Historical evolution and current state of robotic liver surgery

In the 1980s, 'open' liver resection was known to be associated with prohibitively high morbidity and mortality. Several reasons for the poor outcomes were complex vascular and biliary structures within the liver, difficulty in anatomical exposure, and tendency for major bleeding to occur during parenchymal transection. With advancement of surgical techniques, better instrumentation for hemostasis, and improved perioperative care, the feasibility and safety of liver resection improved significantly. Cure from hepatocellular carcinoma now became a reality for many patients, who were otherwise facing a death sentence (1,2).

The emergence of minimally invasive surgical approach for liver resection has been fostered by the introduction of digital technology including fiberoptic imaging and development of laparoscopic hemostatic tools such as clips, linear staplers, and ultrasonic/bipolar energy devices. The advantages of minimally invasive surgery are widely accepted, which include decreased postoperative pain, shorter recovery, decreased length of hospital stay, rapid return to preoperative activity, a lower rate of wound complication, and improved cosmesis. Laparoscopic liver resection was subsequently shown to be feasible and safe in experienced hands with minimal morbidity and mortality, for both minor and major resections. Several studies evaluating oncologic outcomes after liver resection for hepatocellular carcinoma have reported similar 5-year survival rates, regardless of the approach (3,4).

Although laparoscopic liver resection is associated with benefits of minimally invasive approach, it is encumbered by limited degree of freedom for manipulation, fulcrum effect against the ports, tremor amplification, poor ergonomics, and two-dimensional visualization. The robotic surgical system provides solutions to these limitations. The robot offers the EndoWrist technology on its instruments with 7 degrees of freedom, ease of suturing even in difficult to reach areas, tremor filtering, a three-dimensional optic visualization, and excellent ergonomics. In 1998, Himpens *et al.* reported the first successful clinical application of telerobotics for cholecystectomy using an early daVinci surgical system prototype (5). After the initial success in the clinical arena, robotic system was then utilized for other surgical procedures such as hysterectomy, prostatectomy, antireflux operations, Heller myotomy, Roux-en-Y gastric bypass for morbid obesity, colorectal surgery, and abdominal wall reconstructions.

In the field of hepatobiliary surgery, the use of robotic surgical systems for liver operations was initially reported only for pedicle dissection and initial parenchymal transection. Since then, several single institutional small case series have been published reporting on the feasibility, safety, low conversion rate to 'open', limited blood loss, and minimal postoperative complications (6-9). At the early years of robotic liver resection, the most commonly reported procedure was wedge resection and anterolateral/peripheral segmentectomy (37.7%) (2). Port placement in the robotic technique is slightly different to that of the conventional laparoscopic technique. Five or six ports were used (three for the robotic working arms, one for the robotic camera, and one or two for the bedside assistant surgeon). Most surgeons place the robotic camera in the umbilical or right paraumbilical area. The parenchymal transection is undertaken with robotic harmonic or bipolar vessel sealing energy device in combination with fenestrated bipolar forceps for tissue coagulation. Hemostasis of small vessels (<7 mm in diameter) is achieved with energy device, while larger vessels (>7 mm in diameter) are handled with clips, ligature, or vascular stapler.

In a systematic review by Ho *et al.*, 'open' conversion rate associated with robotic liver resection was much lower compared to that of the conventional laparoscopic liver resection (4.6% versus 20.3%, respectively), whereas other postoperative outcome parameters were similar (2). The most common reasons for conversion to 'open' approach were intraoperative bleeding, difficulty in securing resection margins, anatomical distortion of the liver hilum, and morbid obesity. Tsung *et al.* reported the largest matched series of robotic versus laparoscopic hepatectomy for liver tumors (10). The patients in the robotic group were more likely to have their operation completed purely minimally invasively without the need for hand-assistance or conversion to a hybrid approach, when compared to the matched patients in the laparoscopic group. Boggi *et al.* demonstrated the usefulness of robotic suturing for a large caval injury should one occur in the process of liver mobilization or parenchymal transection (11). In a similar note, Idrees *et al.* described that the use of three robotic arms by the operating (console) surgeon, articulating feature of the instruments that can be locked in place as vascular clamps, and ease of suturing by the EndoWrist instruments are extremely useful in controlling hemorrhage without requiring an immediate 'open' conversion (12). In a large modern series containing 80 consecutive patients undergoing robotic liver resection reported by Sucandy *et al.*, only one patient required a conversion to 'open' approach due to bleeding (13). This suggested that robotic liver resection is safely done and it is being continuously perfected at major hepatobiliary centers with significant expertise. Other reports also indicated that robotic technology extends the application of minimally invasive techniques in the field of hepatic surgery (14,15).

