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ORIGINAL ARTICLE

The robotic Whipple: operative strategy and technical considerations

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Abstract Advances in robotic surgery have allowed the frontiers of minimally invasive pancreatic surgery to expand. We present a step-by-step approach to the robotic Whipple procedure. The discussion includes port setting and robotic docking, kocherization and superior mesenteric vein identification, portal dissection, releasing the ligament of Treitz, uncinate dissection, and reconstruction. A brief report of our initial 2-year experience with the robotic Whipple procedure is also presented.

Keywords Robotic Whipple · Robotic pancreaticoduodenectomy · Robotic surgery · Minimally invasive surgery · Pancreatectomy · Pancreatic resection · Pancreaticoduodenectomy · Whipple

Introduction

The adoption of a minimally invasive approach to pancreaticoduodenectomy has evolved with advances in surgical robotics. With few exceptions, the Whipple has remained an open procedure due to the difficulty, complexity, and risk in performing the operative dissection and intricate suturing required for the pancreatic duct anastomosis. The robotic technology provides scaling of movement and magnified imaging, allowing pancreas duct-to-mucosa anastomosis construction to a similar standard to the open anastomosis.

The first reported robotic Whipple procedure was completed between 2000 and 2002, by Giulianotti et al. [1, 2]. Over the last 10 years, additional hepatobiliary centers have developed robotic surgery programs where robotic Whipple procedures are performed. But due to the technical difficulties inherent in a Whipple procedure, widespread adoption of the totally robotic pancreaticoduodenectomy has lagged behind other general surgery procedures. In an attempt to share procedural operative strategy, our totally robotic Whipple technique is described in a detailed step-wise approach.

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Pre-operative considerations: patient and disease factors

Embarking on robotic surgery on the pancreas for the first time requires detailed planning and support from the entire operating team. The primary surgeon should not only be proficient at laparoscopic surgery, but also be skilled at open pancreaticoduodenectomy. Demonstration of proficiency in pancreas resections should be supported by resection volumes qualifying the surgeon as a high volume pancreas surgeon, as well as objectively measured quality outcomes [3–9]. The assembled operating team requires a skilled bedside assisting surgeon, a knowledgeable surgical scrub technician, and senior circulating nurse, with the primary surgeon at the robotic console. The operating room assisting team should be proficient in robotic surgery, but also familiar with and capable of assisting during an open Whipple procedure.

A high quality pancreas protocol computed tomography scan with arterial and venous phase images is essential for pre-operative planning. In addition to the appropriate staging evaluation, the pancreas lesion is assessed for local invasion into the portal–superior mesenteric vein confluence. Any suspected invasion requiring a portal vein resection will necessitate an open resection. It is also important to evaluate for evidence of acute and/or chronic pancreatitis. If present, the inflammation from pancreatitis may make robotic dissection difficult, due to destruction of tissue planes; and, again, open resection may be prudent. The presence of a replaced right hepatic artery should be assessed pre-operatively. Robotic resection may still be possible with aberrant hepatic artery anatomy, but knowledge of the position and relationship to the tumor may help avoid complications in the operating room. The position of the 1st jejunal vein (J1) branch, as it enters the right side of the superior mesenteric vein, should be routinely mapped; again, knowledge of its position and significance can help avoid inadvertent injury during the case.

While the robotic Whipple procedure may provide an oncologically sound operation, there is limited available data supporting this claim, as it relates to margin status and lymph node retrieval [10–12]. Based on the deficit of objective data, pancreas tumor resection should be limited to benign and pre-malignant lesions, unless performed in the setting of a surgical clinical trial or data registry. The safety data of robotic-assisted pancreaticoduodenectomy is still being acquired, and adoption of this technique for the standard pancreas adenocarcinoma may be premature at this time.

