

# Role of Robotics in Whipple's Surgery

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## ABSTRACT

Whipple is one of the most demanding and complex surgeries of the abdomen. It is the most commonly performed operation for pancreatic cancer, the fourth leading cause of cancer death in the United States. For patients with benign as well as malignant pancreatic tumors, it is believed that the robotic Whipple procedure will be a major improvement over the traditional procedure. The robotic surgery involves five small incisions (one to accommodate a miniature camera), rather than a large incision and separation, not cutting of muscles.

**Keywords:** Robotic Whipple's surgery, Robotic surgery, Da Vinci Whipple's surgery.

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## INTRODUCTION

A robotic device is a powered, computer-controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a wide range of tasks.<sup>1</sup> Telem manipulators and robots were first developed by the National Aeronautics and Space Administration (NASA) for use in space exploration. In 1985, NASA instituted a research program in telerobotics to develop the technology for the United States Space Program.<sup>2</sup>

The medical robotic systems of present generation are the brainchild of the United States Department of Defence's desire to decrease war casualties with the development of 'telerobotic surgery'. The 'master-slave' telem manipulator concept was developed for medical use in the early 1990s where the surgeon's (master) manual movements were transmitted to end-effector (slave) instruments at a remote site. The field of surgical robotics has undergone massive transformation since then and the future is even brighter.<sup>2</sup>

Robotically-assisted surgery was developed to overcome the limitations of minimally invasive surgery.

Methods of controlling the instruments in robotic surgery:

1. Telem manipulator
2. Computer-controlled system

A telem manipulator is a remote manipulator that allows the surgeon to perform the normal movements associated with the surgery, while the robotic arms carry out those movements using end-effectors and manipulators to perform the actual surgery on the patient.

In computer-controlled systems, the surgeon uses a computer to control the robotic arms and its end-effectors, though these systems can also still use telem manipulators for their input. One advantage of using the computerized method is that the surgeon does not have to be present, indeed the surgeon could be anywhere in the world, leading to the possibility for remote surgery.

## HISTORY

- 1985: A robot, the PUMA 560, was used to place a needle for a brain biopsy using CT guidance.<sup>3,4</sup>
- 1988: The PROBOT, developed at Imperial College London, was used to perform prostatic surgery.
- 1992: The ROBODOC from Integrated Surgical Systems was introduced into mill out precise fittings in the femur for hip replacement.<sup>9</sup>
- 1997: A reconnection of the fallopian tubes operation was performed successfully in Cleveland using ZEUS.
- May 1998: Dr Friedrich Wilhelm Mohr using the da Vinci surgical system performed the first robotically assisted heart bypass.
- September 2010: The Eindhoven University of Technology announced the development of Sofie surgical system, the first surgical robot to employ force feedback.

The intuitive surgical introduced the da Vinci surgical system and computer motion with the AESOP and the ZEUS robotic surgical system. (Intuitive surgical bought computer motion in 2003; ZEUS is no longer being actively marketed).<sup>5-7</sup>

Three main types of surgical robots available at present are as follows:

1. Supervisory-controlled Robotic Surgery Systems (e. g. the ROBODOC<sup>®</sup> system from CUREXO Technology Corporation): It is the most automated surgical robots available till date. Surgeons can plan their surgery preoperatively in a 3D virtual space and then execute the surgery exactly as planned in the operating theater.
2. Shared-control Robotic Surgery Systems: These robots aid surgeons during surgery, but the human does most of the work.
3. Telesurgical devices: Here, the surgeon directs the motions of the robot, e.g. the da Vinci robotic system, the ZEUS surgical system.

The da Vinci surgical system comprises three components:

- A surgeon's console,
- A patient-side robotic cart with four arms manipulated by the surgeon (one to control the camera and three to manipulate instruments), and
- A high-definition 3D vision system. Articulating surgical instruments are mounted on the robotic arms which are introduced into the body through cannulas.

Three generations of da Vinci surgical systems have developed so far:<sup>8</sup>

1. *da Vinci surgical system (1999)*: It consists of three components: The viewing and control console, surgical arm unit (three or four arms depending on the model) and optical three-dimensional vision tower (Figs 1A to C).
2. *da Vinci S HD surgical system (2006)*: This second generation surgical robot is equipped with wide range of motion of robotic arms and extended length instruments, interactive video displays and touch screen monitor.
3. *da Vinci Si HD surgical system (2009)*: It has dual console capability to support training and collaboration, advanced 3D HD visualization with up to 10× magnification, 'EndoWrist'<sup>®</sup> instrumentation with dexterity and range of motion more than the human hand and 'Intuitive'<sup>®</sup> motion technology' (Figs 2A and B), which replicates the experience of open surgery by preserving natural eye-hand-instrument alignment.<sup>8</sup> The new da Vinci HD SI released in April, 2009 currently sells for \$1.75 million.