The robotic surgical platform is gradually being applied worldwide by liver surgeons even in developing countries with comparable outcomes to those of open liver surgery, while gaining the benefits of the minimally invasive approach. In India, a successful robotic hepatectomy was first performed and reported by Goja *et al.* in 2015 for recurrent pyogenic cholangitis (16). In Korea, the robotic system was first introduced in 2005, with the first robotic cholecystectomy performed in July 2005 (17). The first robotic liver resection was undertaken in 2007 for a 2.4 cm hepatocellular carcinoma in the left lateral section with excellent perioperative and short-term outcomes. In 2012, a series containing outcomes of robotic major hemihepatectomies for malignant liver tumors was published by the same institution (8). The robotic system was found to significantly facilitate the extrahepatic Glissonean pedicle approach, especially for the right hepatectomy. Parenchymal transection is considered the most difficult step during robotic liver resection because the currently available robotic instruments are limited and there is no well-established technique. An effort was then made to standardize the parenchymal transection technique including the use of rubber band suspension to achieve effective and Dinamic exposure of the transection plane. They advocated the use of Harmonic scalpel and Maryland forceps for the liver parenchymal transection. The Maryland forceps can be used as a hemostatic and an exposing instrument using the traditional Kelly-clamp crushing technique mimicking 'open' hepatectomy. In terms of oncologic outcomes, the rate of negative resection margins and 5-year disease-free survivals (40.2% versus 50.5%) were similar between the minimally invasive and 'open' group.

Ease of suturing, especially in difficult to reach locations such as in the posterosuperior segments is one of the clear advantages of the robotic platform. Hu *et al.* published a systematic review containing 12 studies of minimally invasive approach for hilar cholangiocarcinoma requiring biliary reconstruction. Four studies utilized robotic technology with good outcomes (18). These were the cases which are conventionally performed using the traditional 'open' approach due to anticipated technical difficulties with hilar dissection and creation of bilioenteric anastomosis.

Currently, the robotic surgical system in hepatic surgery is not only utilized for primary resection of hepatobiliary tumors. In 2015, Vicente *et al.* from Spain reported the first successful robotic ALPPS (Associating Liver Partition & Portal Vein Ligation for Staged Hepatectomy) procedure in a 58-year-old man presenting with multiple right liver metastases from sigmoid adenocarcinoma (19).In the United States, Giulianotti *et al.* described the first robotic-assisted right hepatectomy for living donor liver transplantation (20). The precise nature of robotic dissection allowed proper reconstruction of the vascular structures, including one large branch of middle hepatic vein from segment 8. This initial success was followed by Chen *et al.* who reported 13 right donor hepatectomies in 2016. All donors had uneventful perioperative course, except for one patient who developed delayed bile leak after hospital discharge (21). Clearly, the application of robotic platform in general surgery is steadily expanding toward surgical subspecialties.

Despite its expanding use in hepatobiliary surgery, robotic surgical system faces significant pushback by many institutions. Criticism against robotic surgery mainly revolves around the lack of haptic feedback and high cost. Visual instead of haptic feedback, however, develops as the surgeon gains more experience. Unlike other gastrointestinal procedures, robotic liver resection requires a team approach that includes a highly skilled laparoscopic surgeon at the patient's bedside to manage complex instruments such as laparoscopic stapling, clipping, or laparoscopic Cavitron Ultrasonic Surgical Aspirator (CUSA®) when used. A skilled bedside surgeon is crucial in handling major intraoperative bleeding should one occur, as well as emergently converting the robotic operation to 'open' when necessary. Many surgeons are concerned about the separation of the operating surgeon and the patient, which potentially leads to delays in managing immediate 'open' conversion during major intraoperative bleeding. Installation and exchange of robotic instruments also require time and trained personnel. With increasing experience and proficiency, this is expected to reduce. In 2008, the purchase of a da Vinci robot was reported to be approximately US $1.5 million, with annual service cost of around $110,000, excluding the disposable instruments (22,23). The cost of robotic operation is generally higher due to increased operative time and instruments used, while the costs of hospitalization are similar. In the future, we predict that the cost for the robotic platform will significantly reduce as the robotic system becomes widely available by multiple manufacturers.