The patient's body habitus plays a critical role in pre-operative planning. Short stature and increased abdominal girth create a situation where the intra-abdominal fat makes robotic dissection difficult. Without haptic feedback from the robotic instruments, dissecting through adipose tissue is slow and tedious. The robotic instruments allow for facile dissection along anatomic structures, but once dissection has moved into the adipose tissue it becomes easy to inadvertently stumble upon a vascular structure. In addition, intra-abdominal fat may create a mound in the central abdomen, which blocks the view of the robotic camera, making safe dissection difficult. If body habitus is felt to be an issue, this can easily be assessed during the laparoscopy.

Laparoscopy, port setting, and robot docking

A laparoscopic investigation of the abdominal cavity is essential prior to any major pancreas tumor resection (NCCN guidelines) [13]. The laparoscopy not only allows surgical staging, but also allows identification of acute on chronic pancreatitis, an unfavorable body habitus, or other unforeseen obstacles to a robotic procedure. The patient is positioned in a supine position. We utilize the direct optical technique (Separator abdominal access system, Applied Medical, Rancho Santa Margarita, California, USA) to gain access in the left upper quadrant of the abdomen. The trocar site is later upsized to the 8-mm robotic trocar, through which the right working robotic arm is placed. After the pneumo-peritoneum is created, the additional trocar positions are mapped (Fig. 1) and the target site—the portal and superior mesenteric vein confluence—is identified. Approximately 18–20 cm from the target site, the camera port is positioned along the operative axis; this is usually just inferior and to the right of the umbilicus. Next, the two left robotic arm trocars (8-mm trocar) are positioned approximately 8–10 cm apart along the right side of the abdomen. The upper (number 3 robotic arm) should be just below the right costal margin, as identified after peritoneal insufflation. Two additional 5-mm laparoscopic ports are positioned, one on each side, and slightly inferior, to the camera port. The robotic camera is a high-definition three-dimensional image camera with a 30-degree downward angle. If the uncinate process is to be released from its retroperitoneal attachments using an endo GIA stapler (Endo GIA Ultra Stapler, Covidien, Mansfield, Massachusetts or Echelon Flex Endopath stapler, Ethicon, Cincinnati, Ohio, USA), then the 5-mm tocar in the right lower quadrant may be upsized to a 11-mm trocar, to accommodate stapler access to the abdomen. Once the ports are set, the robot (Da Vinci S Surgical System, Intuitive Surgical, Sunnyvale, California, USA) is moved into position. The axis to which the robot should be aligned is slightly to the right of midline. The patient is positioned in steep reverse Trendelenberg position, with a slight roll to the left (right side up). The

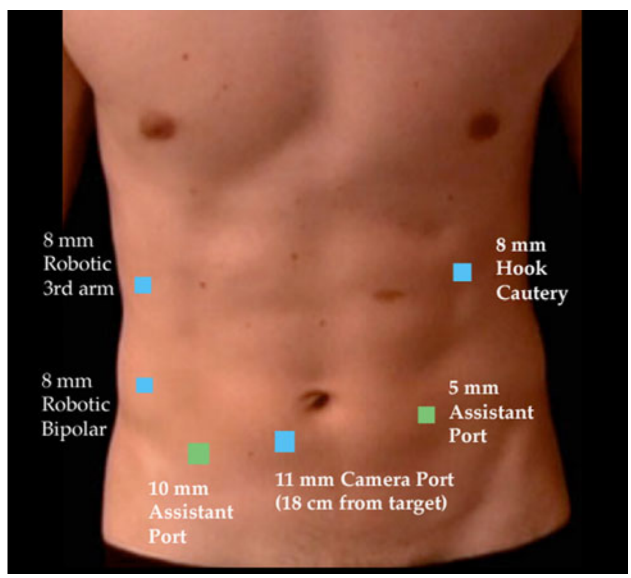

Fig. 1 Robotic trocar placement—the camera port is positioned slightly to the patient's right side and inferior to the umbilicus. The camera port is approximately 18 cm from the operative focus, and the robotic axis is slightly to the patient's right side of midline. The right robotic arm is placed in 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 pneumo-peritoneal insufflation). Assistant operating ports are positioned in the right and left abdominal quadrants. The robotic ports should be 8–10 cm apart, if possible, while the assistant ports should be at least 5 cm from additional port sites

goal in port setting is to place the trocars as far away from the operative target as possible, thereby allowing the robotic arms the maximal amount of freedom of movement within the operative field. The robot is docked, ensuring clearance of the patient's head by the robotic arms. As the camera port is docked to the robot, the camera trocar needs to be elevated or burped anteriorly. The movement stretches the abdominal wall away from the underlying abdominal organs, providing additional operating space. Once docking is complete the procedure is initiated.

