The marriage of robotics and medicine: the current role and critical review of robotic-assisted cholecystectomy

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Abstract

Introduction

In 1979, the Robot Institute of America defined ‘robot’ as a machine comprised of four characteristics it is ‘reprogrammable’; it is capable of manipulating materials, parts and tools; it performs ‘programmed’ movements and it possesses the ability to perform more than one task. While robots in industry, manufacturing, military and space exploration meet this definition of ‘robot’ set forth by the Robot Institute of America, scientists and engineers were rightfully more hesitant to grant robots the freedom to perform highly technical operations on delicate human tissue. Yet as technology proves more reliable, surgeons have recently placed their faith in field of medical robotics, allowing robots to assist in many minimally invasive procedures. The intent of this critical review is to provide a more focused review of medical robotics, specifically robotic-assisted cholecystectomy and its aim to remove the shortcomings of laparoscopy. This critical review will also discuss the future role of robotics in cholecystectomy, as well as the current and future barriers of robotic surgery in general.

Conclusion

Robotic-assisted cholecystectomy is a safe and feasible procedure, even in a community hospital setting, based on current preliminary work done both in Europe and in the United States. However, the current published literature recommends further prospective controlled trials to evaluate further benefits to patients over the standard laparoscopic techniques.

Introduction

The rapid ascent of laparoscopic surgery in the 1980’s was largely driven by the number of people who requested it. Not only did laparoscopy produce better cosmesis, in many cases it was the superior surgical option, with fewer traumas and therefore, had lower morbidity, reduced post-operative pain, shorter hospital stay and accelerated return to normal activity. Although a major breakthrough in the broad field of surgery, laparoscopy is not without its limitations and still leaves much to be desired by surgeons. The reduced visibility and two dimensionality of the surgical field make operations more difficult to perform. In the confined two-dimensional environment, depth of perception is lost and so does the surgeon’s command of his or her field of view, which is in the control of an assistant handling the camera. Manual camera holding disrupts the smoothness of the operation because of unstable camera handling and orientation mistakes. In addition, the decreased freedom of laparoscopic instruments as compared to numerous components of wrist motion limits maneuverability and complicates tasks. The learning curve of laparoscopy is made steeper by the transmission of tremors from the surgeon’s hands to the instruments and by the disruption of normal hand-eye coordination, with the introduction of the long, thin instruments that are inserted inside the body through small incisions. This demands greater skill and dexterity in order to manipulate the surgical tools. Laparoscopy further removes intuitive control by introducing the ‘fulcrum effect’, where tool endpoints move in the opposite direction of the surgeons’ hands.

These disadvantages have fuelled the efforts to develop a robotic technology in the medical field. For example, AESOP® (Computer Motion), a robotic laparoscopic camera holder that moves by voice control and effectively restores command of the visual field to the surgeon, found its way onto operating tables for minimally invasive procedures after the US Food and Drug Administration (FDA) approved its use in 1994. In the late 1980’s and early 1990’s, PROBOT by Imperial College London was developed. This robotic cutter resects different volumes of prostatic tissue without any interven-

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Figure 1: AESOP®, a voice-controlled robotic endoscopic positioning system.

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Critical review

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Current uses of robotics in medicine
Robotic-assisted surgery (RAS) served as a major breakthrough in the performance of complex laparoscopic procedures; many surgeons have found benefits in RAS over traditional laparoscopy. Noticeable advantages are the wristed instruments, three–dimensional view, easy accessibility into narrow areas, like pelvis and filtering of tremor. These advantages have considerably increased the range of minimally invasive surgical procedures that can be performed.

The set-up of the da Vinci creates a better working environment, both by eliminating the need for awkward body and tool movements and by allowing the surgeon to comfortably sit down while operating, a benefit especially apparent in long operations. RAS also reinstates proper hand–eye coordination, implements ergonomically positioned controls, improves visualisation of the operative field and renders technically difficult operations more feasible.

