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The History of Robotics in Surgical Specialties

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Introduction

A major positive step in the field of surgery was made when a robot was first used in the theater of surgery about 25 years ago. The robot was a PUMA 200 (Westinghouse Electric, Pittsburgh, PA) which was used for needle placement in a CT-guided brain biopsy¹. Since then it has been exciting to see that the field of robotic surgery grow in leaps and bounds. Part of the reason for this is the plethora of benefits afforded by robotics that are simply absent in traditional surgical methods. For example, robots offer stability, accuracy, integration with modern imaging technology, greater range of motion, telesurgery, in addition to multiple other benefits inherent to individual surgical specialties². Since the introduction of robotic surgery, many advances have been made in the field. In order to fully utilize the potential of the surgical robot it is important to understand the past in order to build towards the future. In order to understand the past, it is important to look at both the advances and achievements of robotic surgery in the various fields of surgery such as otolaryngological, neurosurgery, gynecological, cardiothoracic, gastric, urologic, orthopedic, endoscopy, and miniature after which the future developments that are on the horizon can be evaluated. This article will enumerate major milestones and will continue with limitations in subsequent articles.

Engineering

While robots have been in existence for a long while now, their entrance into the realm of medicine is relatively novel. In the 1980s the field became popular as a way to do minimally invasive surgery. While laparoscopy already was seeing widespread use, the actions that

could be done were relatively limited compared to the believed potential of robotic surgery at that time. Also, around that time, the Ames Research Center of NASA started working on the concept of telepresence in surgery. They were joined by Stanford in the 1990s which lead to the development of a technologically advanced telemanipulator. This served as the building block for future systems. In 1994, AESOP (Computer Motion, Inc., Goleta, CA) was FDA approved. AESOP combined a telemanipulator with a foot pedal. Later on, the foot pedal was replaced by voice-control. At that time, however, the functionality was limited. The major benefit it offered was stability in that it offered a steady view of the operating field and eliminated the problems caused by fatigue and inexperience of the scope holder.^{3,4} Therefore, it was seen at times to be a valid substitute to a human scope holder, but the potential for significant clinical benefit was not seen at that time.⁵

However, the technological advancements made with AESOP were not abandoned and further progress was made. Eventually, all the progress was combined into a telemanipulator system ZEUS (Computer Motion, Inc., Goleta, CA) has two separate hubs: the patient side and the surgeon side. The surgeon side is designed to control the patient's side. The patient side was the one that actually did the procedure. It had two arms that were controlled by the surgeon's manipulation on the surgeon's side, and one arm that was designed to hold the camera which was voice controlled. The two robotic arms were fitted with interchangeable instruments. It was designed as a cardiothoracic surgical tool for internal mammary artery takedown, but the feasibility of its use for other uses and other surgical subspecialties was recognized. It received FDA approval for limited uses in 2001.⁴

Around that same time, the daVinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA) was first introduced. This system offers the surgeon 7 degrees to freedom allowing the robotic arm to replicating exactly what the human arm could do. It consisted of the surgeon's console, the patient's "trolley" (the robot itself), and the imaging system (allowing the view of the image captured by the camera). Initially, the robot was built with two robotic operating arms and one camera holder. The initial two operating arm system became available in Europe in 1999 and received FDA approval for use in the US in 2000.⁶ A newer system that contained 3 operating arms but was identical in other ways to the initial system was FDA approved in December 2002.⁷ In 2006, another model was introduced with the added benefit of better handling and increased range of motion of the arms allowing for a bigger surgical field. The latest model, released in April 2009 upgraded the imaging system to HD and also allowed for a second surgeon's console which allows for the training of a less experienced surgeon. The company is currently working on a new type of instrument called VeSPA which are inserted through curved trocars which prevents collisions and are intended to extend the indications for single incision surgery.⁸ The daVinci has become one of the most ubiquitous and recognized systems throughout the world in the robotic surgery era.