The choice of robotic operative instruments is based on surgeon preference. We utilize a hook cautery in the right robotic arm. This replicates the cold-push cautery dissection utilized for open Whipple procedures. In the left robotic arms—which may be used interchangeably—we utilize a fenestrated bipolar bowel grasper and Cadiere grasper. This choice of instruments appears to minimize robotic instrument exchanges, thereby reducing operating time. The robotic camera provides 13× magnification and 3D visualization of the operative field. The magnification allows facile dissection of delicate structures, and suturing of a normal size pancreatic duct.

Kocherization and exposure of the superior mesenteric/portal vein

The goal for robotic surgery is to recapitulate the open procedure. Therefore, the robotic Whipple procedure described here needs to be modified to confiorm to the individual surgeon's method of performing the open Whipple procedure. The robotic Whipple needs to conform to the standards that have been set and validated for an open Whipple. Modifications and/or short cuts 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.

The robotic dissection begins with exposure of the duodenum. The right hepatic flexure of the colon must be released, to allow adequate kocherization of the duodenum. The second portion of the duodenum is grasped with the 3rd arm of the robot and retracted anteriorly. The assistant, using laparoscopic instruments, gently retracts the colon caudually, with the assistance of gravity from the patient positioning. The most adept robotic assistant is one who remains stationary during robotic dissection; frequent movement by the assisting surgeon may impede robotic progress. Kocherization extends medially to the aorta, exposing the inferior vena cava and left renal vein. Mobilization of the duodenum continues to the release of the ligament of Treitz, from the right side of the patient, under the superior mesenteric vein and artery (Fig. 2). This is accomplished by gentle but firm retraction on the duodenum, pulling the ligament under the vascular structures to be released. Care must be taken when grasping bowel tissue to prevent injury, due to the lack of haptic feedback.