The improved geometric accuracy and manipulation of instruments is achieved by the increased degrees of freedom of the robotic arms, whose movement capabilities mimic that of the wrist. The engineers also instituted hardware and software that filter out hand tremors and scale the surgeon’s movement. Essentially, scaled movement enables a 3 cm forward movement of the surgeon’s hand, for example, to translate into a proportionally smaller forward movement of 1 cm of the robotic arm, effectively enabling ‘micromotions’, inside the patient. The three-dimensional view, with depth perception along with the surgeon’s ability to control a steady visual field, is superior to the laparoscopic camera views, as well. A recent upgrade used by our institution is the use of the single site upgrade by Intuitive Surgical, Inc., which is a single-port system, comprised of several cannula lumens where the insufflator, camera and instruments can all be placed. This add-on to the da Vinci, further reduces the invasiveness of the procedure by requiring only one small incision near the umbilicus, thus better cosmesis.

All these advantages of RAS theoretically provide the surgeon with a greater command of the surgical environment, enabling him or her to detect and dissect complex anatomic arrangements and perform challenging procedures in a safer surgical environment.
Still, many argue that the da Vinci’s true merit is overestimated because of its many drawbacks. One such disadvantage is its cost\textsuperscript{11}. With a price tag of upwards of a million dollars per unit and costing thousands of dollars per year to replace parts and upkeep the equipment, it is no wonder that hospitals and healthcare organisations hesitate to empty their wallets on a product that lacks the long-term studies testifying to its monetary and medical worth\textsuperscript{3}. Opinions vary on whether or not the price of the da Vinci will change. Some argue that as more experience is gained with robotic systems and as competitors enter the market, prices will drop\textsuperscript{15,17}. With the increase in case volumes, many claim that the 1.5 billion dollar increase in healthcare expenditure per year as a result of this technology may be offset by lower complication rates\textsuperscript{18,19} and shorter length of stay in hospitals and intensive care units\textsuperscript{20}. However, as Gurusamy et al.\textsuperscript{21} pointed out, studies of RAS are few and more randomised control trials are required to determine its true economic and clinical impact\textsuperscript{21}. The studies that do exist are constrained by single institution experiences and small sample size\textsuperscript{22}. Contrasting these theories are assertions that prices will increase as more complex software becomes available\textsuperscript{23}. Clearly, there are many variables that need to play out before we can expect to see any change in its market value.

The da Vinci disadvantages do not end with cost. The large robotic arms prove cumbersome, and the three-component da Vinci only adds to the already congested operating rooms\textsuperscript{23}. This shortcoming, though, can be surmounted by miniaturising the robotic arms and instruments, and technology from competing companies is already underway to deal with this issue\textsuperscript{3}. There are other issues with robots that need to be addressed in the future, such as eliminating the need to undock when changing the patient position; this can be potentially overcome by incorporating the arms of the robot into the operating room table to make them move as a single unit in a safe manner. In addition, many reports have argued that operative time is longer for RAS than laparoscopic surgery, while others demonstrated no difference\textsuperscript{21}. One study demonstrated that set up and operative times significantly decrease as surgeons and staff became more familiar with the equipment and performed more cases\textsuperscript{24}. By encouraging surgeons to enrol in the available robotic training programs or to practice with robotic simulation consoles, operating times and complication rates are expected to decrease\textsuperscript{25–27}.