In October 2001, the CyberKnife radio-surgical robotic system (Accuray, Madison, WI) received FDA approval and it is useful for the radiation therapy of cancers, tumors, and other lesions. The army designed the RAVEN in 2005 and it serves as a foundation for further research and development into the field of robotic surgery. In February of 2001, it became possible for global collaboration of one surgeon with another via the SOCRATES

system (Computer Motion, Inc., Santa Barbara, CA). The SOCRATES system is a telecollaboration system that allows for a surgeon from a remote operating station to control the robotic arm, view real time video input from the site of surgery, and obtain real time audio communication from the location of the surgery. One study looked at six cases (three craniotomies for brain tumors, one craniotomy for AV malformation, a carotid endarterectomy, and a lumbar laminectomy) where this technology was used. The study showed that there were no surgical complications from its use and that surgeons found that the information the system provided was indispensable during the surgery.⁹ The MIROSURGE robotic system developed in 2009 is currently just a prototype undergoing limited testing, but is envisioned to take operative imaging during cases to a new level and will be able to take into account and make adjustments for the heart beat allowing for beating heart surgery¹⁰.

Otolaryngological surgery

With advances in robotic surgery, it is now possible to complete more complex surgical tasks using robotics. This made the application of robotic surgery to the field of ENT surgery not only possible, but better than other options. In general, head and neck procedures that are usually done by ENTs require significant dissection that has to be done through large incisions which can lead to significant collateral tissue damage, impaired functionality, and reduction in quality of life.¹¹ Endoscopy offers a solution to several of these problems, but presents with some unique problems of its own. For example, the surgical field is limited to “line of sight”, the instruments are severely impaired in mobility, the scale increases the consequences of physiological tremors, and dexterity is compromised.¹² The benefits afforded by robotic surgery overcome several of these problems.^{13,14}

Currently, the only FDA-approved robotic surgical system for head and neck surgery is the da Vinci.¹⁵ In 2005 a surgical technique was documented in canine and cadaveric models called transoral robotic surgery (TORS).¹⁶ In 2006, three patients underwent robotic resection of the tongue based using the TORS technique. The benefit was shown to be more clear visualization of cranial nerves IX and XII, the lingual nerves, and the lingual artery. Also, the group that developed the TORS technique also did a study of 27 patients undergoing robotic tonsillectomy for squamous cell carcinoma. The technique allowed meticulous dissection to negative margins in 25 of the patients, and retained ability to swallow postoperatively in 26 of the patients¹⁷. A prospective study with 57 patients with t1-t3 tonsillar cancer comparing the TORS method to conventional surgery found that the TORS method did not offer any significant improvement in survival rate. However, there was a significantly higher rate of margin negativity, faster recovery to normal swallowing, and shorter hospital stays¹⁸. In terms of oropharyngeal squamous cell carcinoma, a prospective study of 81 patients showed that the patients that received surgery using the TORS protocol had a significantly higher quality of life at 1 year post-operatively as measured by the Head and Neck Cancer Inventory compared to patients that received the standard approach¹⁹. Also there is a randomized control trial comparing radiotherapy to the TORS protocol in terms of patient quality of life post-treatment that is currently in progress.²⁰ One of the major benefits of the TORS is faster operating times. While the robot

does have a learning curve associated to familiarize with it, and according to one study it reduces average operating times by almost half²¹. The other important outcome to consider is blood loss which is less with this technique. All of this occurs without causing a negative impact in survival.¹⁵

Robotic surgery has also been used in thyroidectomies. The technique that is used was first described in a 2005 case report of a hemithyroidectomy.²² It involves a transaxillary approach with electrocautery-assisted tunneling through the pectoralis major and clavicle. The robotic dissection uses the nonvascularized area near the sternocleidomastoid muscle branches and below the infrahyoid muscles. In a study of 100 patients that underwent this procedure for thyroid cancer, it was reported that this led to fewer complications but that operative times were higher.²³ This procedure was also found to be associated with lower post-operative discomfort and a better cosmetic outcome in a study of 84 patients that either received open or robotic thyroidectomies.²⁴

Neurosurgery

Around the time that robotics was starting to be used in the operating room, neurosurgery was hitting a ceiling of sorts. They were approaching the limits of human dexterity. While there were phenomenal technological developments in the field, human hands simply could not complete procedures at that microscopic scale. Also, in order to involve human hands, it took major incisions and often an open skull surgery. Therefore, neurosurgery was one of the first fields where robotic surgery was used and it allowed surgeons to surpass the limits of human dexterity and work at the microscopic scale.

