Robotics as the natural evolution for minimally invasive surgery liver surgery: technological advances for patient and surgeon benefit

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Introduction

One of the most important areas of surgical advances in the last three decades has been the adoption of minimally invasive surgery (MIS). Laparoscopic and thoracoscopic techniques now allow rapid recovery from many abdominal and thoracic procedures (1). Adoption of MIS techniques to liver resection has been slower than most other procedures for clear reasons. Liver resection is a highly technical operation fraught with many potential risks, including catastrophic intraoperative hemorrhage and death. With improvements in surgical, anesthetic, and peri-operative support seen at the end of the 20th century (2), laparoscopic hepatectomy techniques began to be adopted. By 2009, Nguyen *et al.* were able to report a collected review of 2,804 laparoscopic liver resections. Laparoscopic liver surgery has become a mature field (3). A consensus conference in 2008 concluded that laparoscopic minor liver resections in the inferior part of the liver had become standard practice, while major resections and resections of lesions at the superior portions of the liver are still considered expert surgery (4). Of note, less than 25% of liver resections are currently performed laparoscopically (5).

Robotic liver resection was first reported in 2003 with the introduction of the DaVinci Robot (Intuitive Surgical, Sunnyvale, CA, USA). The worldwide experience has been increasing. In a recent review in Digestive Medicine Research, Croner *et al.* summarized the findings of 29 studies comparing robotic to laparoscopic resections, which involved 1,392 robotic and 1,965 laparoscopic liver resections (6). The major findings were that there was no difference in cancer survival between robotic and laparoscopic surgery. Conversion trended to higher in the laparoscopic approach. Costs and operative times were higher in robotic surgery. These data echo those recently published in a six-center propensity-matched comparison of robotic versus laparoscopic liver resection (7). These papers show the MIS hepatectomy approach to be safe and equivalent in long-term oncologic results. These collected reviews are likely a comparison of the mature field of laparoscopic liver resection with the learning-curve experience in robotic liver surgery. The importance of these studies is that it demonstrates increasing penetrance of robotic hepatectomy and that robotic surgery is equivalent to laparoscopic surgery in terms of long-term cancer outcome.

Value of robotic liver resection

Robotic surgery is technologically advanced laparoscopic

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Table 1 Value proposition for robotic surgery

Group	Advantages
Patients	● Allows for shorter hospital stay and faster recovery than open surgery
	● Greater ease of adoption allows more patients to benefit from MIS
	● A lower rate of conversion allows more patients treated by MIS to achieve benefits
Health system	● Shorter hospital stays mean less need for health resources
	● Better ergonomics provide for longer surgical careers and preserve the pool of experienced surgeons that is a vital health care resource
All surgeons	● Cases are more comfortable and result in fewer injuries
Young surgeons and surgeons learning new robotic systems	● Cases that can be performed easily allow for training and credentialing
	● These cases also allow for teaching

MIS, minimally invasive surgery.

surgery. By allowing better visualization through 3-dimensional (3D) displays with image stabilization that are always in front of the surgeon, robotic surgery offers ergonomically superior performance and better visualization. By having articulated instruments and dampening tremors, robotics allows the surgeon to be more precise in movement, especially in anatomic locations that are hard to reach with straight laparoscopic instruments. Allowing the robotic arms to apply the forces rather than human hands and joints improves ergonomics and prevents injuries. The sum of these advantages results in robotics being a more straightforward MIS platform for adaption than traditional laparoscopic surgery. Essential surgical moves can be more easily performed robotically. Sewing is an expertise in laparoscopic surgery, while it is a competency in robotic surgery (8). This is the reason for the lower conversion rates in robotic surgery, including resections for rectal cancer (9) and gastric cancer (10).

Many comparative discussions of laparoscopic surgery versus robotic surgery involve only economics and the fact that at present robotic surgery costs more. The higher cost is because of more prolonged OR times in the learning curve portion of adaption and more costly instrumentation. In more recent series in robotic liver surgery (11) and robotic gastric surgery (12), no difference in OR time was noted compared to laparoscopy. With additional robotic platforms entering the market, the cost of instrumentation will decrease.

For most operations, it is hard to distinguish robotic surgery from traditional laparoscopy by the usual surgical outcome parameters of operative mortality, complication, and length of hospital stay. This is because robotics is simply computer-aided laparoscopy. For simple operations with minimal sewing and with surgical fields approachable by straight instruments such as cholecystectomy or oophorectomy, it will be hard to see a difference in traditional outcome parameters, especially if both are performed by experts. Discussion on the value of robotic surgery should center on documenting the advantages of computer assistance for the surgeon and, therefore, the patient (*Table 1*).

The primary advantage of robotics is the ability to allow many more patients to undergo MIS. Emerging data shows that robotic surgery is a technology that is easier to adopt than traditional laparoscopy (13). A recent study looked at trends over a five year period for MIS and open surgery for esophageal (n=11,023), gastric (n=30,664), pancreas (n=30,689), colon (n=260,669), and rectal (n=52,239) cancer (13). Robotic resections increased nearly fourfold in all organ sites (esophagus: 3.8 fold increase, stomach: 4.4, pancreas: 4.4, colon: 3.8 and rectum: 4), while the number of laparoscopic resections increased at a slower rate (1.3–1.9 fold increase) (13). It is also clear that open surgeons can go straight from open operations to robotics without an intermediary step of learning laparoscopy (14). Since most hepatectomies nationwide (>75%) are still performed through open surgery (5), converting surgeons to robotic surgeons will give many more patients the benefits of an MIS option.

