regards,

Authors

Response to comments

Reviewer 1

1. **BDI acronym is apt in this manuscript and should be considered by authors**

   As suggested by the reviewer, BDI acronym is used for bile duct injury.

2. **In surgical technique section - when authors comment that most BDI are repaired at 6–10-week time, it actually excludes the ontable recognized BDI that are many times repaired with HPB surgical consult during index procedure itself. This diversity has to be mentioned for readers I am unaware of any large series that reported ontable index admission BDI repair by minimal access route as in many instances open conversion might have been done or delayed repair contemplated.**

   As suggested by the reviewer, the following sentence was included in the manuscript

   Several case studies report applying minimally invasive methods for the on-table repair of BDI[10-12]. However, the availability of expert HPB surgeons to repair BDI is a challenge and can be considered in the presence of adequate expertise.

Also, the rate of conversion to open surgery is high (31%) for on-table BDI repair [11,12].

3. **I recommend to add comments to propose life long followup with 10 year or long duration patency rates of the repair, considering this is a benign disease and QoL is not a matter of few years, but long term matter**

As suggested by the reviewer, the following sentence is included in the revised manuscript under the heading **LIMITATIONS OF MINIMALLY INVASIVE SURGERY FOR REPAIR OF POST-CHOLECYSTECTOMY BILIARY STRICTURE.**

Upcoming studies have to consider reporting long-term follow-up and ten year patency rates of the bilio-enteric anastomosis, which could confirm the better quality of life with the minimally invasive repair of BDI.

4. **I also recommend mentioned 1-2 statement about health economics related to this problem of BDI, economics of robotics versus conventional laparoscopy, and also the 3D laparoscopy versus conventional 2D laparoscopy.**

As suggested by the reviewer the following senstence is included in the revised manuscript under the heading **FUTURE PERSPECTIVE – A NEW ERA OF BILE DUCT REPAIR**

'In the economic foreground, the robotic approach can increase the total cost of BDI management compared to the laparoscopic approach. However, with the availability of new robotic platforms, the cost of the robotic approach is expected to decrease in the near future. While 3D laparoscopy could overcome some of the limitations of conventional laparoscopy, more studies are required to compare the outcomes of BDI repair done with 3D laparoscopic and robotic approaches.

5. **Also the use of barbed sutures is increasingly common and reported as safe in biliary repair PMID 34667894 and some comment is warranted. What sutures do you use? Do you place internal stents or recommend it?**

As suggested by the reviewer the following senstence is included in the main manuscript (under the heading **SURGICAL TECHNIQUE: IS MINIMALLY INVASIVE SURGERY DIFFERENT FROM OPEN SURGERY**

'Absorbable suture materials are preferred for anastomosis. As in the open technique, 3-0 or 4-0 polydioxanone sutures are commonly used to create hepaticojejunostomy. Barbed sutures, initially used in tendon repair to reduce the need for knot tying and increase gripping strength, are increasingly used in minimally invasive pancreatobiliary surgeries, including BDI repair for anastomosis. Avoidance of repeated suture tightening and traction after each stitch during continuous suturing is the primary advantage of barbed sutures. However, more evidence is required regarding its safety in BDI repair, especially in patients with thin bile ducts. Internal stents are not routinely recommended.

6. **You mention potential for AI and computer-guided technology use - but you did not tell how exactly will this be used or useful. Give examples**

As suggested by the reviewer, the following sentence and reference were included in the revised manuscript (under the heading **FUTURE PERSPECTIVE – A NEW ERA OF BILE DUCT REPAIR)** as an example of the use of AI and computer-guided technology in the management of BDI.

'Lopez et al. demonstrated the use of machine learning to develop a risk-scoring model and improve the accuracy of predicting the success of surgical repair in managing iatrogenic BDI [33]. Also, AI and computer-guided technology could avoid misidentifying critical structures during minimally invasive BDI repair.

7. **You mention ICG but i dont see any mention on IOC. Please comment on it. I am sure some authors will have reported on this too.**

   The use of intraoperative cholangiogram in delineating biliary anatomy and preventing biliary injuries is well reported. Still, the use of the IOC in managing BDI is unclear in the literature. IOC is primarily used in patients planned for on-table repair. The current review focused on managing biliary strictures, so we didn't add IOC.

8. **What energy device do you use for dissection to minimize collateral thermal injury**

   Close to the bile duct, we prefer to use bipolar energy devices (Maryland forceps) to minimize collateral damage to adjacent structures.

9. **How do you incorporate enhanced recovery pathways in this surgery**

   Since our centre is a tertiary high-volume centre, we follow ERAS protocol for most of the patients undergoing surgery, such as preoperative counselling, optimization of nutrition, standardized analgesic and anaesthetic regimens, early removal of a nasogastric tube, drains and early mobilization. Minimally invasive repair of BDI facilitates implementation of ERAS protocol.

10. **What is the scope of informed consent and shared decision-making before surgery**

As suggested by the reviewer, the following sentence is included in the main manuscript (under the heading **SURGICAL TECHNIQUE: IS MINIMALLY INVASIVE SURGERY DIFFERENT FROM OPEN SURGERY**

As a minimally invasive approach is still not a standard technique to repair benign biliary stricture, appropriate informed consent and shared decision making is imperative.

11. **What is the followup protocols like and role of interventional radiology in patients who develop bile leak post-op**

Follow-up evaluation was done by clinical history and examination, liver function tests, and Ultrasound abdomen. The outcome of surgical repair was graded as per McDonald criteria.: Grade A (asymptomatic, normal liver function test), B (asymptomatic, mild liver function test derangement or occasional episodes of pain or fever), C (pain, cholangitis defined as fever with jaundice, and abnormal liver function test), and D (surgical revision or dilatation required). Patients with McDonald's grades A and B were classified as treatment successes. In a patient with postoperative bile leak with bilioma ultrasound or computed tomography guided percutaneous drainage was performed.

