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REVIEW ARTICLE

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Current progress in robotic hepatobiliary and pancreatic surgery at a high-volume center

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Abstract

There has been steady growth in the adoption of robotic HPB procedures worldwide over the past 20 years, but most of this increase has occurred only recently. Not surprisingly, the vast majority of robotics has been in the United States, with very few, select centers of adoption in Italy, South Korea, and Brazil, to name a few. We began our robotic HPB program in 2008, well before almost all other centers in the world, with the most notable exception of Giullianotti and colleagues. Our program began gradually, with smaller cases carefully selected to optimize the strengths of the original robotic platform and included complex biliary and pancreatic resections. We performed the first reported series of choledochojejunostomy for benign biliary strictures and first series of completion cholecystectomies. We began performing robotic distal pancreatectomies and longitudinal pancreaticojejunostomies, reporting our early experience for each of these procedures. Over time we progressed to robotic pancreaticoduodenectomies. Initially, these were performed with planned conversions until we were able to optimize efficiency. Now we have performed over 200 robotic whipples, reaching a 100% robotic completion rate by 2020. Finally, we have added robotic major hepatectomies, including resections for hilar cholangiocarcinoma to our repertoire. Since the program began, we have performed over 1600 robotic HPB cases. Outcomes from our program have shown superior lymph node harvest, lower DGE rates, shorter hospitalizations, and fewer rehab admissions with similar overall complications to open and laparoscopic procedures, signifying that over time a robotic HPB program is not only feasible but advantageous as well.

KEYWORDS
hepatectomy, hepatobiliary surgery, high-volume, minimally invasive, pancreatectomy, robotics

1 | INTRODUCTION

Minimally invasive hepato-pancreato-biliary (HPB) surgery has been a slowly growing field. With the introduction of robotics, interest has begun to rise over the last two decades. The vast majority of robotics have been performed in the United States, with few select centers in Europe, Asia, and South America. The first notable HPB center to begin utilizing the robotic platform reported their first cases in 2003.[1] Other centers have described their success with complex laparoscopic HPB surgery; however, this has been difficult for many to replicate.[2] It has been frequently mentioned in the literature that the robotic platform has theoretical advantages providing surgeons the dexterity to perform complex operations in a minimally invasive fashion that may not be seen with laparoscopy.[3–5] The downfalls, however, seem to be two-fold; the learning curve that needs to be overcome prior to experiencing superior outcomes and cost. Over the last 16 years, we have established a high-volume center for complex robotic hepatobiliary and pancreas surgery and published outcomes that surpass some of those for open and laparoscopic HPB surgery within our institution.[6–8] With increasing experience using robotics, we have been able to address some of the concerns with cost of major HPB procedures as well.[9] Advances have been made in robotic HPB surgery world-wide and we have now progressed to a phase of developing training models for future robotic HPB surgeons. Given a peak interest in robotic HPB surgery, we aim to present our experience building a robotic HPB program and the challenges along the way as well as describe the current progress in robotic hepato-pancreato-biliary surgery around the world.

2 | OUR INITIAL EXPERIENCE BUILDING A ROBOTIC HPB PROGRAM

Carolinas Medical Center (CMC) is a high-volume hepato-pancreato-biliary (HPB) center in Charlotte, North Carolina. Our current faculty consists of six HPB surgeons performing a vast array of procedures, both minimally invasive and open (Figure 1). In 2008 the senior author, JBM, began introducing robotics into practice at CMC, well before most other centers in the world. Integration of the robotic platform was done very gradually. Index procedures included smaller cases carefully selected to optimize the strengths of the original robotic platform. Examples of early cases were re-operative and difficult cholecystectomies, biliary reconstructions, and distal pancreatectomies. In 2008 we reported our first experience with total intra-corporeal Roux-en-Y choledocho-jejunostomy performed robotically.[10] Later we published a series of our first cases of robotic-assisted completion cholecystectomies.[11] We found that the robotic platform provided something that laparoscopy did not. We saw improved dexterity provided by the endowristed instruments, fine movement stabilization and three dimensional high-definition camera. Perhaps the most significant benefit at that time was the ability to suture thin and tenuous tissues such as the common bile duct. After gaining experience with robotic left pancreatectomy, we were able to report outcomes comparable to laparoscopic left pancreatectomy.[8,12] We then began to expand the indication for robotics to include operations for chronic pancreatitis such as lateral pancreaticojejunostomy and pancreatic necrosectomy with cyst-gastrostomy.[13–15] The procedure for drainage of pancreatic fluid collections evolved to include robotic cyst-jejunostomy and trans-mesenteric pancreatic debridement for pancreatic necrosis that may not be accessible through the stomach. We later incorporated a technique for internal drainage of persistent pancreatic fistulae by performing robotic fistula-jejunostomy after a fibrous tract had been matured.