### Robotics in cholecystectomy

Currently, robotic-assisted cholecystectomy is one of the most commonly performed robotic surgeries by general surgeons in the United States. The multiple-port approach and single-port approach are currently available techniques employed by surgeons in different institutions across the board. Most of the surgeons move along from multiple-port technique to single-port technique as with the progression of their skills level\textsuperscript{28}. The single-port approach has the advantage of improved cosmetic results and decreased post-operative pain due to the small single incision\textsuperscript{16,28}. In addition, the surgeons find that the computerised reversion of the crossed instruments permits superior manoeuvrability and ergonomics than other non-robotic single-port laparoscopic surgeries\textsuperscript{16}. Furthermore, the semi-rigid, curved instruments provide a sturdy and secure platform to perform procedures compared to other single-port surgeries\textsuperscript{16}. The overall docking for a robotic-assisted single-port cholecystectomy does not significantly increase operating time as demonstrated by Iranmanesh et al.\textsuperscript{25} and docking of the da Vinci is a rapidly learned process\textsuperscript{29}.

Despite these promising outcomes, the question of whether robotic-assisted single-port cholecystectomy remains cost-effective and safer compared to traditional laparoscopic methods, remains unanswered.

### Discussion

Anderson et al.\textsuperscript{30} performed the first national analysis of RAS in the United States by reviewing the Nationwide Inpatient Sample (NIS) database in 2008 and 2009\textsuperscript{30}. The review showed that RAS has decreased length of stay and mortality, especially when compared to open technique\textsuperscript{30}. When compared with laparoscopy, these findings were not as apparent; however, their work was not directed towards cholecystectomy, but towards RAS in general\textsuperscript{30}. RAS, as a new and emerging technology in the field of medicine, has little data to support or oppose its use in robotic cholecystectomy. As previously mentioned, the biggest debate with robotic cholecystectomy as with other robotic procedures is cost and time duration. The robotic surgical systems costs between 1.5 and 1.75 million dollars, with an annual maintenance fee of around 14,0000 dollars\textsuperscript{21}. Many hospitals own at least one robotic unit and the initial cost of the robot is considered as a one-time investment\textsuperscript{21}. Of note, the daily operative cost of robotic cholecystectomy is only slightly higher than that of the standard laparoscopic cholecystectomy\textsuperscript{21}.

In a study performed by Salman et al.\textsuperscript{22}, using the NIS database, they analysed the data for patients undergoing various robotic procedures. Procedural costs for robotic cholecystectomy was found to be lower than its laparoscopic counterparts\textsuperscript{22}. In another study that compared single-port laparoscopic cholecystectomy, with single-port robotic-assisted cholecystectomy, the authors concluded that the two surgical modalities were equivalent in regards to operative time and cost\textsuperscript{28}. However, a prospective case-matched study conducted on 50 consecutive patients, by a Swiss University,
concluded that the cost of robotic gall bladder surgery, was higher due to extensive expenses for both the robotic system itself and the expendable components of some of the equipment\textsuperscript{24}. While the study showed comparable time of surgery, hospital stay and complications, the authors argued that the costs of the robots did not justify its use since there was no clear benefit for the patients over traditional laparoscopic surgery\textsuperscript{34}. Several other studies have also demonstrated similar or even lesser operative time, even on patients with high body mass index (BMI)\textsuperscript{16,35,36}. Importantly, many articles demonstrated a significant decrease in operative and set up time, as well as a comparably shorter learning curve for the mastery of the robotic console, as basic surgical tasks could be performed perfectly in a short period of time\textsuperscript{24}. These advantages of the robotic system may be areas where its high cost could be offset. Salman et al.\textsuperscript{22} agrees, concluding that the high cost of the robot and its maintenance are already counterbalanced by the fewer complications and shorter hospital stay\textsuperscript{22}.