It is also clear that conversion rates are lower for robotic surgery than for laparoscopy (10). Consequently, patients treated with robotic surgery are more likely to achieve the benefits of MIS surgery because of the lower likelihood of conversion to open surgery. The lower conversion rate is at least in part due to the ease of sewing during robotic surgery. It is easier for the surgeon to fix inadvertent injuries to the vasculature or adjacent organs during robotic surgery than during laparoscopy.

Robotic surgery makes some expert laparoscopic operations accessible to more surgeons. In the Louisville statement on laparoscopic surgery, the consensus was that surgery on superior liver segments (7, 8, 4a, 2, 1) was complex and considered expert surgery. The articulated instruments on a surgical robot allow better access to these segments. Several reports have documented the safety of robotic operations in these segments of the liver (11). As robotic surgery evolves, new technologies will emerge that can actuate surgical moves not previously possible. For example, recent advances in intraluminal robotics have allowed transbronchial robotics to transform thoracic surgery and allow routine access to the 5th and 6th order bronchi. In the future, such modifications of robots will likely be used in robotic liver surgery for precise navigated access to the biliary tree for intraluminal extractions of stones, tumors, and stent placements.

The most significant benefit offered by robotics to a patient is rapid recovery from "incision dominant" procedures. Recovery from major liver resection is dominated by the physiology of liver regeneration recovery. That is why outcomes of major liver resection, when measured by hospital stay or complications, do not distinguish robotic surgery. Recovery from minor liver resections is dominated by the incision. There are many surgeries where access to the surgical field in open surgery requires a big incision and where straight laparoscopic instruments make traditional MIS surgery challenging. Minor liver resections in posterior and superior segments epitomize such an "incision dominant" operation (11,15). Cyst fenestrations, wedge resections, segmentectomies, and bisegmentectomies by robotic surgery can achieve rapid recovery and shorter hospital stays and recovery than open surgery (11). Some centers are now performing such robotic hepatectomies as outpatient and extended-stay surgeries (15), which provides clear value to patients, hospitals, and payers.

Robots may prevent occupational injury and prolong surgical careers. Occupational injury during laparoscopy is not unusual. Robotics, with displays directly in front of the surgeon, and with the forces on the instruments applied by the robotic arm rather than the surgeons' hand and arms, is ergonomically easier for the surgeon than laparoscopy (16-18). We would posit that a talented, well-trained surgeon with long clinical experience is the most valuable asset in an operating room. Maintaining the health of the surgeon sustains an important healthcare resource.

Simple procedures have value in robotic training and maintaining the competency of a surgeon. The value in doing simple procedures robotically lies in training young surgeons to become experts. A rational robotic training program involves increasingly complex surgeries. A curriculum that starts with simple operations such as cholecystectomies and oophorectomies, then moves to more complex hysterectomies, progressing to luminal surgery such as gastrectomy or colectomies, and finally to esophageal and HBP surgery would provide a well-rounded training. Such curricula would conform to our traditions and philosophy of surgical training based on graduated complexity of cases. Moving straight from robotic cholecystectomy to robotic hepatectomy is not the optimal path. As new robots are introduced to the market, simple robotic operations will also be essential for credentialing surgeons for new platforms safely and efficiently (19).

Augment reality, artificial intelligence, and automation

A significant advantage of robotics over conventional laparoscopy is the logical next technological evolution to augmented reality (AR), artificial intelligence, and automation.

Advanced display and AR

The 3D display in robotic surgery involves merging the images from two different cameras on the laparoscope to present an environment that recreates depth that is very important for the accuracy and speed of surgical moves. Work is already underway to evolve to 3D reconstructions of CT or magnetic resonance scans to overlay onto the white-light-visible anatomic structures (20,21). This could improve the speed of surgery while increasing safety by identifying and displaying vessels and vital structures deep to the visible area.

Many dyes are already in human trials to aid in the visualization of vessels, nerves (22), anatomic structures such as ureters, and tumors (22,23). Overlay of these onto the visible surgical field is likely to improve the safety of surgery. It may also improve the likelihood of R0 resections in cancer cases. These anatomic data can help set "no-go" zones to limit the use of surgical instruments in safe areas to further improve the safety of the operations.

AR display will not only be limited to the surgeon's console. Wearable 3D display goggles are already in testing to let bedside assistants and scrub nurses see the surgical field in an ergonomic fashion (24). In robotic surgery, the bedside assistant has the most challenging job from an ergonomic standpoint. They have to perform many skilled maneuvers, including firing staplers, using ultrasonic dissectors and sealers, suction, apply clips, and introduce/retrieve needles, all while avoiding the moving robotic arms. The usual OR monitors are often obstructed by the robotic arms or placed in poor ergonomic positions for use by the bedside assistant. There is great promise for AR goggles to significantly improve efficiency and accuracy while improving ergonomics (24).

Research efforts are underway to automate surgical tasks, scenes, and operations. While the value for automating very simple operations such as oophorectomies and cholecystectomies is questionable, automating tedious, repetitive, and intricate tasks such as liver parenchymal transection or abdominal wall flap dissection is attractive. The tireless computer-aided robot could be a safe and efficient automated surgeon of the future. The robot-auto-surgeon will process multichannel, macro-confocal images of blood vessels, nerves, bile ducts, and tumors to perform surgery with great precision and speed.

Conclusions

Robotic surgery is being adopted rapidly to many intricate surgical procedures necessary for alleviating human suffering from cancer, infection, and congenital malformations, and trauma. Such adoption is increasing the number of patients treated by the MIS approach for faster recovery. In liver resection, the robotic approach is transforming many resections to outpatient hepatectomy. Advances and engagement in this field by surgeons, scientists, and engineers are also transforming robotic hepatectomy to a field of AI and AR-enhanced surgery.

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