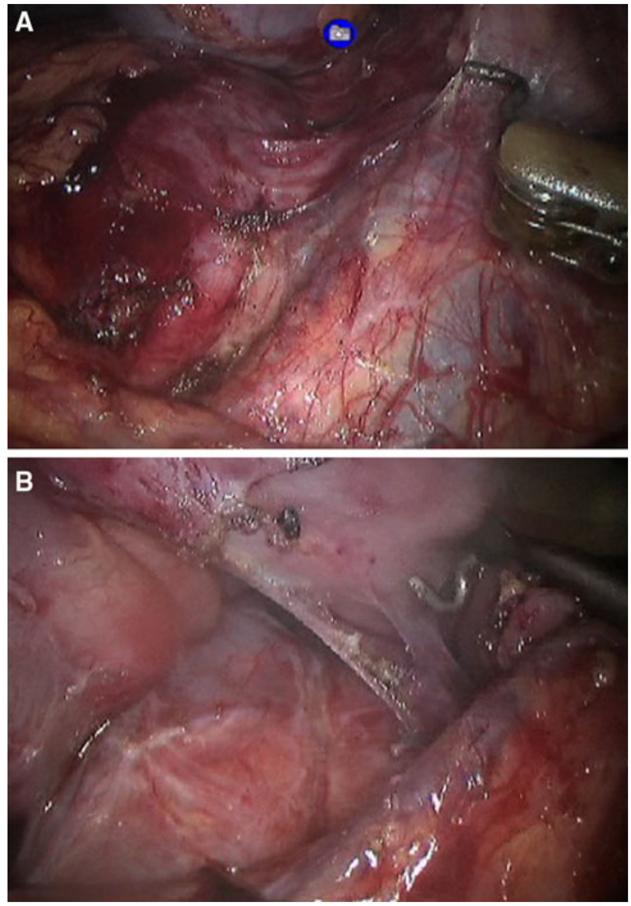

Fig. 2 **a** Demonstration of the extensive kocherization required for the robotic Whipple procedure. The hook cautery is dissecting along the anterior inferior vena cava. The left renal vein is visualized on the left-hand side of the inferior vena cava at the inferior border of the photograph. **b** Releasing of the ligament of Treitz from the patient's right side of the superior mesenteric artery and vein—seen here extending along the *right side* of the photograph

The superior mesenteric vein is identified as it passes under the inferior border of the pancreas neck. There are three methods for identifying this portion of the superior mesenteric vein: in a thin individual, mobilization of the duodenum may allow vein identification in the right side of the small bowel root mesentery. If the vein is anticipated, this may be the most expeditious manner in which to find the vein. In larger individuals or patients where the vein is not easily found during duodenal mobilization, the gastroepiploic vein and middle colic vein common trunk can be used to identify the region of the superior mesenteric vein. The gastroepiploic vein, which travels from the greater curvature of the stomach, passes anterior to the pancreas and joins with the middle colic vein in a common trunk. This common trunk passes directly into the anterior superior mesenteric vein just inferior to the pancreas neck. If the common trunk is absent, both of these veins will still find their way to the region of the superior mesenteric vein. The robotic camera positioning allows for identification of either of these veins, and, once identified, allows for facile dissection along the vein to the superior mesenteric vein. If additional help in identifying the superior mesenteric vein is needed, the inferior border of the pancreas should be dissected in a left to right fashion. As the dissection continues toward the right, the superior mesenteric vein will be encountered. This method should be used with caution in the robotic setting, due to the blind nature of this dissection. Once the superior mesenteric vein is identified, the gastroepiploic vein is ligated and transected. The dissection along the anterior border of the superior mesenteric vein, beneath the pancreas neck, is straightforward with the positioning of the robotic camera (Fig. 3). The entire superior mesenteric vein and portal vein tunnel is created under direct visualization. The tunnel is advanced to the region of the superior border of the pancreas neck.

Dissection of the porta hepatis

The field of focus is moved from the inferior border of the pancreas to the porta hepatis. The gallbladder is dissected free from the liver bed in a retrograde fashion; the cystic duct may be utilized to find the common hepatic duct, if the duct is not obvious in the porta. Dissection within the porta starts on the left side in the region of the proper hepatic artery and the associated hepatic artery lymph node. In cancer, this node should be evaluated interoperatively via frozen section to accurately provide an oncological stage. Once this node is removed the gastroduodenal artery takeoff can be visualized on the inferior portion of the hepatic artery. A trial clamping of the gastroduodenal artery is required to rule out proximal hepatic artery or celiac axis occlusion. The course of the gastroduodenal artery and the proper hepatic artery, with its right and left branch, as well as any aberrant anatomy, needs to be fully elucidated before the gastroduodenal artery is clipped using a Weck Hem-o-lock clip (Teleflex Medical, Triangle Park, North Carolina, USA) and transected. After the gastroduodenal artery has been released the superior portion of the retro-pancreatic tunnel can be completed. This may actually be the most difficult portion of the tunnel to create, and once started from above, completion of the tunnel may be easier from an inferior approach. The pancreas neck is then looped with a vessel loop. Once the lesser sack is entered and the distal stomach transected (endoscopic stapler utilizing green 4.50 mm staples), a greater exposure of this area will be visualized. The porta hepatis dissection is completed by removing lymph node tissue, and transecting the common hepatic duct cephalad to the cyst duct insertion.