### SYNONYMS

- Robotic surgery
- Computer-assisted surgery
- Robotically-assisted surgery.

### AIM OF STUDY

The aim of this review article is to appraise and to evaluate the present and future role of robotics in Whipple's surgery. The following parameters were evaluated:

1. Patient and disease factors
2. Technical considerations
3. Operating time
4. Intra- and postoperative complications
5. Postoperative morbidity
6. Hospital stay
7. Cost-effectiveness
8. Quality of life analysis.

### MATERIALS AND METHODS

A literature search was performed using search engine google, Springer, HighWire, Sages, IJA, PubMed, etc. and the literature analyzed.

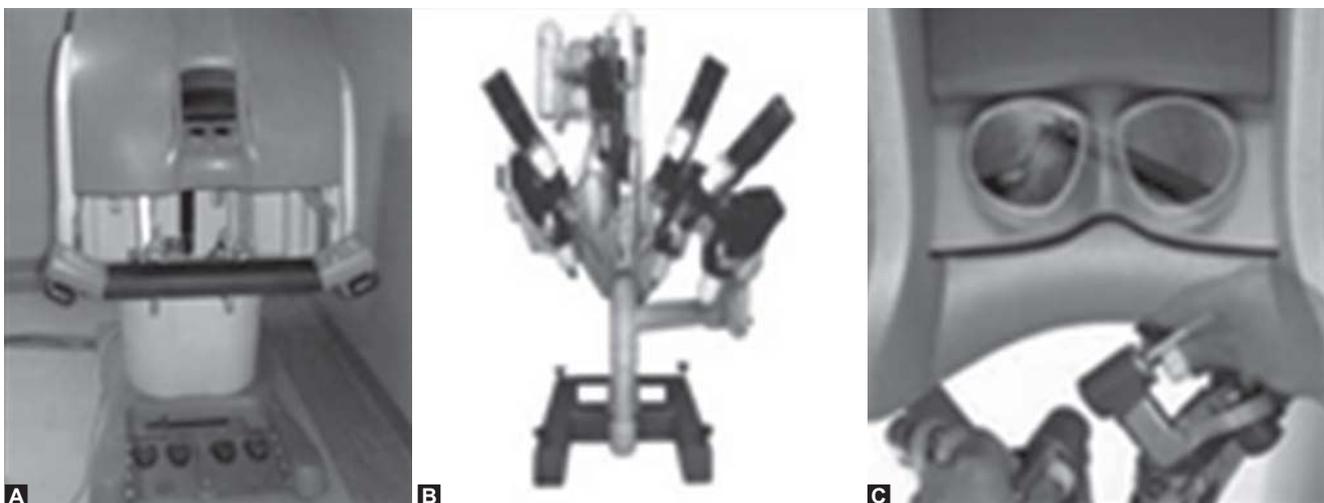
### KEYWORDS

- da Vinci robotic system
- Robotic Whipple
- Robotic pancreaticoduodenectomy
- Robotic surgery
- Minimally invasive surgery
- Pancreatectomy
- Pancreatic resection
- Pancreaticoduodenectomy
- Whipple's surgery.

### CARCINOMA OF THE PANCREAS AND PERIAMPULLARY AREA

Essentials of diagnosis:

- Obstructive jaundice (may be painless)
- Enlarged gallbladder (Courvoisier's sign)



**Figs 1A to C:** (A) The da Vinci system surgeon console (B) The cart with three mounted surgical arms (C) joysticks with viewing ports in the console (courtesy: Intuitive Surgical Inc, Sunnyvale, CA)

- Upper abdominal pain with radiation to back, weight loss and thrombophlebitis are usually late manifestations.

Risk factors for pancreatic cancer:

- Age
- Obesity
- Tobacco use
- Family history
- Heavy alcohol use
- Chronic pancreatitis
- Prior abdominal radiation
- Previous H/O partial gastrectomy.