An example where the microscopic accuracy of the robot would be very beneficial is the resection of a brain tumor. It is a painstakingly long and difficult procedure. Part of what makes it so difficult is the goal of complete removal coupled with the goal of preservation of the maximal amount of salvageable neurological function. A study showed that the 5 year survival rate after removal of a malignant glioma is 40% after complete removal, but with 95% removal it falls to 22%. With less than 95% removal, the rate is a dismal 10–15%²⁵. Therefore, the importance of optimal resection cannot be understated and being able to work at the microscopic scale with robotics and intelligent surgical tools allows for better outcomes²⁶.

In 1985, the PUMA, a robot that was formerly used for industrial tasks, was used for the positioning of a biopsy cannula. At that time, the robot was only used to hold the biopsy cannula and as a stable platform off which the tool could be used.¹ Development on the NeuroMate image-guided robotic surgical system (Integrated Surgical Systems, Inc., Davis, CA), the first commercially available neurosurgery robot was started in 1987. This device was FDA approved and was used for preoperative imaging in order to position the robot and plan the procedure. This system was used in more than one thousand cases.²⁷ After the PUMA and the NeuroMate, the Minerva (University of Lausanne, Lausanne, Switzerland) was developed in 1991. The Minerva was the first system of its kind to not rely on pre-operative imaging, and instead use real time image-guidance. This allowed for better positioning of surgical tools and compensation with subtle brain shifts. The major

limitations of the Minerva system were that the patient had to remain inside a CT scanner and the robot could only work in one dimension.²⁸

The Robot-Assisted Microsurgery System (NASA, Washington D.C.) developed in 1995 was a major step forward for robotics in neurosurgery. It did not rely on CT scanning for real-time imaging, but instead allowed for the use of MRI. This was beneficial because the brain is best seen with MRI since it allows for the visualization of anatomical details in soft tissue. Also, this system allowed for 6-directional motion control and lead to an increase in surgical dexterity. It had integrated tremor filters and motion scalers which decreased the error rate and increased the microscopic accuracy of neurosurgeons.²⁹ The successor to this system was the NeuRobot (Shinshu University School of Medicine, Matsumoto, Japan) which utilized a 10mm endoscopic port with twin tissue forceps, light, and a laser. This allowed for greater accuracy in manipulation with decreased need for invasive procedures.³⁰

While the field of robotic surgery in relation to applications to neurosurgery has grown significantly, there are still some limitations present and there is still room for improvement. The speed of the robotic movements is currently much slower than that of the human hand and the sense of touch is for the most part lacking. Current technological developments are focused on decreased invasiveness, increased access to deeper neural structures, and increased tactile feedback to the operator.

Gynecological Surgery

The history of robotic gynecological surgery is relatively brief. In 1998 a study was published evaluating the feasibility of using the ZEUS system for tubal reanastomoses of the in six pigs. The study found that there were no complications and four weeks after the operations eight of the twelve tubes were patent. This led to the conclusion that robotic surgery allowed for a higher rate of patency due to allowing for more precise movements.³¹ The next step evaluated the outcomes of the procedure when performed on humans. Out of the nineteen tubes reanastomosed, seventeen were patent postoperatively as proven by hysterosalpingography, and five of the ten women had conceived children within one year postoperatively.³² While the benefits in clinical outcomes were modest and cost was higher compared to the traditional approach, this was the spark needed for future research. In 2000 a follow up trial was done using the daVinci system and it found 9 of 10 tubes were patent based on hysterosalpingogram.³³

In 2002 a trial examined the efficacy of using the daVinci robotic system for a more complicated gynecological surgery: the hysterectomy with bilateral salpingo-oophorectomy. This study demonstrated the use of robotic-assistance was superior to conventional means because it allowed for a better picture of the operative field, better manipulation, and easier dissection.³⁴ In 2004 a study was published that studied 36 cases of robotic myomectomy. The main benefit offered by robotic myomectomy is that many surgeons are not comfortable with the laparoscopic approach and thus tend to do the surgery with an open approach. However, the robot offers a high level of hand dexterity which provides the surgeon the tools to do a more detailed surgery offering an alternative to the open approach³⁵. Recently

there has been some case reports published in regards use of robotic surgery for endometriosis.