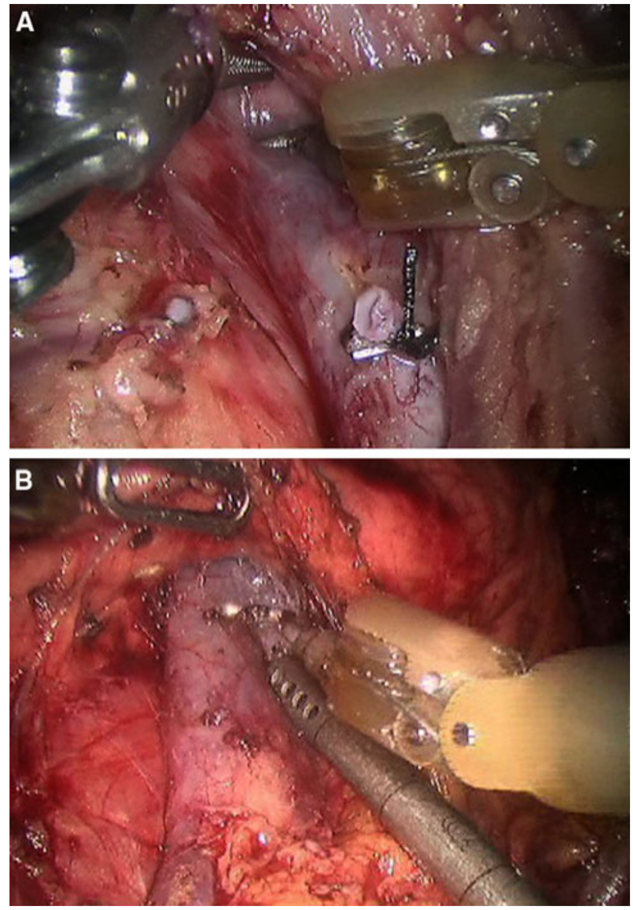

Fig. 3 **a**, **b** Creation of the retro-pancreatic tunnel, along the anterior border of the superior mesenteric vein and portal vein confluence. Dissection is completed under direct visualization, which is facilitated by the position of the robotic camera. Completing the tunnel under direct visualization improves the safety of the Whipple procedure

Mobilization of the ligament of Treitz

The majority of the ligament of Treitz has already been released with the extensive kocherization of the duodenum. The field of focus must now be moved to the left side of the abdomen. The robot positioning has to be set to allow ease of mobility in the right upper quadrant, and now the view is moved away from the primary operative field to mobilize the 4th portion of duodenum and the jejunum. The assisting surgeon will play a major role during this portion of the operation due to the fact that robotic positioning does not hinder his or her instruments. The colon is elevated and the partially dissected ligament of Treitz is identified. The jejunum is transected with blue (3.85 mm) endoscopic staples approximately 10–15 cm beyond the ligament. The vascular supply to the small bowel is taken along the border of the jejunum using the LigaSure (LigaSure Tissue Fusion Device, Covidien, Mansfield, Massachusetts, USA). As this dissection approaches the root of the small bowel mesentery, care must be taken not to injure the superior mesenteric artery, which may be closer than anticipated. Once free, the jejunum is passed under the root of the mesentery to the right upper quadrant, and the surgical field is again focused in that area.