### GENERAL CONSIDERATIONS

Ductal adenocarcinoma is the most common neoplasm of the pancreas. Other neoplasms of pancreas include:

- Mucinous cyst adenocarcinoma
- Serous cyst adenoma
- Mucinous cyst adenoma
- Malignant exocrine tumors
- Benign exocrine tumors
- Endocrine
  - Gastrinoma
  - Insulinoma.

Carcinomas involving the head of the pancreas, the ampulla of Vater, the distal common bile duct and the duodenum are considered together, because they are usually indistinguishable clinically; of these, carcinomas of the pancreas constitute over 90%. About 75% are in the head and 25% in the body and tail of the organ. They comprise 2% of all cancers and 5% of cancer deaths. Risk factors include new-onset diabetes mellitus after the age of 45 years, occasionally heralds the onset of early pancreatic cancer.

### IMAGING

*CT scan:* A multiphase helical CT scan is the initial diagnostic tool and detects a mass in more than 80% of cases.

- Endoscopic ultrasound
- PET scan
- MRI
- ERCP
- MRCP.

### WHIPPLE'S SURGERY

Whipple's surgery is done for:

- Cancer of the head of the pancreas
- Cancer of the duodenum
- Cholangiocarcinoma (cancer of the pancreatic end of the bile)
- Cancer of the ampulla
- Whipple operation may also sometimes be performed for patients with benign (noncancerous) disorders such as chronic pancreatitis and benign tumors of the head of the pancreas.

### Advantages of Robotic Whipple

The robotic Whipple offers patients a minimally invasive option to the traditional surgeries for pancreatic cancer and benign tumors of the pancreas and colon, resulting in the potential for:

- Less pain
- Shorter hospital stays
- Faster recovery times
- Minimized scarring
- Blood loss
- Less complications.



**Figs 2A and B:** (A) New generation robotic instruments have seven degrees of freedom as the human hand, (B) EndoWrist<sup>®</sup> instrument from intuitive surgical (Courtesy: Intuitive Surgical Inc, Sunnyvale, CA)

### LIMITATIONS OF ROBOTIC-ASSISTED SURGERY

Patient safety in the event of robot malfunction and crash down is a concern and the operating room staff should be aware of it. Robotic technology is a complex issue and needs a lot of practice and technical expertise. Robotic surgery needs longer operating room time compared with conventional surgeries. Several pieces of equipment, each being extremely bulky, require large operating room space.<sup>11</sup>

The staff must be trained and prepared to quickly detach and remove the robot from the patient in the event of an emergency. Current robotic systems lack tactile feedback from the instruments.<sup>12</sup>

Surgeons have to rely on visual clues to modulate the amount of tension and pressure applied to tissues to avoid organ damage. The newly launched da Vinci HD SI system costs \$1.75 million. Initial increased operating room setup time and surgical time adds to the cost burden. However, robot-assisted surgery has shown to reduce hospital stay by about half and thereby cutting hospital cost by about 33%.<sup>13</sup>

One major obstacle to the telerobotic surgery is the ‘latent time’, which is the time taken to send an electrical signal from a hand motion to actual visualization of the hand motion on a remote screen. Humans can compensate for delays of less than 200 msec<sup>14</sup> (Table 1). Longer delays compromise surgical accuracy and safety. Incompatibility with imaging equipment is an area that needs attention.