During this early time, development of our program was not without its pitfalls. We recognized a learning curve was necessary to overcome before experiencing improved outcomes. Conversions to open were planned in most cases with increased complexity. We were able to identify some of the predictors for conversion early on including high BMI and technical difficulty, leading to increased blood loss and more frequent ICU admissions.[16] Carefully selecting patients early on helped to build exposure, establish the learning curve for the platform, and pave the way for more complex operations in the future.

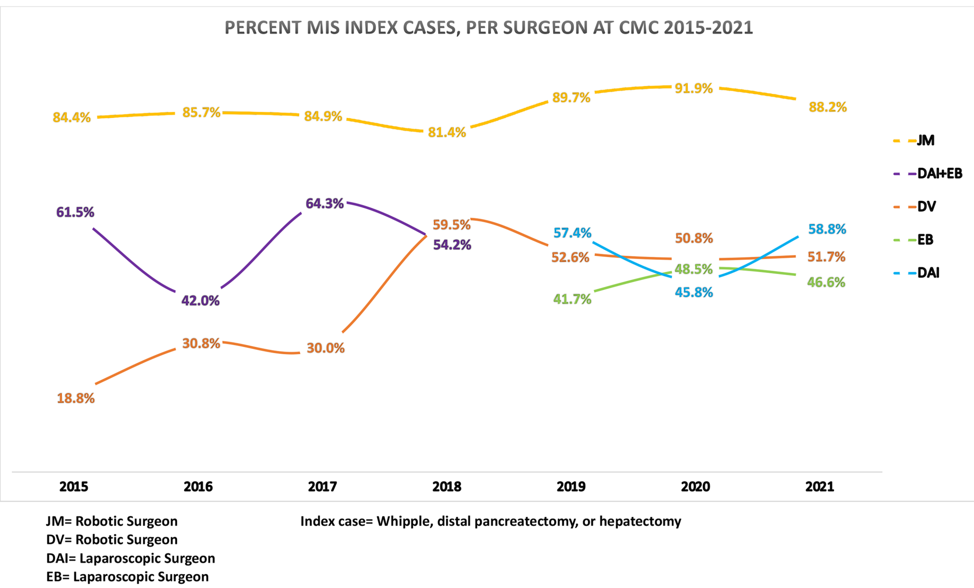

FIGURE 1 Percentage of index cases performed in an MIS fashion from 2015 to 2021 per individual surgeon at Carolinas Medical Center (CMC).

3 | EXPANDING THE INDICATIONS FOR ROBOTIC LIVER AND PANCREAS SURGERY AT CMC

Once we were able to develop mastery of the learning curve for robotics, we began to incorporate major liver resections and pancreaticoduodenectomy into our repertoire. Initial robotic liver cases included minor liver resections, left lateral hepatectomies, and non-anatomic partial resections. Currently we use the robotic vessel sealer for parenchymal transection in one arm accompanied by a bipolar device in the other (Figure 2). Prior to this, laparoscopic vessel sealing devices and staplers were used. We later found the robotic platform to be particularly useful for fine dissections of the porta hepatis and along the vena cava (Figure 3). This prompted the first robotic major hepatectomy at CMC which was performed in 2012. Since then, we have performed over 100 major robotic hepatectomies including trisectionectomies, hemi-hepatectomies, right posterior sectionectomies, central hepatectomies, ALPPS procedures, and Klatskin resections. In a comparative study we saw shorter hospital length of stay, fewer ICU admissions, and fewer hospital re-admissions after robotic major hepatectomy compared to laparoscopic.[5] We also noticed that more complex cases, such as right posterior sectionectomy, were able to be performed minimally invasively when using the robotic platform. We then began to offer robotic hepatectomy to patients that required biliary and vascular reconstructions. In 2018 we presented our technique for robotic ALPPS with positive outcomes. All our comparison studies for robotic liver surgery have shown similar clinical outcomes to laparoscopic and improvements in length of stay and decreased blood loss compared to open cases.[5,17]