Reviewer 2

1. **The manuscript lacks originality and does not significantly contribute to the existing literature on the topic. It predominantly summarizes previous studies without offering new insights or perspectives.**

In addition to summarizing the available evidence we have elaborated the surgical technique that will be useful for readers. Also, we have highlighted the limitations of the available evidence and future perspectives that can guide prospective studies in future. The following sentences were added under the headings limitations and future perspectives

Upcoming studies have to consider reporting long-term follow-up and ten year patency rates of bilio-enteric anastomosis, which could confirm the better quality of life with the minimally invasive repair of BDI.

The availability and expertise of a hepatobiliary surgeon are of prime importance in managing BDI patients, and the application of minimally invasive procedures would complement the surgery results

In the economic foreground, the robotic approach can increase the total cost of BDI management compared to the laparoscopic approach. However, with the availability of new robotic platforms, the cost of the robotic approach is expected to decrease in the near future. While 3D laparoscopy could overcome some of the limitations of conventional laparoscopy, more studies are required to compare the outcomes of BDI repair done with 3D laparoscopic and robotic approaches.

Lopez et al. demonstrated the use of machine learning to develop a risk-scoring model and improve the accuracy of predicting the success of surgical repair in managing iatrogenic BDI [33]. Also, artificial intelligence and computer-guided technology could avoid misidentifying critical structures during minimally invasive BDI repair.

2. **The writing style and structure of the manuscript need substantial improvement. The content is disorganized, making it difficult to follow the logical flow of ideas**

As suggested by the reviewers the manuscript has been reviewed by the native English speaker to improve the writing style. Also, the content is organized under the following headings 1. Surgical technique 2. Laparoscopic repair of postcholecystectomy biliary stricture 3. Robotic repair of postcholecystectomy biliary stricture 4. Robotic versus laparoscopic repair of post-cholecystectomy biliary stricture 5. Limitations of minimally invasive surgery for repair of post-cholecystectomy biliary stricture 6. future perspective – a new era of bile duct repair

3. **The methodology section lacks sufficient detail, such as the search strategy, inclusion criteria, and selection process of the literature. Additional information is required to ensure transparency and replicability.**
   We have mentioned the keywords and Boolean operators used under the search strategy.

For the inclusion criteria and selection process we have added the following statement "Case reports and case series with less than five patients were not included in the review. "

4. **The conclusions drawn from the available evidence are not adequately supported. The manuscript fails to provide a balanced analysis of the strengths, limitations, and unanswered questions in the field.**

   As mentioned above we have elaborated the limitations of the existing literature to support the conclusions of the present review.

5. **Overall, the scientific quality and contribution of the manuscript do not meet the standards required for publication in World Journal of Gastrointestinal Surgery.**

   As suggested by the reviewers the manuscript has been modified and we are hopeful that the revised manuscript would meet the standards required for publication

Reviewer 3 –

1. **Please use the correct surnames only of Authors cited in the text. Giulianotti (not Pier Giulianoti), Marino (not Marco Vito Marino) I think the use of the first name is redundant and leads to some mistakes in citation (the first name instead the surname).**

   We apologise for the mistake. As suggested by the reviewer, only the surname is included in the revised manuscript.

2. **Lastly, please stress the concept of Third Referral Center in where to treat these lesions: I am strongly convinced that the crucial point is not the need of a minimally invasive approach (to be achieved whenever possible), but the need of searching for an hepatobiliary surgeon.**

As suggested by the reviewer the following senstence is included in the main manuscript (under the heading **FUTURE PERSPECTIVE – A NEW ERA OF BILE DUCT REPAIR)**

'The availability and expertise of a hepatobiliary surgeon are of prime importance in managing BDI patients, and the application of minimally invasive procedures would complement the surgery results.'

Reviewer 4 –

1. **In the abstract section the authors wrote: "Future studies should overcome the current evidence's limitations and help choose the right patient for the minimally invasive repair of postcholecystectomy biliary stricture." - you cannot choose "the right' patient. It is better to write e.g. "the most suitable method for the patient with bile duct injury". Please correct this.**

A similar sentence that was used in the abstract is

'Future trials with long-term follow-up are required to confirm the initial promising outcomes with minimally invasive surgery.' is paraphrased to

'High volume prospective studies are required to confirm the initial promising outcomes with minimally invasive surgery'

2. **The above sentence is mentioned again in the core tip – please paraphrase the sentence**

   As suggested by the reviewer, the following corrections are included in the revised manuscript.
   Core tip modified as

   'Future studies should overcome the current evidence's limitations and help choose the most suitable method for the repair in a patient with bile duct injury.'

3. **What do you mean by: "The long-term success rate has been reported to be 80-90%." Please specify what is this long – term success?**

As suggested by the reviewer the following sentence is included in the revised manuscript (under the heading **INTRODUCTION)**

'The reported success rate at 30 months follow up period is as high as 80-90%.'

4. **In the section Patient positioning and port placement you mentioned only one position in the laparoscopic approach. Have you heard of any other?**

As suggested by the reviewer, the following sentence is included in the main manuscript (under the heading **Patient positioning and port placement)**

'The patient is positioned supine or supine with a leg split, with the operating surgeon standing on the left side of the patient or between the patient's legs.'

Name of Journal: *World Journal of Gastrointestinal surgery*

Manuscript No: 05083802 (invited manuscript ID)

Manuscript Type: Review

Title: Minimally invasive surgery for post cholecystectomy biliary stricture: current evidence and future perspectives

Running title: Minimally invasive surgery for biliary stricture

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Author contributions:

Raja Kalayarasan and Pothugunta Sai Krishna did the literature search. Pothugunta Sai Krishna wrote the first draft of the review. Raja Kalayarasan conceptualized the work, supervised the writing, gave intellectual inputs, and critically revised the manuscript.