### THE STEPS IN A ROBOTIC WHIPPLE PROCEDURE<sup>10</sup> (FIGS 3 TO 5)

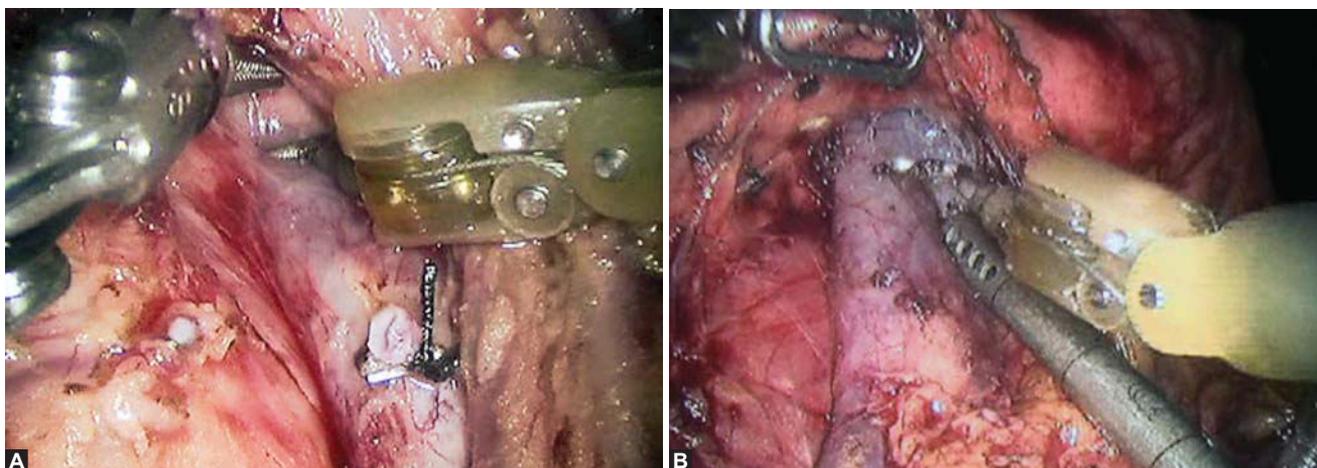
1. *Preoperative considerations: Patient and disease factors:*

- Preoperative evaluation of acute or chronic pancreatitis which if present makes robotic dissection difficult

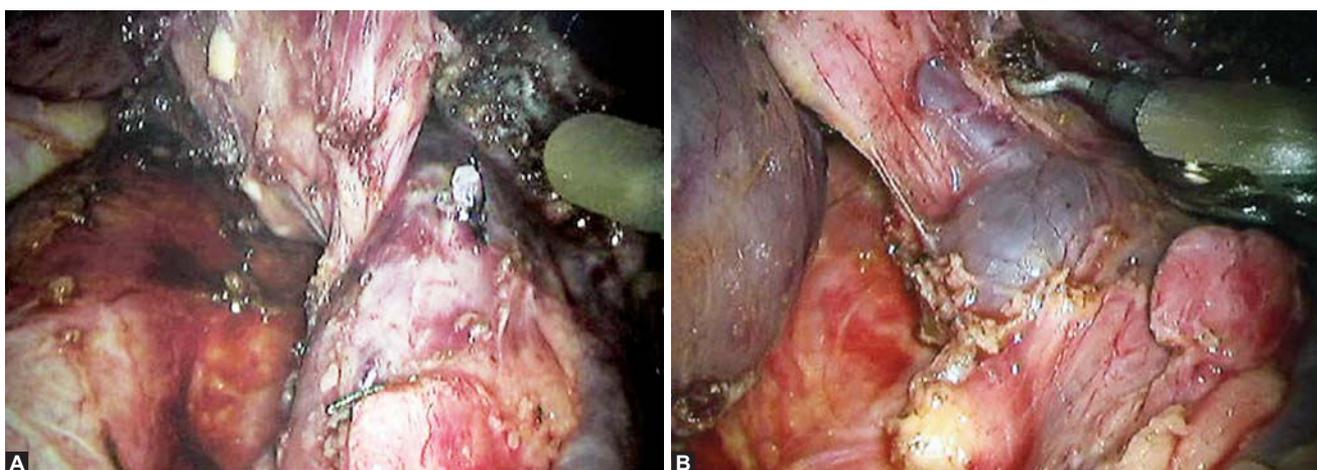
- The presence of a replaced right hepatic artery and the position of the 1st jejunal vein (J1) branch, as it enters the right side of the superior mesenteric vein, should be assessed in order to avoid any inadvertent injury
  - Short stature and obesity create excess intra-abdominal fat which makes robotic dissection difficult.
2. *Laparoscopy, port setting and robot docking:* A laparoscopic investigation of the abdominal cavity is essential prior to any major pancreas tumor resection (NCCN guidelines). The laparoscopy not only allows surgical staging, but also allows identification of acute or chronic pancreatitis, an unfavorable body habitus or other unforeseen obstacles to a robotic procedure.<sup>10</sup>  
*Robotic trocar placement:* The camera port is positioned slightly to the patient’s right side and inferior to the umbilicus. The camera port is approximately 18 cm from the operative focus, and the robotic axis is slightly to the patient’s right side of midline. The right robotic arm is placed in the upper left-hand corner of the abdomen. The robotic left hand is in the patient’s left lower quadrant, with the robotic 3rd arm below the patient’s right costal margin (after pneumoperitonealization). Assistant operating ports are positioned in the right and left abdominal quadrants. The robotic ports should be 8 to 10 cm apart, if possible, while the assistant ports should be at least 5 cm from additional port sites.<sup>10</sup>
  3. Mobilization of duodenum (kocherization) and exposure of the superior mesenteric/portal vein
  4. Exploration of the porta hepatis
  5. Mobilization of the ligament of Treitz
  6. Transecting the pancreas and dissecting the uncinate process
  7. Reconstruction: Pancreaticojejunostomy, hepaticojejunostomy and gastrojejunostomy.