In 2011 we performed the first robotic pancreaticoduodenectomy, 5 years after initiation of the program. Integration of these complex cases occurred gradually. We started with carefully selected patients; those with smaller pancreatic head lesions without

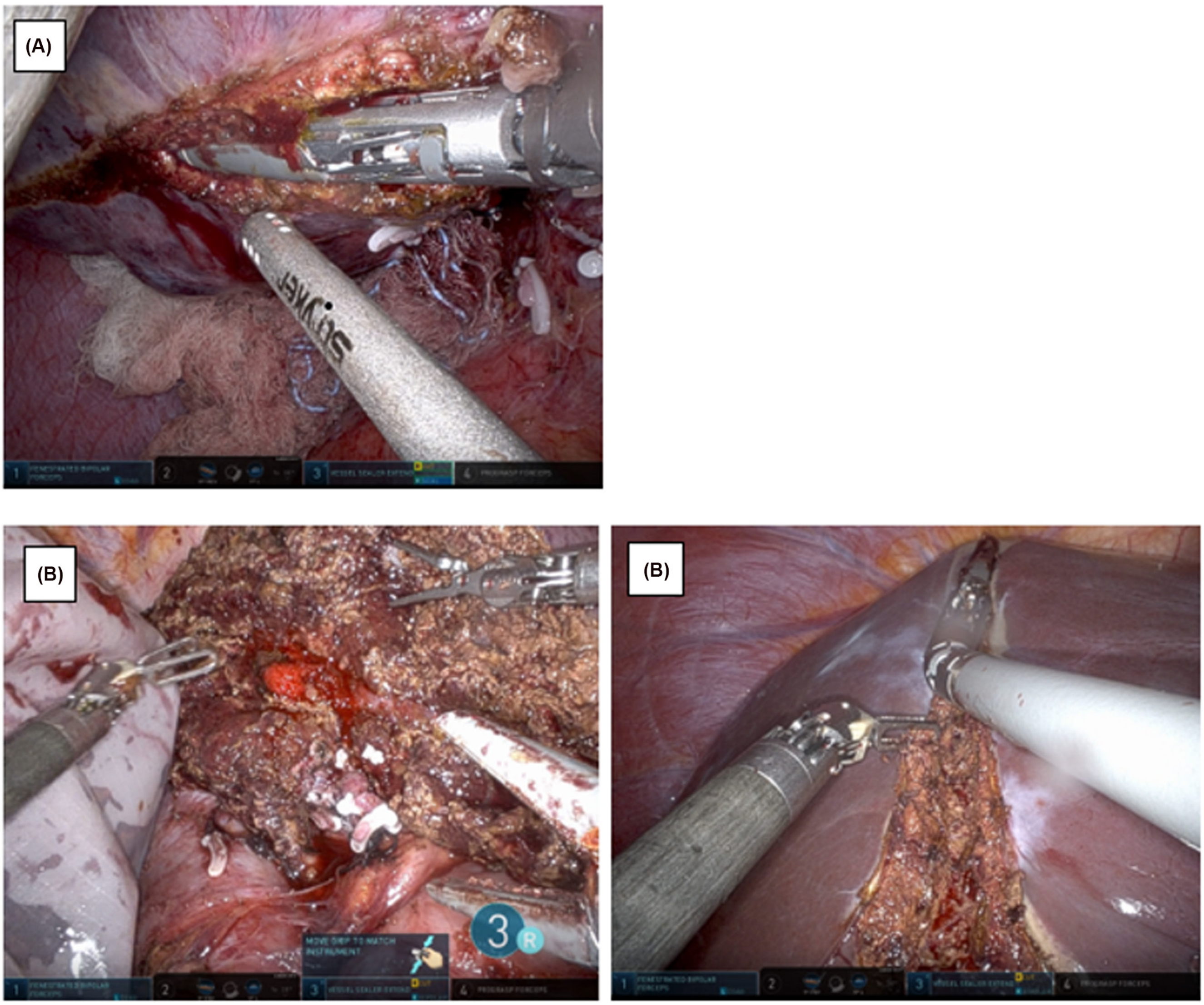

FIGURE 2 Liver parenchymal transection and hemostasis during (A) right posterior sectionectomy and (B) right hemi-hepatectomy.