Transecting the pancreas and dissecting the uncinate process

The pancreatic parenchyma is transected using electrocautery, after inferior and superior stay sutures are positioned to control the transverse pancreatic arteries (4-0 silk on an RB1 needle). As the pancreatic duct comes into view, every attempt should be made to transect the duct cleanly using sharp transection. Any small pancreatic parenchyma bleeders should be controlled with fine vascular suturing and not simply cauterized. The pancreas head and uncinate process are then dissected free from the portal and superior mesenteric vein confluence. The superior pancreatic head vein (the vein of Belcher) and an inferior branch from the first jejunal vein should be anticipated (Fig. 4). Injury to the first jejunal vein or its branch may cause impressive hemorrhage, which is difficult to control even during the open procedure. As the portal vein is separated from the pancreas, the region of the superior mesenteric artery becomes the major concern. The retroperitoneal tissue and the accompanying inferior anterior and posterior pancreaticoduodenal arteries, which originate from the first few centimeters of the superior mesenteric artery, may be controlled via two methods. If the lesion being resected is cancer, then the superior mesenteric artery should be skeletonized on its right side, allowing identification of the inferior anterior and posterior pancreaticoduodenal arteries. These arteries can then be controlled individually with suture ligation. If the pancreatic lesion is a benign tumor or a pre-malignant pathology, then the retroperitoneal tissue and the associated arteries may be transected, en bloc, with white (2.50 mm) endoscopic staples (Fig. 5). After the stapler is positioned and closed, assessment of unimpeded flow in the superior mesenteric artery needs to be confirmed. This can usually be assessed by identifying pulsatile flow during direct visual inspection of the superior mesenteric artery; if necessary evaluation of Doppler flow using intra-abdominal ultrasound is also possible. Upon completion of the pancreaticoduodenectomy, the specimen is removed through an enlargement of the left lower assistant port, via a specimen retrieval sac (Laparoscopic Tissue Retrieval System, Anchor, Addison, Illinois, USA). The enlargement should be no larger than is absolutely necessary to remove the specimen. Pneumoperitoenum is restored by placing a small hand-port sealing device (Gelport, Applied Medical, Rancho Santa Margarita, California, USA) through the enlarged port site. The specimen

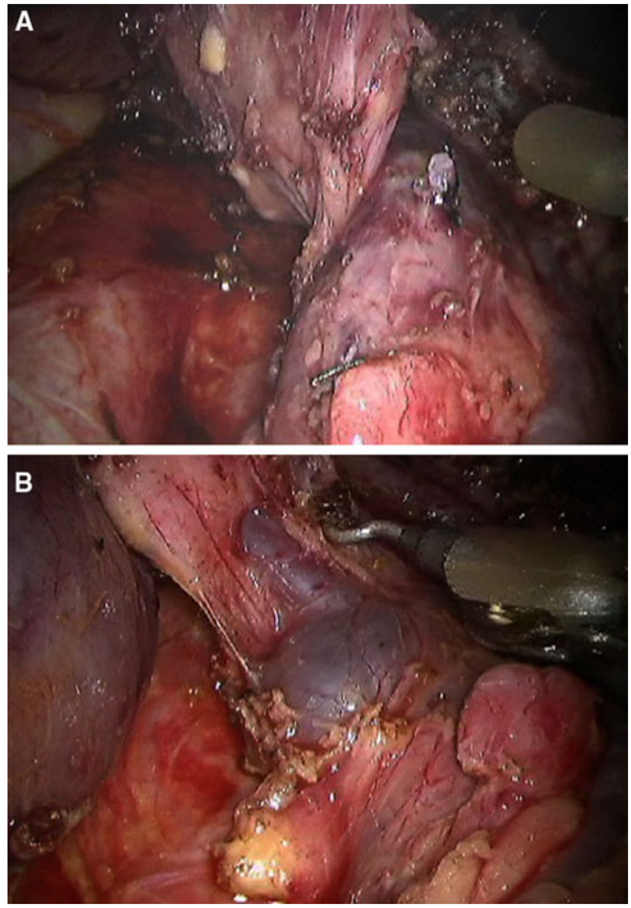

Fig. 4 **a** Elevation of the pancreatic head and uncinate process in an anterior fashion out of the retroperitoneum. The superior mesenteric vein and portal vein confluence is visualized in the *center* of the photograph. The elevation of the pancreatic tissue allows excellent visualization of the uncinate process and its retroperitoneal attachments. **b** As the uncinate process is mobilized from the retroperitoneum, the first jejunal vein branch must be anticipated. The photograph illustrates the 1st jejunal vein, with the vein branch entering the inferior portion of pancreatic head

is evaluated intra-operatively for surgical margins prior to the reconstruction. If a benign diagnosis is confirmed preoperatively, then the specimen may remain in the abdominal cavity until the completion of the reconstruction, which will save a significant amount of operating time. Once the margins are clear the reconstruction is initiated.