**Table 1:** Advantages and disadvantages of conventional laparoscopic surgery vs robot-assisted surgery

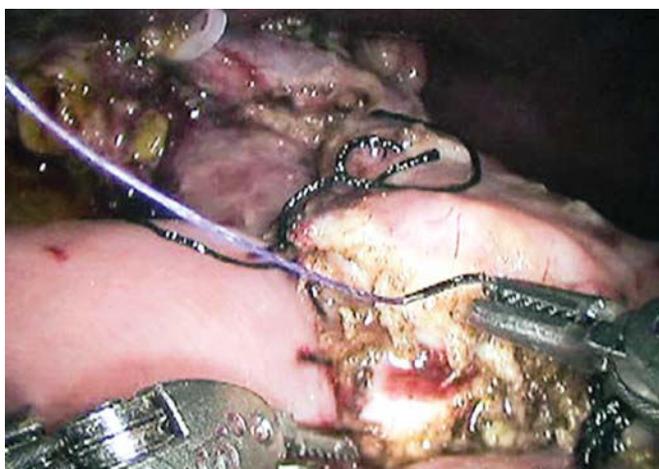
	<i>Conventional laparoscopic surgery</i>	<i>Robot-assisted surgery</i>
Advantages	Well-developed technology Affordable and ubiquitous Proven efficacy	3D visualization Improved dexterity Seven degrees of freedom Elimination of fulcrum effect Elimination of physiologic tremors Ability to scale motions Microanastomoses possible Telesurgery
Disadvantages	Loss of touch sensation Loss of 3D visualization Compromised dexterity Limited degrees of motion The fulcrum effect Amplification of physiologic tremors	Ergonomic position Absence of touch sensation Very expensive High start-up cost May require extra staff to operate New technology Unproven benefit



**Figs 3A and B:** Creation of the retropancreatic tunnel, along the anterior border of the superior mesenteric vein and portal vein confluence. Dissection is completed under direct visualization, which is facilitated by the position of the robotic camera. Completing the tunnel under direct visualization improves the safety of the Whipple procedure<sup>10</sup>



**Figs 4A and B:** (A) Elevation of the pancreatic head and uncinate process in an anterior fashion out of the retroperitoneum. The superior mesenteric vein and portal vein confluence is visualized in the center of the photograph. The elevation of the pancreatic tissue allows excellent visualization of the uncinate process and its retroperitoneal attachments. (B) As the uncinate process is mobilized from the retroperitoneum, the Wrst jejunal vein branch must be anticipated. The photograph illustrates the 1st jejunal vein, with the vein branch entering the inferior portion of pancreatic head<sup>10</sup>



**Fig. 5:** Suturing of the pancreatic duct during the pancreaticojejunostomy creation. The duct-to-mucosa anastomosis is created with a 4-0 Vicryl suture on an RB1 needle. The pancreas parenchyma and pancreatic duct are seen on the right side of the photograph, while the jejunum is visualized on the left<sup>10</sup>

## LITERATURE REVIEW

Whipple procedure remains a standard surgical procedure for periampullary carcinoma.<sup>16</sup>

Since the first laparoscopic cholecystectomy in 1989, minimally invasive surgery has become the alternative approach to conventional open surgery in many abdominal procedures.<sup>17</sup> In early laparoscopic years, most surgeons used only diagnostic laparoscopy to evaluate periampullary malignancies or staging pancreatic cancer.<sup>18</sup> With the benefit of minimal invasive surgery and new advances in technology and instrumentation, some surgeons began to apply it to more sophisticated procedures such as Whipple procedure.<sup>19</sup>

Gagner and Pomp reported the first laparoscopic Whipple procedure in 1994.<sup>20</sup> However, because of the technical difficulty, not many laparoscopic Whipple procedures were performed. Several prospective randomized