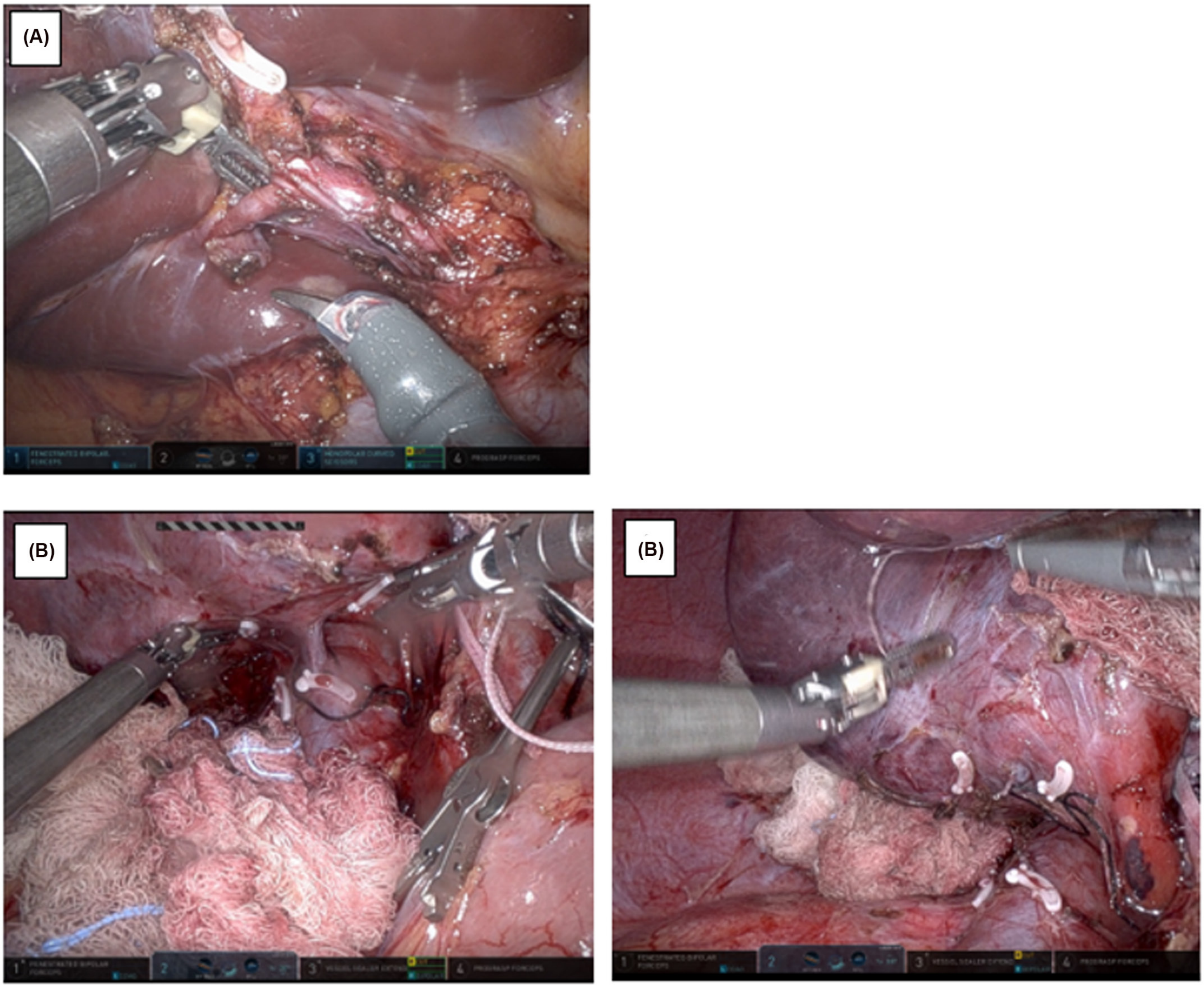

FIGURE 3 (A) Hilar dissection and isolation of right hepatic artery branches. (B) Liver mobilization from the vena cava.