Cardiothoracic Surgery

The use of robotics in cardiothoracic surgery started a bit later than in other fields, but this field is the source of the most literature regarding robotic surgery.³⁶ There are many procedures in the field of cardiothoracic surgery that can now be done with robotics. Robotics has allowed surgeons to forgo median sternotomy and instead rely on small incisions. This reduces patient trauma and morbidity and decreases recovery time.³⁷

The initial cases are documented in Europe where they had cardiac procedures that are part of coronary artery bypass grafting of increasing complexity done by the same surgeon using the ZEUS system. For the first twelve cases the robot was used solely for internal thoracic artery harvesting starting in 2002. In the next group of patients the ZEUS system was utilized to complete 17 coronary artery anastomoses on arrested hearts in 13 patients. The same procedure (coronary artery anastomosis) was then done on beating hearts in six patients. These patients did have a median sternotomy. Finally, the final eight patients in the group underwent endoscopic CABG surgery without cardiac bypass. Of these, one patient had to be converted to an open approach. Through this stepwise introduction, the success rate of the procedures, despite the increasing complexity remained high.³⁸

In 1998, the Food and Drug Administration approved a single center trial to evaluate the efficacy of robotic surgical systems for endoscopic coronary artery bypass surgery. At Pennsylvania State University Dr. Damiano performed robot-assisted anastomosis of the left internal thoracic artery to the left anterior descending artery in nineteen patients. At post-operative follow-up all vessels remained patent and there were no complications. In fact, none of the grafts had greater than 50% stenosis and all the patients were classified as Class I on the New York Heart Association scale.^{39,40}

In Canada, Dr. Boyd was at the forefront of the use of robotics in cardiothoracic surgery. Initially, the AESOP system was used along with a limited sternotomy in order to take down the internal thoracic artery.⁴¹ Then the harmonic scapel (Ethicon Endo-Surgery, Cincinnati, OH) was attached to the ZEUS system to harvest the internal thoracic artery in 19 patients.⁴² He eventually performed the first case of a closed-chest, totally endoscopic beating-heart CABG was done by Dr. Boyd in 1999 using the ZEUS system.

The daVinci system was used on 131 patients undergoing CABG in a similar stepwise fashion (1998–2000) as compared to the ZEUS system. It was initially used only for LIMA takedown. Then it was used for anastomoses on arrested heart and finally for anastomoses on a beating heart. Regardless of the system, these procedures showed no difference in ICU stay, hospital stay, or ventilation requirements when compared to the conventional CABG cohort. In June 1998, the daVinci was used to perform the first total endoscopic CABG. In 2004, a new type of technology was used to create an anastomosis which represented a major step forward in beating heart, minimally-invasive CABG surgery. The EndoMVP (Ventrica, Inc., Fremont, CA) is a tool used in robotic surgery that when used can create a self-sealing connection between two blood vessels.⁴³

Another type of procedure that can be done robotically in the field of cardiothoracic surgery is mitral valve surgery. Initially, these procedures were done with smaller incisions without sternotomy, but under direct visualization. One way the view was improved was by removing the tubing for the bypass machine from the thoracic incision and moving it to the femoral vessels. This was possible through the Heartport technology (Redwood City, CA).⁴⁴ This allows for a minimally invasive surgery without the need for a median sternotomy. Between 1996 and 2001 a study of 449 patients with robotic mitral valve surgery was done. Of these patients 327 cases required mitral valve repair, and 122 cases required mitral valve replacement. During the study, the protocol for the surgery was changed due to the high rate of intraoperative problems that were occurring. In 366 of the cases, the AESOP system was used for direct visualization. However, in 23 cases the daVinci system, was used for the complete procedure.⁴⁵ Even in the cases where the AESOP was used for direct visualization, there was a significant reduction in mortality and morbidity.^{46,47} However, even with the high complication rate in the beginning only 9 patients had a failed repair and all of the failures occurred in the first 80 patients which suggests that experience does make a difference for the surgeons doing the procedure. Overall, patients were more satisfied with the minimally invasive procedure, had less pain, and were able to return to normal activity quicker.⁴⁸