**Table 2:** Advantages and disadvantages of robot-assisted surgery vs conventional surgery

<i>Human strengths</i>	<i>Human limitations</i>	<i>Robot strengths</i>	<i>Robot limitations</i>
<ul style="list-style-type: none"> <li>• Strong hand-eye coordination</li> <li>• Dexterous</li> <li>• Flexible and adaptable</li> <li>• Can integrate extensive and diverse information</li> <li>• Rudimentary haptic abilities</li> <li>• Able to use qualitative information</li> <li>• Good judgment</li> <li>• Easy to instruct and debrief</li> </ul>	<ul style="list-style-type: none"> <li>• Limited dexterity outside natural scale</li> <li>• Prone to tremor and fatigue</li> <li>• Limited geometric accuracy</li> <li>• Limited ability to use quantitative information</li> <li>• Limited sterility</li> <li>• Susceptible to radiation and infection</li> </ul>	<ul style="list-style-type: none"> <li>• Good geometric accuracy</li> <li>• Stable and untiring</li> <li>• Scale motion</li> <li>• Can use diverse sensors in control</li> <li>• May be sterilized</li> <li>• Resistant to radiation and infection</li> </ul>	<ul style="list-style-type: none"> <li>• No judgment</li> <li>• Unable to use qualitative information</li> <li>• Absence of haptic sensation</li> <li>• Expensive</li> <li>• Technology in flux</li> <li>• More studies needed</li> </ul>

trials showed no difference in leakage and fistula rate between pancreaticogastrostomy and pancreaticojejunostomy.<sup>21-23</sup> The duct to mucosa technique was utilized for both pancreaticogastrostomy and hepaticojejunostomy. Such a technique showed low or at least the same rate of leakage compared to the conventional method.<sup>24,25</sup>

Two major concerns that anticipate early adoption of laparoscopic Whipple comprised of the difficult surgical technique, resulting in a long operative time, as well the oncologic question about the adequacy of the laparoscopic operation.<sup>19,26</sup> To shorten the learning curve of laparoscopic approach, the hand-assisted hybrid technique had been used with favorable results Table 2. Recently, robotic Whipple using the da Vinci system has also been shown to be feasible and efficient.<sup>27</sup>

All the benefits of minimally invasive surgery may be expected from the robotic Whipple procedure. Patients undergoing robotic procedure mobilize earlier than their open counterparts. The median length of hospital stay is 6.2 days (range, 5.2-18.8), which compares favorably to open Whipple procedure, where the median length of hospital stay is 7.9 days.<sup>10</sup> One of the principal objections to the robotic procedure is the increased duration of operating time. The mean robotic operating time is 8 hours (range 5.9-9.6), which again compares favorably open surgery where the mean operating time is 5.4 hours.<sup>10</sup>

The robotic Whipple needs to conform to the standards that have been set and validated for an open Whipple. Modifications and/or shortcuts to allow for use of the robot should be avoided if the robotic resection cannot be performed to a similar standard to the open procedure, then the procedure needs to be converted.

Giulianotti et al have reported a series of eight patients in whom pancreaticoduodenectomies were performed completely laparoscopically with the assistance of the robot. In this advanced technique, the hepaticojejunostomies and gastrojejunostomies were handsewn intracorporeally and the remnant pancreatic duct was injected with surgical glue.<sup>28</sup>

Whether the current-generation surgical robot is advanced enough to allow routine performance of pancreatic head tumor resections remains to be seen. In an operation like the Whipple procedure, where we rely so heavily on blind palpation for careful dissection of the portal vein off the posterior pancreatic surface, it is possible that the da Vinci's lack of haptic feedback may preclude its safe application.<sup>28-30</sup>

## CONCLUSION

Robotic-assisted minimally invasive pancreaticoduodenectomy can be performed safely and effectively with significant individual and institutional preparation and commitment. Safety is directly related to the surgical team's ability to complete the operative procedure in an open fashion, and a breadth of experience dealing with complex interoperative hepatobiliary complications. If oncological principles and/or safety are compromised, the procedure needs to be converted to a standard open Whipple.<sup>10</sup>

The patient requires an upfront frank preoperative discussion regarding the novel approach of the minimally invasive pancreaticoduodenectomy.<sup>15</sup> Informed consent can be obtained if the benefits, risks and the alternatives—an open procedure—are discussed in detail. The robotic team should consist of expert pancreas and skilled robotic surgeons, nurses and operating room technicians. When the surgical team is motivated to push the frontiers of pancreas surgery, the patient will benefit from the minimally invasive procedure.

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