Supportive foundations: Nil

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Conflict-of-interest statement: All authors have no conflicts of interest to report.

Acknowledgment: Nil

Minimally invasive surgery for post-cholecystectomy biliary stricture: current evidence and future perspectives

ABSTRACT

Postcholecystectomy bile duct injury (BDI) remains a devastating iatrogenic complication that adversely impacts the quality of life with high healthcare costs. Despite a decrease in the incidence of laparoscopic cholecystectomy-related BDI, the absolute number remains high as cholecystectomy is a commonly performed surgical procedure. Open Roux-en-Y hepaticojejunostomy with meticulous surgical technique remains the gold standard surgical procedure with excellent long-term results in most patients. As with many hepatobiliary disorders, a minimally invasive approach has been recently explored to minimize access-related complications and improve postoperative recovery. Since patients with gallstone disease are often admitted for a minimally invasive cholecystectomy, laparoscopic and robotic approaches for repairing postcholecystectomy biliary stricture are attractive. While recent series have shown the feasibility and safety of minimally invasive post-cholecystectomy biliary stricture management, most are retrospective analyses with small sample sizes. Also, long-term follow-up is available only in a limited number of studies. The principles and technique of minimally invasive repair resemble open repair except for the extent of adhesiolysis and the suturing technique with continuous sutures commonly used in minimally invasive approaches. The robotic approach overcomes key limitations of laparoscopic surgery and has the potential to become the preferred minimally invasive approach for the repair of postcholecystectomy biliary stricture. Despite increasing use, lack of prospective studies and selection bias with available evidence precludes definitive conclusions regarding minimally invasive surgery for managing postcholecystectomy biliary stricture. High-volume prospective studies are required to confirm the initial promising outcomes with minimally invasive surgery.

Key words: Robotics; Laparoscopy; Surgery; biliary stricture; cholecystectomy; Gallstones

CORE TIP

Minimally invasive postcholecystectomy biliary stricture repair is an attractive and controversial option to manage this iatrogenic injury with serious health and litigation consequences. Recent evidence suggests a potential role of minimally invasive approaches especially robotic surgery. Refinements in minimally invasive techniques can widen the scope of minimally invasive surgery. Future studies should overcome the current evidence's limitations and help choose the most suitable method for repair in a patient with bile duct injury.

INTRODUCTION

Iatrogenic post-cholecystectomy bile duct injury (BDI) resulting in biliary stricture is a devastating complication for any patient who experiences it and can be a nightmare to the surgeon responsible for it. The incidence of BDI following laparoscopic cholecystectomy is about 0.2% to 0.6% and slightly less following an open cholecystectomy (0.1-0.2%)[1,2]. Recent series have shown comparable incidences of BDI between open and laparoscopic cholecystectomy[2,3]. However, considering the number of cholecystectomies done for gallstone disease worldwide, even this lower incidence turns into a substantial absolute number. On admission for elective laparoscopic cholecystectomy, often done as an outpatient procedure, the patient expects a prompt postoperative recovery. Hence, consequences of BDI like large abdominal incisions, the need for multiple drains and stents, a prolonged hospital stay, and the inability to continue routine work make it difficult for the patient to accept, often ending with litigations against the operating surgeon[4,5].

The implication of postcholecystectomy biliary stricture on quality of life mandates a meticulous surgical repair with utmost care. Roux-en-Y hepaticojejunostomy (RYHJ) is the gold standard surgical treatment for benign biliary stricture[5,6]. The reported success rate at 30 months follow up period is as high as 80-90%[6]. Conventionally, an open approach is used for performing RYHJ in postcholecystectomy biliary stricture patients. A minimally invasive approach for repairing postcholecystectomy biliary stricture is considered controversial as often the injury is a consequence of a laparoscopic approach. However, in recent years, the application of laparoscopy has yielded promising results in managing complex biliary tract diseases, including the repair of iatrogenic bile duct injuries[7-10]. Also, the robotic platform with a stable camera, tremor filtration, immersive 3-dimensional imaging, intuitive movement of surgeon's wrist, and enhanced dexterity allow the performance of complex procedures with increased precision[11-13]. Better cosmetic outcomes and early postoperative recovery with laparoscopic and robotic approaches could decrease the patient's attitude towards litigations[11]. However, literature on laparoscopic and robotic approaches for managing postcholecystectomy biliary stricture is still limited. The current evidence is reviewed to give an overview of the minimally invasive management of postcholecystectomy biliary strictures and future perspectives.

SEARCH STRATEGY

Both authors independently did a PubMed search of relevant articles. Further, the reference lists of selected manuscripts were searched for additional appropriate studies. The keywords and combinations included in the search were: "bile leak"; OR "hepaticojejunostomy"; OR "biliary anastomosis"; OR "Bile duct injury repair"; OR "iatrogenic bile duct injury"; OR "biliary anastomosis," OR "laparoscopic cholecystectomy"; "hepaticojejunostomy" AND "Laparoscopic"; "hepaticojejunostomy" AND "robotic". The search was limited to publications in English literature till March 2023. Case reports and case series with less than five patients were not included in the review. All the authors agreed that the articles selected for review were relevant.

SURGICAL TECHNIQUE: IS MINIMALLY INVASIVE SURGERY DIFFERENT FROM OPEN SURGERY

The fundamental principles of surgical repair in a patient with postcholecystectomy biliary stricture are exposure of well-vascularized ducts, tension-free anastomosis and drainage of all segments[6]. While the principles of surgical repair remain the same in both open and minimally invasive approaches, the critical differences in operative steps between both approaches are highlighted in this section. In most series, elective repair is undertaken after a waiting period of 6-10 weeks or even longer if an uncomplicated external biliary fistula is present[10-12]. Several case studies report applying minimally invasive methods for the on-table repair of BDI[10-12]. However, the availability of expert HPB surgeons to repair BDI is a challenge and can be considered in the presence of adequate expertise. Also, the rate of conversion to open surgery is high (31%) for on-table BDI repair [11,12]. As a minimally invasive approach is still not a standard technique to repair benign biliary stricture, appropriate informed consent and shared decision making is imperative.