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References

1. Fan ST, Mau Lo C, Poon RT, et al. Continuous improvement of survival outcomes of resection of hepatocellular carcinoma: a 20-year experience. Ann Surg 2011;253:745-58.
2. Ho CM, Wakabayashi G, Nitta H, et al. Systematic review of robotic liver resection. Surg Endosc 2013;27:732-9.
3. Nguyen KT, Gamblin TC, Geller DA. World review of laparoscopic liver resection-2,804 patients. Ann Surg 2009;250:831-41.
4. Tranchart H, Di Giuro G, Lainas P, et al. Laparoscopic resection for hepatocellular carcinoma: a matched-pair comparative study. Surg Endosc 2010;24:1170-6.
5. Himpens J, Leman G, Cadiere GB. Telesurgical laparoscopic cholecystectomy. Surg Endosc 1998;12:1091.
6. Berber E, Akyildiz HY, Aucejo F, et al. Robotic versus laparoscopic resection of liver tumours. HPB (Oxford) 2010;12:583-6.
7. Giulianotti PC, Coratti A, Sbrana F, et al. Robotic liver surgery: results for 70 resections. Surgery 2011;149:29-39.
8. Choi GH, Choi SH, Kim SH, et al. Robotic liver resection: technique and results of 30 consecutive procedures. Surg Endosc 2012;26:2247-58.
9. Lai EC, Yang GP, Tang CN. Robot-assisted laparoscopic liver resection for hepatocellular carcinoma: short-term outcome. Am J Surg 2013;205:697-702.
10. Tsung A, Geller DA, Sukato DC, et al. Robotic versus laparoscopic hepatectomy: a matched comparison. Ann Surg 2014;259:549-55.
11. Boggi U, Moretto C, Vistoli F, et al. Robotic suture of a large caval injury caused by endo-GIA stapler malfunction during laparoscopic wedge resection of liver segments VII and VIII en-bloc with the right hepatic vein. Minim Invasive Ther Allied Technol 2009;18:306-10
12. Idrees K, Bartlett DL. Robotic liver surgery. Surg Clin North Am 2010;90:761-74.
13. Sucandy I, Schlosser S, Bourdeau T, et al. Robotic hepatectomy for benign and malignant liver tumors. J Robot Surg 2019. [Epub ahead of print].
14. Sucandy I, Gravetz A, Ross S, et al. Technique of robotic left hepatectomy: how we approach it. J Robot Surg 2019;13:201-7.
15. Sucandy I, Durrani H, Ross S, Rosemurgy A. Technical approach of robotic total right hepatic lobectomy: How we do it? J Robot Surg 2019;13:193-9.

16. Goja S, Singh MK, Vohra V, et al. Robotic Left Hepatectomy: a Case Report (First Reported Case of Robotic Hepatectomy in India). Indian J Surg 2015;77:338-40.
17. Choi GH, Chong JU, Han DH, et al. Robotic hepatectomy: the Korean experience and perspective. Hepatobiliary Surg Nutr 2017;6:230-8.
18. Hu HJ, Wu ZR, Jin YW, et al. Minimally invasive surgery for hilar cholangiocarcinoma: state of art and future perspectives. ANZ J Surg 2019;89:476-80 .
19. Vicente E, Quijano Y, Ielpo B, et al. First ALPPS procedure using a total robotic approach. Surg Oncol 2016;25:457.
20. Giulianotti PC, Tzvetanov I, Jeon H, et al. Robot-assisted right lobe donor hepatectomy. Transpl Int 2012;25:e5-9.
21. Chen PD, Wu CY, Hu RH, et al. Robotic liver donor right hepatectomy: A pure, minimally invasive approach. Liver Transpl 2016;22:1509-18.
22. Steinberg PL, Merguerian PA, Bihrle W 3rd, et al. A da Vinci robot system can make sense for a mature laparoscopic prostatectomy program. JSLS 2008;12:9-12.
23. Leung U, Fong Y. Robotic liver surgery. Hepatobiliary Surg Nutr 2014;3:288-94.

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