Kordan et al.\textsuperscript{37} reported decrease in blood loss and less need for transfusions, with the use of RAS\textsuperscript{37}. Nevertheless, the debate still stands as to whether robotic cholecystectomy is a safer alternative to traditional laparoscopic cholecystectomy. Some studies examining the safety of robotic-assisted cholecystectomy found no clinical advantages over the laparoscopic approach, reporting similar complications rates as well as conversions to open cholecystectomy\textsuperscript{24,38,39}. Yet, the surgeons from these same studies admit that the dissection in the triangle of Calot was easier with the robotic system. Interestingly, Salman et al.\textsuperscript{22} testified that RAS appeared to be as safe as non-robotic surgery, except in cholecystectomy and oesophagogastric procedures\textsuperscript{22}. A meta-analysis comparing benefits and harms of robotic-assisted cholecystectomy versus the traditional laparoscopic method, reported no serious co-morbidities in either groups and no significant difference in the conversion rate to open cholecystectomy\textsuperscript{21}. However, the author concluded that determining if robotic-assisted cholecystectomy is truly better or worse, requires thousands of subjects and conduction of randomised control trials\textsuperscript{21,22}.

Investigators tried real-time near infrared fluorescent cholangiography by using indocyanine green (ICG) with robotic-assisted single-port cholecystectomy in order to help reduce operative time, improve safety and better identify biliary structures during dissection. Buchs et al.\textsuperscript{40} compared the operative times between patients, who underwent single incision robotic-assisted cholecystectomy using this technique, with those patients who underwent the standard single incision robotic-assisted cholecystectomy. They found that the operative time deceased by using cholangiography only in selected patients, with low BMI, because of the inability of near-infrared light to penetrate tissues in patients, with higher BMI\textsuperscript{40}. Prior to this, Spinoglio investigated the use of this technique in a prospective study on 45 patients. The procedure was found to be effective in identifying biliary anatomy. However, the operative time in this study was slightly higher in patients having cholangiography\textsuperscript{41}.

In addition to removal of gall bladders due to complications arising from stones and biliary dyskinesia, according to a study performed in China on five patients with gall bladder cancer, robotic-assisted cholecystectomy was also reported to be feasible and safe for radical resection of gall bladder cancer\textsuperscript{42}. Typically, these procedures are performed open, because of the technical demands. With laparoscopic approach, a high degree of skill and care must be taken in order to avoid gall bladder rupture and the subsequent peritoneal spread of the tumour. For this reason, laparoscopic resection of gall bladder cancer was rarely reported\textsuperscript{42}. The robotic approach is potentially advantageous over laparoscopy given its ability to dissect in narrow spaces when skel- etonising the hepatoduodenal liga- ment, celiac and hepatic arteries and in the removal of lymph nodes close to the pancreas\textsuperscript{42}. Given the scarcity of cases performed, however, further evaluation and comparison with laparotomy is required to justify the continued role of robotics in gall bladder cancer\textsuperscript{42}.

Clearly, opinions vary about RAS’s true value in the field, especially in cholecystectomy. With so many variables at play—cost, complication rates, length of stay, operative time, utility in oncological and radiologic procedures—the role of robotic-assisted cholecystectomy in surgery remains unclear. Yet, improved technology on the horizon as well as newer competing robotic models may help settle the argument once and for all.

Conclusion
Robotic-assisted cholecystectomy is a safe and feasible procedure, even in a community hospital setting, based on current preliminary work done both in Europe and in the United States. However, the current published literature, recommends further prospective controlled trials to evaluate further benefits to patients over the standard laparoscopic techniques. Robotic-assisted cholecystectomy is comparable to laparoscopic approach, in terms of conversion to open and complication rates. However, single-port robotic-assisted cholecystectomy appears to be more promising than single-port laparoscopic cholecystectomy in terms of safety, ease to perform and conversion rates. While cost of the robotic system is still the main drawback of robotic cholecystectomy, institutions that utilised robotics for other complicated procedures found

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the cost to be reasonable. Other institutions demonstrated that the cost of disposable instruments for robotic-assisted cholecystectomy is also comparable to that of laparoscopy. Furthermore, its cost is expected to be driven down in the future with the expansion of the market. The use of robotics in radical gall bladder resection is another candidate for future research work.

Abbreviations list

BMI, body mass index; FDA, US Food and Drug Administration; NIS, Nationwide Inpatient Sample; RAS, robotic-assisted surgery.

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