Patient positioning and port placement

The patient is positioned supine or supine with a leg split, with the operating surgeon standing on the left side of the patient or between the patient's legs. Trocar position is determined after creating the pneumoperitoneum and initial exploratory laparoscopy. In the laparoscopic approach, commonly, five trocars are placed in a semi-circular line at the level of the umbilicus[9,10]. In patients undergoing robotic repair, four robotic trocars are placed in a straight line at the level of the umbilicus, with an assistant trocar placed in the infraumbilical region.

Adhesiolysis

Most patients with postcholecystectomy biliary have dense intra-abdominal adhesions that require careful adhesiolysis. In open surgery, perihepatic adhesions are completely released before reaching the hepatic hilum. Whereas in minimally invasive surgery, perihepatic adhesions, if present, are left undisturbed because they serve as a natural source of liver retraction facilitating exposure and dissection of the hilum (Figure 1)[10]. In biliary stricture patients undergoing robotic repair, docking of the robotic arms is usually done after laparoscopic intra-abdominal adhesiolysis.

Identification of base of segment IV & left hepatic artery

The dissection started in the inferior surface of the liver to identify the base of segment four. Gastro hepatic ligament is taken down to facilitate the same. Dissection proceeds towards the umbilical fissure with careful identification and preservation of the left hepatic artery, as this may be the sole artery supplying the liver and bile duct in patients with associated right hepatic artery injury (Figure 1). The lack of tactile sensation of palpating blood vessels in minimally invasive surgery is compensated by visualization of pulsations under magnified vision.[11,12] While intravenous indocyanine green (ICG) can be used to identify the blood vessels, it is often used to determine the ductal anatomy.

Identification of hepatic duct and lowering the hilar plate

After delineation of the porta hepatis, the next step is identifying the left hepatic duct and lowering the hilar plate. In patients with internal fistula, frequently with the duodenum, dismantling the fistula facilitates duct identification (Figure 2). ICG is frequently used in minimally invasive approaches to identify the hepatic ducts (Figure 3). Identification of biliary anatomy is facilitated by intravenous injection at least 6 hours before the procedure to minimize background liver fluorescence. However, background fluorescence interferes with ductal anatomy delineation once an intraoperative bile leak occurs.

Lowering the hilar plate is achieved by dissection between the Glissonean sheath surrounding portal structures and Laennec's capsule surrounding the liver (Figure 3). Magnified vision in a minimally invasive approach facilitates the identification of the correct plane to lower the hilar plate. Once the left hepatic duct is identified, it is widely opened, and its confluence with the right hepatic duct is defined (Figure 4). In patients with type IV and V stricture, coring of hilar liver tissue or partial resection of segment IV may be required to have good exposure to the ducts. Delineation of the distal bile duct is neither required nor recommended, as it may result in vascular injury.

Creation of Roux limb and performance of RYHJ

The loop of the jejunum about 30cm from the duodenojejunal flexure is identified and divided using an endoscopic bowel stapler. Creation of a Roux limb can be technically challenging, especially in a robotic approach due to changes in the quadrant. Similarly, the creation of a mesocolic window in minimally invasive surgery is complex in patients with extensive periduodenal adhesions and inflammation. A wide side-to-side tension-free hepaticojejunostomy to the healthy bile duct, ensuring complete drainage of all the bile ducts, is a crucial step of the surgical procedure (Figure 5). Due to difficulty in handling multiple sutures, stay sutures on the hepatic duct are not commonly used in a minimally invasive approach. Also, continuous sutures are frequently used in minimally invasive surgery, especially the laparoscopic approach[8-10]. Absorbable suture materials are preferred for anastomosis. As in the open technique, 3-0 or 4-0 polydioxanone sutures are commonly used to create hepaticojejunostomy. Barbed sutures, initially used in tendon repair to reduce the need for knot tying and increase gripping strength, are increasingly used in minimally invasive pancreatobiliary surgeries, including BDI repair for anastomosis. Avoidance of repeated suture tightening and traction after each stitch during continuous suturing is the primary advantage of barbed sutures. However, more evidence is required regarding its safety in BDI repair, especially in patients with thin bile ducts.

Preservation of perihepatic adhesions, frequent use of ICG to delineate ducts and anastomosis technique are some of the critical technical differences in the minimally invasive repair of postcholecystectomy biliary stricture compared to open RYHJ.

LAPAROSCOPIC REPAIR OF POST-CHOLECYSTECTOMY BILIARY STRICTURE

The feasibility of laparoscopic repair of postcholecystectomy biliary stricture was first reported in 2002 by Crema et al[14]. Despite the encouraging results, the laparoscopic approach was not widely used, and publications were limited only to case reports. Apprehension of abdominal adhesion due to previous bile leak and technical challenges in dissecting the scarred tissues were the primary reasons for surgeon's hesitation to adopt a minimally invasive approach. In 2016, Adolfo Cuendis-Velázquez et al. published the first laparoscopic reconstruction series, which included 29 patients with post-cholecystectomy biliary strictures[7].The authors have given a detailed description of the procedure and reported excellent outcomes with minimal morbidity. During a median follow-up of 36 months, one patient developed hepatico-jejunostomy stricture requiring endoscopic intervention. While most laparoscopic series had a single study arm, Javed et al., in a retrospective study, compared the outcomes of 29 patients who underwent laparoscopic repair with 34 patients who underwent open RYHJ[10]. More than three fourth of patients in both groups had high strictures (Strasberg E3, E4 and E5 types). While median operative time was comparable between the two groups (210 versus 200 min, P = 0.93), the mean blood loss (50 *vs* 200 mL, P = 0.001), time to resume oral diet (2 *vs* 4 days, P= 0.023), and duration of hospital stay (6 *vs* 8 days, P= 0.04) were significantly less in the laparoscopic group. While all patients in the open group underwent RYHJ, hepaticoduodenostomy for biliary reconstruction was used in more than half of the patients included in the laparoscopic group. Median operative time (190 *vs* 230 min, $p = 0.034$) was significantly less in the laparoscopic hepaticoduodenostomy group as it requires single anastomosis compared to additional small bowel anastomosis with hepaticojejunostomy.