radiographic vascular involvement, ampullary tumors, and pancreatic cystic disease. After 5 years of prior robotic experience, we quickly began to incorporate more complex cases. Referencing the published international benchmarks in pancreatic surgery and the definitions proposed by the University of Zurich, the majority of pancreaticoduodenectomies at our institution were considered high-risk even in the early years.[18] From 2011 to 2021 we performed over 200 robotic pancreaticoduodenectomies. As our experience evolved, we began to see the advantages in oncologic outcomes for patients with pancreatic cancer. In a propensity matched single institution comparison study we witnessed superior outcomes to open pancreaticoduodenectomy.[7] Here we saw not only improvements in length of stay but also significantly fewer rates of delayed gastric emptying (3% vs. 32%), higher number of lymph nodes harvested (21 vs. 13), trends toward longer median overall survival (30 vs. 23 months), and longer time to disease recurrence (402 vs. 284 days) in patients who had robotic pancreaticoduodenectomy for pancreatic cancer compared to open. By 2020 we reached 100% completion rates between two surgeons performing robotic pancreaticoduodenectomy, including a significant number of borderline resectable disease and vascular reconstructions. We have created a technique for performing robotic pancreaticoduodenectomy that allows for a single surgeon to complete the procedure without the need for a second surgeon at bedside.[19] Although in our early years we did use laparoscopic assistance for tasks such as stapling and dissection, we have adapted to a truly robotic technique (Figure 4). We retract the liver by securing the fundus of the gallbladder to the abdominal wall which also opens the porta hepatis (Figure 5). The fourth arm of the robot is constantly moving to provide counter traction during the dissection phase (Figure 6). A 15-mm assistant port is placed infra-umbilical to allow a scrub technician to pass suture and suction if needed. This port is also used as our extraction site. These key maneuvers, to name a few, allowed for us to improve on efficiency and cost. When compared directly to open pancreaticododenectomy at our institution, the overall cost was no different.[9]

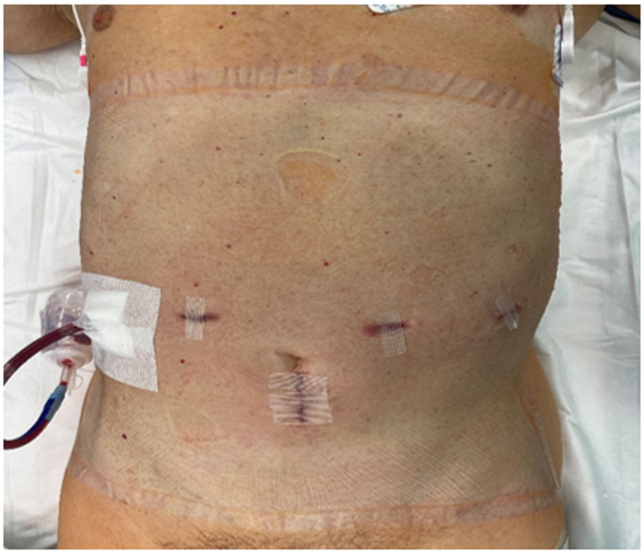

FIGURE 4 Incisions and trocar placement for purely robotic pancreaticoduodenectomy.

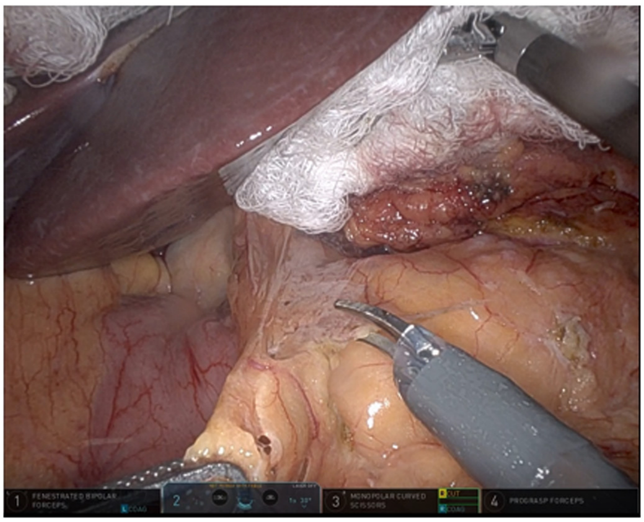

FIGURE 5 Liver retraction for purely robotic pancreaticoduodenectomy.