Reconstruction: pancreaticojejunostomy, hepaticojejeunostomy, and gastrojejunostomy

The jejunal limb is positioned in the right upper quadrant, via a retro-colic route. The pancreaticojejunostomy is completed in a manner replicating the open procedure. The pancreas-to-jejunal anastomosis is fashioned using a two-layer duct-to-mucosa technique. The back wall is created

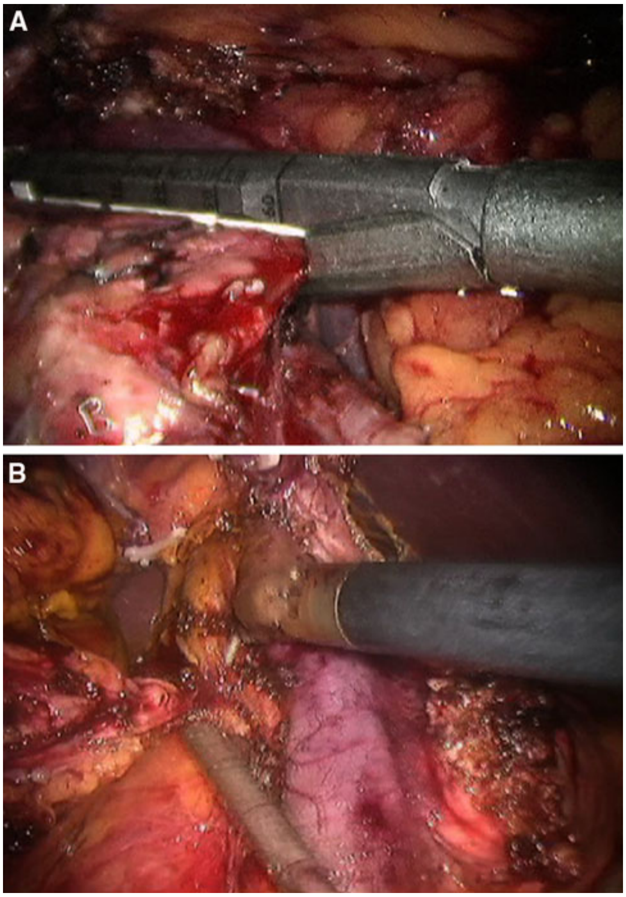

Fig. 5 **a** Stapling the retroperitoneal attachments of the uncinate process and pancreatic head. The superior mesenteric artery must be protected and preserved during stapling. The superior mesenteric artery is visualized to the left of the superior mesenteric vein, seen on the far side of the stapler in this photograph. **b** The photograph demonstrates the release of the retroperitoneal attachments from the replaced right hepatic artery. The portal vein is seen in the *middle* of the photograph, to the patient's left of the cautery. At the tip of the hook cautery the aberrant artery can be visualized. The Weck clips in the *upper portion* of the photograph are placed on the transected gastroduodenal artery and the common bile duct

using a running 4-0 silk (RB1 needle) Lembert-type suture. Once the pancreatic parenchyma is secured to the jejunum, the duct-to-mucosa anastomosis is created using multiple interrupted fine Vicryl sutures (polyglactin 910, Ethicon, Cincinnati, Ohio, USA). The standard choice for reconstruction is a 5-0 Vicryl on an RB1 needle, but if the duct is not dilated a 6-0 Vicryl utilizing a TF needle can be used. Once the back wall of the duct-to mucosa anastomosis is completed, a 5 or 8 French pediatric Silastic feeding tube is positioned across the anastomosis. The purpose of stenting the duct-to-mucosa anastomosis is twofold. First, the stent may provide some protective shunting of pancreas secretions through the new anastomosis. More importantly, the stent prevents inadvertent occlusion of the duct, by protecting the duct back wall during anastomosis creation (Fig. 6). Once the duct-to-mucosa