Hepaticoduodenostomy is commonly used for reconstruction following choledochal cyst excision in the pediatric age group[15-17]. However, its use in postcholecystectomy biliary stricture is documented only in a single series[10]. Authors suggested that in patients with choledochoduodenal fistula or those with dense adhesion of the duodenum to the hilum, hepaticoduodenostomy can be safely performed without difficulties in mobilizing the duodenal knuckle. Hepaticoduodenostomy is primarily used in Strasberg E1-2 and some E3 strictures. In addition to the single anastomosis, the feasibility of the endoscopic intervention in patients with postoperative stricture is an added advantage of hepaticoduodenostomy. More severe presentation of anastomotic leak compared to hepaticojejunostomy is the primary risk with hepaticoduodenostomy. As the current evidence is limited, more studies are required to document the safety of hepaticoduodenostomy in patients with a postcholecystectomy biliary stricture. A few other series published from high-volume centres with significant experience in advanced laparoscopic hepatobiliary procedures report that the laparoscopic approach may be equivalent, if not better, for managing post-cholecystectomy biliary strictures[18-21]. Published laparoscopic case series with at least ten patients included in the analysis are summarized in Table 1.

ROBOTIC REPAIR OF POST-CHOLECYSTECTOMY BILIARY STRICTURE

With the development of Devol's first robotic machines using a magnetic process controller in the 1940s, robotic surgery made immense progress in recent years[22]. Since the first robotic cholecystectomy performed by Himpens in 1997, the use of robotics in hepatobiliary and pancreatic surgery, including complex surgeries, has shown noticeable growth[23,24].The initial case series on the use of robots for biliary stricture repair was published by Giulianotti et al. in 2018, which analyzed fourteen patients[11]. Interestingly, 42.9% of included patients had Bismuth type II injuries underscoring the careful selection of patients for the robotic approach in the initial phase. However, complex reconstructions were also performed in their series. Two patients, one with isolated right hepatic duct stricture and the other with type IV stricture because of small duct size, underwent Robotic assisted Kasai procedure. One patient with previous Roux en-y gastric bypass underwent dismantling of gastric bypass, sleeve gastrectomy of the remnant stomach, and an anastomosis between the gastric pouch and sleeve gastrectomy portion with the use of Roux limb for biliary anastomosis. The authors highlighted the potential advantage of the robotic approach over the laparoscopic repair of bile duct injuries: improved magnification (10X), enhanced range of motion, ambidextrous handling with precise dissection and tremor filtration with better ergonomics. The study concluded that robot-assisted biliary reconstruction for postcholecystectomy biliary stricture is feasible and safe in expert hands[11]. Marino et al. published the only prospective series on Robotic assisted repair of biliary stricture in 2019[12]. Twelve patients who underwent robotic repair from 2014 to 2017 were analyzed. However, the duration of follow-up was only 12 months. Sucandy et al. compared the robotic approach with open surgery and reported less blood loss in the robotic group (50 vs 150 mL)[13]. However, the study had only eight patients in the robotic arm. Since then, a few other series have documented the usefulness of the robotic approach, although the number of patients included was small with a short follow-up period[25-27]. Published robotic case series with at least five patients included in the analysis are summarized in Table 2. [12].

ROBOTIC VERSUS LAPAROSCOPIC REPAIR OF POST-CHOLECYSTECTOMY BILIARY STRICTURE

Only one study compared the outcomes of two minimally invasive approaches for biliary reconstruction in post-cholecystectomy biliary stricture patients[28]. Of the 75 patients included in the study 40 were managed laparoscopically, and 35 underwent robotic reconstruction. The BDI 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 and robotic-assisted hepaticojejunostomy respectively. The blood loss, operative times, length of hospital stay and anastomotic patency rate at the 90-day index period were comparable between the two groups (Table 3). Though overall morbidity and anastomotic patency rate were slightly superior in the robotic group, the difference was not statistically significant. The authors concluded that both minimally invasive approaches are safe and effective for biliary reconstruction in a high-volume centre[28]. However robotic approach has technical superiority over the laparoscopic approach. As the duration of follow-up was different in the two groups, the 90-day-index treatment period rather than the actuarial anastomotic patency rate was compared, which is a limitation of the study. Also, the selection of patients for the robotic and laparoscopic approach was based on the availability of the equipment, which could result in selection bias. A cost-effective analysis between the two approaches was not performed as the robot adds cost to the surgical procedure.