4 | WHERE ARE WE GOING AT CMC?

Since the program began, we have performed over 1600 robotic HPB cases by two surgeons. With the addition of robotic pancreaticoduodenectomy and major hepatectomy we have been able to create a program where the majority of HPB cases are performed in a minimally invasive fashion with favorable outcomes. Like our institution, many have seen improved outcomes with the robotic platform for both benign and malignant diseases.[20–23] Unlike others, however, we continue to develop new techniques with only two robotic HPB surgeons on staff.[24] We continue to expand the usage of the robotic platform, performing pancreas sparing duodenal resections, and recently developing a technique for robotic transmesenteric sleeve duodenectomy.[25]

5 | THE INTERNATIONAL EVOLUTION OF ROBOTIC HPB SURGERY

Liver and pancreas surgery historically carries significant risk for morbidity and for decades surgeons have been searching for strategies to improve outcomes. Since the first robotic cholecystectomy was performed in 1997 by Jacques Himpens of Belgium, the robotic approach to HPB surgery was seen as a way to perform cases in a minimally invasive fashion without the restrictions of laparoscopy.[26] Although it would be many years before robotics was accepted world-wide by HPB and general surgeons, there were some pioneers of the platform that provided us with data from their early experiences paving the way for future HPB surgeons. From a community hospital in Italy, Guillianotti and colleagues described their experience with the DaVinci Surgical System (Intuitive Surgical, Sunnyvale, California) in 2003.[1] They performed a myriad of HPB operations including pancreaticoduodenectomy, hepatectomy, and biliary reconstructions. This was the first account documenting the safety and efficacy of robotics in HPB surgery. In the decade to follow many more reports of robotic assisted complex HPB operations were described in regions such as the United States, Europe, and Asia.[10,16,27–35] As outcome data started to emerge, comparative studies between robotic, laparoscopic, and open approaches naturally followed.[36–40] For liver resections, the robotic approach showed improved outcomes such as shorter hospitalizations, less postoperative pain, and fewer blood transfusions than open hepatectomies.[41,42] However, when comparing laparoscopic liver resections, outcomes remained similar.[43,44] As surgeons gained experience with the robotic platform, the true benefit of robotics in liver resections was identified. Liver resections of higher difficulty were found to have better outcomes with the robotic platform than laparoscopy.[6,45] Robotic pancreatic resections also showed similar complication rates to laparoscopy but with fewer open conversions at many centers.[46,47] The benefits compared to open pancreatic resections is clear with less intra-operative blood loss and shorter hospitalizations.[48–50] However, improvements in postoperative complications and oncologic outcomes were also seen.[7,8,51]

6 | WHERE ARE WE GOING INTERNATIONALLY?

Robotic HPB surgery has finally gained worldwide recognition as being a safe and effective minimally invasive option. The platform itself has evolved as well with technical advances in augmented reality and indocyanine green fluorescence.[52,53] Improvements in instrumentation such as vessel-sealing devices, bipolar energy tools, and more ergonomic staplers have allowed HPB surgeons to continue to improve their techniques.[54,55] International consensus statements have been described within the last 5 years for both robotic liver and pancreas surgery providing recommendations for practice.[56,57] A contested topic in robotic HPB surgery is the cost of the robotic platform. Many studies have looked at cost comparisons