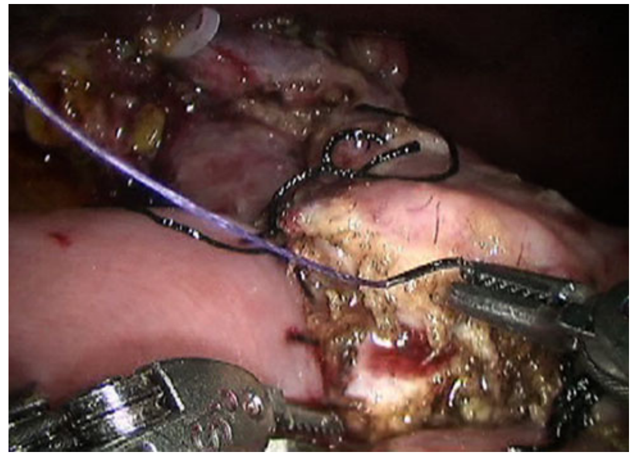

Fig. 6 Suturing of the pancreatic duct during the pancreaticojejunostomy creation. The duct-to-mucosa anastomosis is created with a 4-0 Vicryl suture on an RB1 needle. The pancreas parenchyma and pancreatic duct are seen on the *right side* of the photograph, while the jejunum is visualized on the *left*

anastomosis is complete, the second Lembert-type layer is created in a running fashion. At the completion of the Whipple procedure, the pancreaticojejunostomy may be treated with a topical sealing agent, but objective evidence for decreasing ductal leak is absent.

The hepaticojejunostomy is fashioned as an end-to-side anastomosis, utilizing a running back wall 4-0 Vicryl suture on an RB1 needle. Once the back wall is finished, the front wall is sutured in an interrupted fashion, utilizing the same suture type. The hepaticojejunostomy is not routinely stented. The gastrojejunostomy is created in a retro-colic fashion. The transverse colonic mesentery is traversed to the left of the middle colic vessels. The anastomosis is created with a single firing of the endoscopic stapler, using a blue staple load. The enterotomy created for stapler access in the stomach and jejunum is closed in a two-layer fashion with a running 4-0 Vicryl suture followed by a second layer of interrupted Lembert-type suture, using 4-0 silk. All anastomoses are assessed for tension and leak prior to closing. A closed surgical drain is positioned in the right upper quadrant in the region of the pancreas and bile duct anastomoses. The robotic Whipple patient needs standard open Whipple post-operative care, in a hospital setting that can manage complex hepatobiliary patients.

Initial results

The robotic Whipple procedure may provide all the benefits of minimally invasive surgery to pancreaticoduodenectomy. Preliminary results appear to show that the robotic procedure patients mobilize earlier in their recovery. The median length of hospital stay is 6.2 days (range 5.2–18.8), which compares favorably to our open Whipple procedure, where the median length of hospital stay is 7.9 days. The 18.8-day hospital stay represents the only leak (grade B—ISGPF consensus [14, 15]) in our series. The distal gastric staple line had a subclinical gastric leak, which required percutaneous drainage. The leak healed without additional treatment, with the drainage catheter being removed 2 weeks post-placement. An additional patient stayed 9.7 days in hospital recovering from narcotic addiction, due to chronic pancreatitis that no longer required narcotic pain control at discharge. One of the principal objections to the robotic procedure is the increased duration of operating time. The mean robotic operating time is 8.0 h (range 5.9–9.6), which again compares favorably with our open experience where the mean operating time is 5.4 h. When considering the operating times of the robotic Whipple procedure, it is important to emphasize that one patient had a previous right hemi-colectomy, two patients had aberrant hepatic artery anatomy, and two patients had non-dilated pancreatic ducts (2 mm in diameter). The series had 100% R0 margin resections, a mean lymph node harvest of 11 nodes (7–18 nodes) from benign and pre-malignant tumor resections, no patients required blood transfusions, one gastric leak (Clavien grade complication—Grade B [16, 17]), and a 0% 30- and 90-day mortality.

Conclusions

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 inter-operative hepatobiliary complications. If oncological principles and/or safety are compromised, the procedure needs to be converted to a standard open Whipple. The patient requires an up-front frank pre-operative discussion regarding the novel approach of the minimally invasive pancreaticoduodentectomy [18]. 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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