LIMITATIONS OF MINIMALLY INVASIVE SURGERY FOR REPAIR OF POST-CHOLECYSTECTOMY BILIARY STRICTURE

Although minimally invasive surgery has gained immense popularity in recent years for treating various hepatobiliary and pancreatic disorders, it has limitations, especially in complex procedures[29]. The technical drawbacks related to the laparoscopic approach are an unsteady surgical field, restricted degrees of freedom of movement, a steep learning curve and difficulties in complex suturing [30]. The complexity of the surgery and the steep learning curve comes from the fact that most patients with BDI would have suffered a bile leak and peritonitis, resulting in extensive adhesions, and altered anatomy[30,31]. Also, most patients with bile duct injury have complex strictures (Strasberg E3-E5 types). The need to anastomose delicate and supple lobar ducts to the jejunum necessitates steady vision and a high degree of laparoscopic suturing skills. Difficulty in handling multiple sutures during minimally invasive surgery results in increased usage of continuous suture technique. While meta-analysis comparing two suture techniques has reported comparable outcomes, the evidence in the setting of postcholecystectomy biliary stricture is limited[32]. Hence, the long-term patency rate with the continuous suture technique commonly used in minimally invasive surgery must be analyzed. As documented in most studies, laparoscopic repair of postcholecystectomy biliary stricture was performed by surgeons who have completed more than 30 complex hepatopancreatobiliary surgeries, including laparoscopic Whipple's procedure [18]. On the other hand, the robotic repair of biliary strictures has documented advantages over the laparoscopic approach in terms of magnification, stable vision, and a greater degree of freedom of movement with ease of intracorporeal suturing[11]. However, robotic repair of biliary stricture is not without limitations, the foremost being the availability of equipment, high equipment and maintenance costs restricting its availability to a few centres. Undoubtedly robotic approach increases the treatment cost for patients with severe economic hardships due to the disease.

Regarding drawbacks in the published literature on minimally invasive surgery, most studies were retrospective analyses with several reporting biases. The diagnostic criteria for postoperative complications, timing, and duration of follow-up were non-homogenous. It eventually translated to difficulty in acquiring raw data for some long-term follow-up parameters, including the anastomotic patency rate. Upcoming studies have to consider reporting long-term follow-up and ten year patency rates of bilio-enteric anastomosis, which could confirm the better quality of life with the minimally invasive repair of BDI.

FUTURE PERSPECTIVE – A NEW ERA OF BILE DUCT REPAIR

Studies published in the last five years, despite their limitations, provide hope that minimally invasive procedures could play a greater role in the management, thereby offering short- and long-term advantages to patients experiencing this devastating complication. The availability and expertise of a hepatobiliary surgeon are of prime importance in managing BDI patients, and the application of minimally invasive procedures would complement the surgery results. As minimally invasive surgery can be relatively easily employed in patients with Strasberg E1-E3 strictures, future prospective trials should compare open and minimally invasive approaches in this subgroup of patients. As postcholecystectomy biliary stricture repair requires fine dissection in a small, narrow operating field along with extreme accuracy in suture placement, robotic surgery could have a greater role. In the economic foreground, the robotic approach can increase the total cost of BDI management compared to the laparoscopic approach. However, with the availability of new robotic platforms, the cost of the robotic approach is expected to decrease in the near future. While 3D laparoscopy could overcome some of the limitations of conventional laparoscopy, more studies are required to compare the outcomes of BDI repair done with 3D laparoscopic and robotic approaches. There is significant potential for artificial intelligence and computer-guided technology in surgery for postcholecystectomy biliary stricture. Lopez et al. demonstrated the use of machine learning to develop a risk-scoring model and improve the accuracy of predicting the success of surgical repair in managing iatrogenic BDI [33]. Also, artificial intelligence and computer-guided technology could avoid misidentifying critical structures during minimally invasive BDI repair. Future advancements could widen the application of minimally invasive surgery, offering patients a better quality of life and psychological benefits in addition to the traditional benefits of the minimal access approach. Upcoming studies have to consider reporting long-term follow-up and ten-year patency rates of bilio-enteric anastomosis, which could confirm the better quality of life with the minimally invasive repair of BDI. Early referral to high-volume centres with expertise in advanced minimally invasive hepatopancreatobiliary procedures could widen the scope of minimally invasive surgery. Also, multiple benefits to patients could preclude them from filing lawsuits against surgeons thereby benefitting the surgical community.

CONCLUSION

Open surgical repair remains the gold standard for managing postcholecystectomy biliary stricture, a dreadful complication with severe health and litigation consequences. However, the available evidence suggests that minimally invasive surgery in carefully selected patients could help eliminate the trauma and devastation suffered by these patients, thereby offering superior quality of life. With its unique advantages, the robotic approach can potentially become the preferred minimally invasive approach for repairing postcholecystectomy biliary stricture. Experts from high-volume centres should take the lead in conducting prospective trials to compare different approaches for managing postcholecystectomy biliary stricture with long-term follow-up.

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Figure legends

Figure 1. Adhesiolysis and initial dissection phase. A - Perihepatic adhesions are left undisturbed to facilitate liver retraction and exposure of the hilum. B - Dissection proceeds towards the umbilical fissure with careful identification and preservation of the left hepatic artery(arrow).

Figure 2. Identification of hepatic duct. A – Internal fistula between the hepatic duct and duodenum (arrow). B – Division of the fistula facilitates visualization of the hepatic duct (arrow).

Figure 3. Lowering the hilar plate. A – Indocyanine green fluorescence facilitates hepatic duct identification. B - Hilar plate lowered by dissection between the Glissonean sheath and Laennec's capsule.

Figure 4. Opening the hepatic duct. A – Identification and opening of the left hepatic duct. B – Confluence of left hepatic duct with right hepatic duct identified

Figure 5. Roux-en-Y hepaticojejunostomy. A - Roux limb of jejunum taken to the supracolic compartment through the mesocolic window. B – Completed hepaticojejunostomy