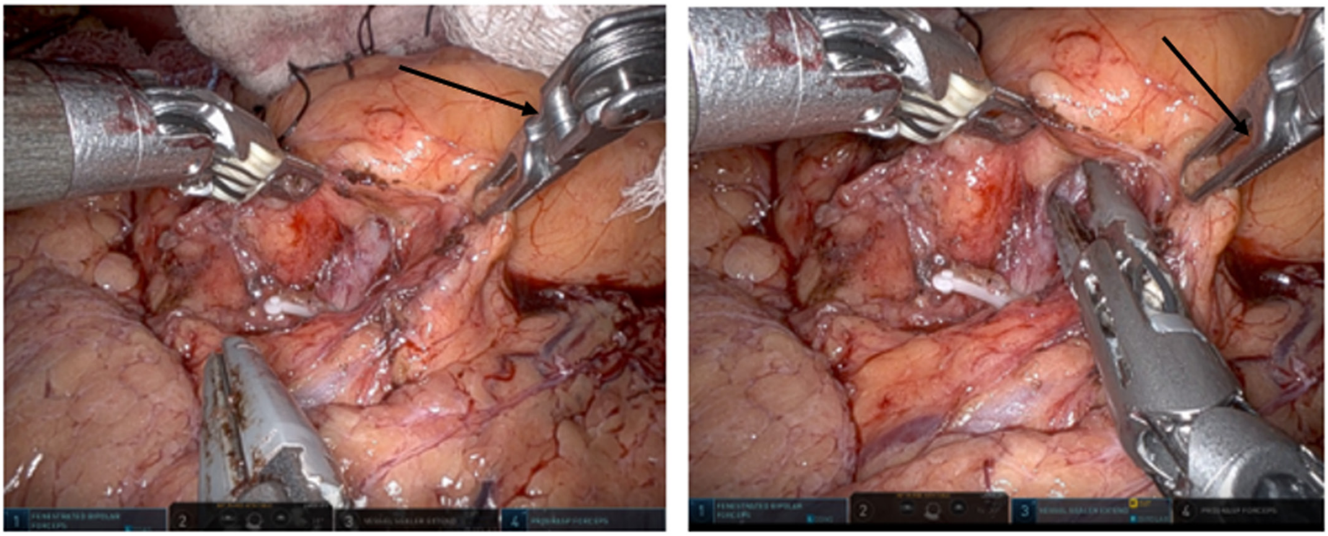

FIGURE 6 Fourth arm countertraction for dissection of the superior mesenteric vein during purely robotic pancreaticoduodenectomy (arrow).

between robotic, laparoscopic, and open HPB surgery with varying results. One US meta-analysis reviewing 18 different studies showed conflicting results on cost savings for distal pancreatectomy, non-significant savings for overall hospital cost after robotic pancreaticoduodenectomy, and similar costs between laparoscopic and robotic hepatectomies.[58] Furthermore, definitive conclusions on cost advantages or disadvantages could not be made due to the changes in learning curves and variable hospital experiences. Regarding learning curves, in order to make robotic HPB surgery more widely available, institutions have now begun to describe structures for implementing robotics into fellowship and residency training of future HPB surgeons.[58–60] These institutions have preliminarily shown shortened learning curves for those who undergo a formal robotic training program within their fellowship or residency.[60–62] In 2020, our center developed the first completely robotic HPB surgery fellowship. This is a 1-year fellowship after completion of formal HPB or abdominal transplant training. Robotic HPB fellows are heavily integrated into the performance of many of our HPB operations and are evaluated with objective assessment tools that we have created here at CMC[63,64] With interest on the rise in the community, implementation of these training programs will be paramount in producing skilled robotic HPB surgeons in the future.

7 | CONCLUSIONS

We have come a long way in the last 20 years to provide patients with a minimally invasive option for complex HPB surgery. As more high-volume centers share their outcomes and experiences, we can continue to develop new standards of care with robotics at the forefront. Our advice to those who wish to build a robotic HPB program is to have patience, an understanding of the surgical technique for open HPB operations and knowledge of the learning curve for robotics first. Once these are mastered, then robotic HPB cases can be implemented starting with carefully selected patients. As high-volume centers begin to provide formal robotic HPB training, we may very well see a rise in robotic HPB centers across the globe.

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CONFLICT OF INTEREST STATEMENT

Author John B. Martinie is a consultant, proctor, case observer, and lecturer for Intuitive Surgical. Author Dionisios Vrochides is a consultant for Intuitive Surgical. Author Frances McCarron is currently a fellow in training receiving a stipend sponsored by Intuitive Surgical. Intuitive Surgical had no role in the design, practice, or analysis of this manuscript.

ETHICS STATEMENT

Approval of the research protocol: N/A.
Informed consent: N/A.
Registry and registration number: N/A.
Animal studies: N/A.

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