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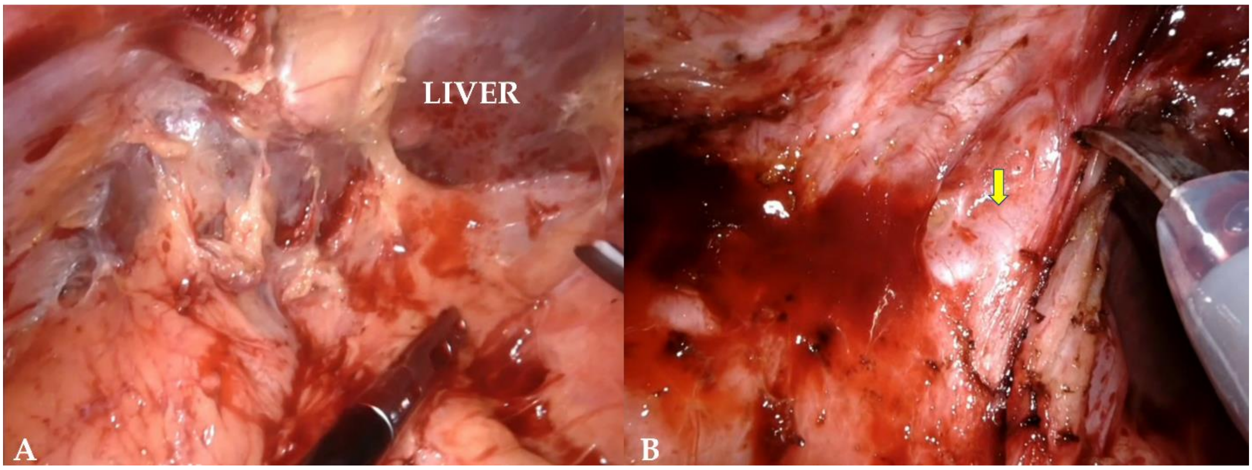

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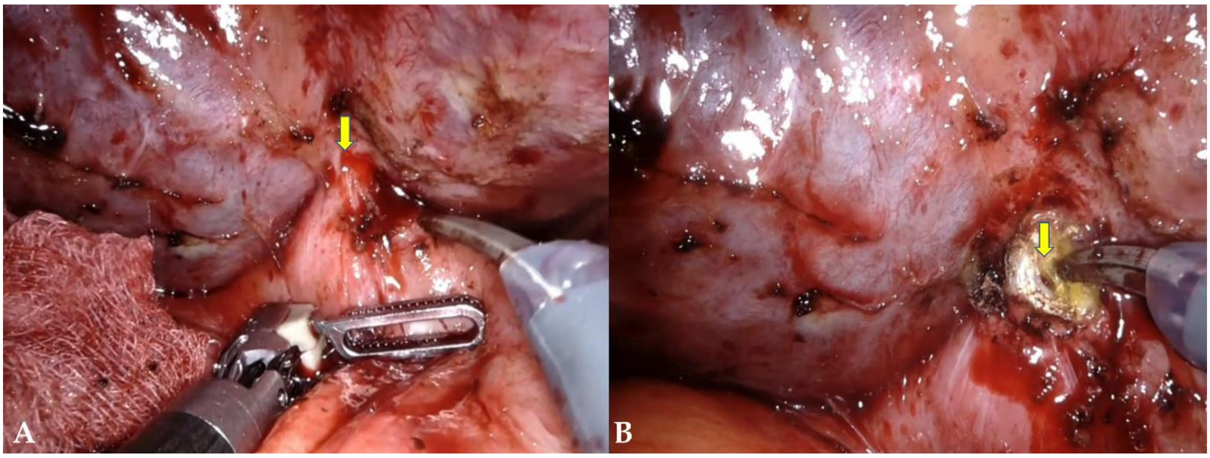

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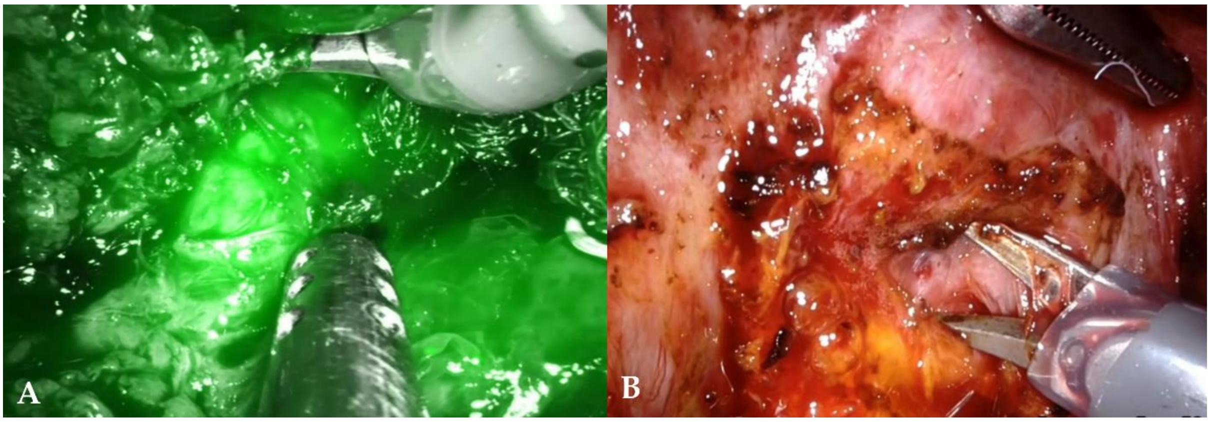

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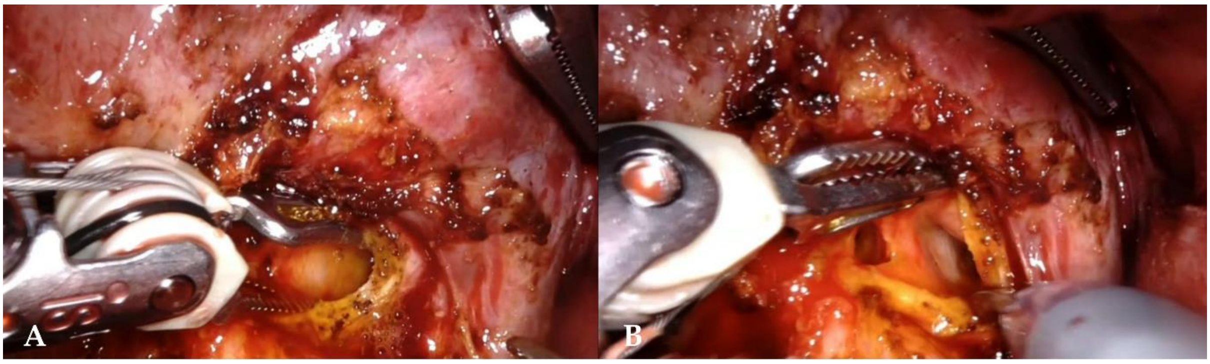

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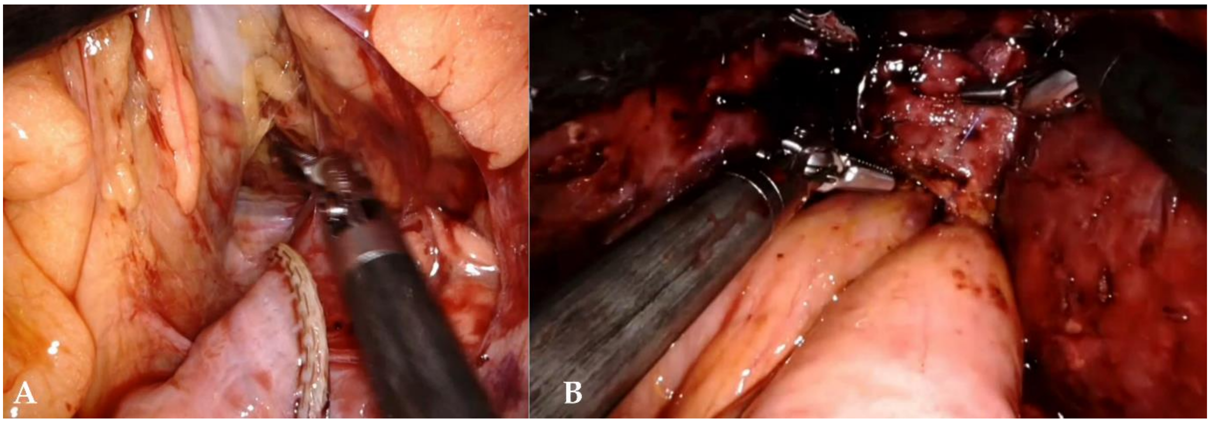

Table 1. Studies on laparoscopic repair of postcholecystectomy biliary stricture

Author[ref], Year	**Patients**	**Strasberg Injury type**	**Method of reconstruction**	**Mean Operative time (minutes)**	**Blood loss (mL)**	**Conversion to open**	**Overall morbidity**	**Specific biliary complications**	**Length of stay (days)**	**Follow up**
Cuendis - Velázquez A[7] 2016	29	C, E1-E4	HJ	240	200	1	31.03	Bile leak – 5 patients. One patient required laparotomy and drainage of bile collection	8	36 (range 7-36) months. Anastomotic patency rate 96.6%.
Gomez[9] 2020	20	E1-E4	HJ	146.5	15-50ml	None	10%	one patient had bile leak and was managed conservatively	4.5 (mean)	5 years – no long-term complications
Sahoo[8] 2021	16	-	HJ	280	176 ml.	None	12.5%	Two patients had bile leak and were managed conservatively	8.5	28 months
Javed [10] 2021	29	E1-E5	HJ – 13 patients HD – 16 patients	210	50 mL	none	20%	Four patients had bile leak and were managed conservatively	6	9 months – One patient had anastomotic stricture and managed with repeated dilations

HJ – Hepaticojejunostomy, HD - Hepaticoduodenostomy

Table 2. Studies on robotic repair of postcholecystectomy biliary stricture

Author [ref], Year	Patients	Strasberg injury type	Method of reconstruction	Operative time (minutes)	Blood loss(mL)	Overall morbidity	Length of stay (days)	Specific complications	Follow up
Guilanotti[11], 2018	14	E1-E5	HJ -12 patients Kasai procedure - 2 patients	280.6	135	28.6%	8.4	Bile leak - two patients and 1 patient required pigtail catheter insertion. Subhepatic abscess - one patient	36.1 months 2 patients had mild HJ stenosis and cholangitis. Managed by PTBD and multiple transhepatic dilatations
Marino[12], 2019	12	E1-E4	HJ	260	252	16.7%	9.4	1 patient developed subhepatic abscess and required pigtail catheter insertion	12 months – 1 patient had anastomotic stenosis and revision robotic HJ was done
Sucandy[13], 2021	8	-	HJ	259	50	14%	8	None	22 months – 1 patient had anastomotic stenosis at 10months and required transhepatic dilatation

HJ – Hepaticojejunostomy, PTBD – Percutaneous transhepatic biliary drainage

Table 3. Study comparing laparoscopic and robotic repair of postcholecystectomy biliary stricture

Author [ref], Year	**Patients**	**Strasberg Injury type**	**Method of reconstruction**	**Mean Operative time (minutes)**	**Blood loss (mL)**	**Conversion to open**	**Overall morbidity**	**Specific complications**	**Length of stay (days)**	**Follow up (months)**
Cuendis-Velázquez A[28] 2019	75 (Laparoscopic – 40, Robotic – 35)	E1-E5	Roux-en-Y Hepaticojejunostomy	Laparoscopic – 240 Robotic – 270	Laparoscopic – 215 Robotic – 150	1 patient in laparoscopic group due to dense adhesions	Laparoscopic – 27.5 Robotic – 22.8	Bile leak Laparoscopic – 2 patients Robotic – 1 patient One patient in each group underwent laparotomy, lavage with additional drain placement for bile leak	Laparoscopic – 7 Robotic – 6	Laparoscopic – 49 Anastomotic patency rate – 92.5% Robotic – 16 Anastomotic patency rate – 100%