In addition, robotic surgery has been used for repair of the atrial septum defect. This type of surgery has not been done robotically many times. In Italy, the daVinci system was used for this purpose in seven patients whose hearts were stopped. The heart was then opened and the defect was sutured shut using either interrupted (one case) or continuous suture (six cases). There were no complications and at one month post-operative all the repairs were intact.⁴⁹

Gastrointestinal Surgery

There are many robotic diagnostic and therapeutic tools available when it comes to the GI tract. The area of most growth in the realm of diagnostic robotics is the capsule that is currently used in the clinical setting as an alternate to colonoscopy. With all the advances in the field of gastroenterology, there are still parts of the GI tract that are difficult to visualize with conventional methods. Add to this, patient's fear and hesitation in regards to flex endoscopy. This is the niche that wireless capsule endoscopy helps to fill. Capsule endoscopy is becoming more technologically advanced in terms of the tools that it contains and the information it can provide. It can capture thousands of images over the course of its passage through the gastrointestinal tract. It greatly reduces the pain and discomfort a patient might feel during the procedure.⁵⁰

The first capsule able to capture images in the small intestine that could be swallowed was introduced in 2000 under the name M2A (Given Imaging Ltd., Yoqneam, Israel) and took 2 images a second. This device was FDA approved in 2003. The PillCam ESO (Ethicon Endo-Surgery Inc., Cincinnati, OH) features two cameras and captures 14 images a second leading to greater clarity and detail. The first trial of this device was in 2004 on patients that had GERD. In 2005 the EndoCapsule (Olympus Corporation, Tokyo, Japan) was developed that included auto brightness control and real-time image viewing capabilities, but takes only 2 images a second. In 2006 SmartPill developed a capsule called the SmartPill (Buffalo, NY)

that monitored the pH, temperature, and pressure present in the GI tract^{51,52}. Next generation capsules will be taking biopsies real time with images to make endoscopy more pleasant.

The adaptation of therapeutic robotic surgery to the field of GI surgery is also starting to become more prevalent. There are case reports of several types of GI surgeries being done using either the daVinci or ZEUS robotic surgical suites. One such surgery is gastrectomy for gastric cancer. Until now, the aspect that limited the utilization of robotics for this procedure was the complexity of the D2 lymph node dissection. There is the potential for robotic surgery with future innovations coupled with increased operator expertise that could potentially allowed for a greater degree of standardization than available with laparoscopy. The accuracy of the current robotic systems allows for dissection in congested abdominal cavity and cases where the lymphatics and vasculature are very close together. This type of surgery, when compared to open or laparoscopic methods, results in similar outcomes, but significantly lower amounts of blood loss. Based on studies it is suggested that the technological benefits of robotic surgery are resulting in improved clinical outcomes⁵³. The list of gastrointestinal organs operated with the robot range from stomach, liver, gall bladder, pancreas, small bowel, adrenal, colon and others.

One type of GI surgery that is done is the silicon-gastric banding as a treatment for obesity. In 1999, the first use of robotic surgery in order to do this procedure was documented. The procedure took a total of 90 minutes to complete and there were no complications.⁵⁴ Robotic surgery is appealing for this area because compared to an open surgical approach, laparoscopic approach yields better outcomes, but laparoscopy is significantly more difficult due to the patient's body habitus and less surgeon fatigue.³⁶ In 2003 there was a multi-institutional series of 107 patients that underwent robot-assisted gastric bypass surgery. The study found the outcome to be excellent with no post-operative leaks or anastomotic failure. This study found robotic surgery to be superior in comparison to traditional means because hand-sewing the gastrojejunostomy by hand using the robot is much easier, smaller gastric pouches are possible due to lack of intraluminal stapler, and the obvious advantages afforded in regards to the thicker abdominal wall.⁵⁵

Another type of surgery is the Nissen fundoplication. There was a case series reported in 1999 consisting of two patients. The two patients did not experience any complications and their recovery was uneventful. This study proved that this type of procedure was feasible to do with robot-assistance. In 2001, the same surgeon participated in a prospective randomized trial with 21 participants: 11 treated with conventional methods, and 10 treated robotically. While the robotic group had a significantly longer intraoperative time, other outcomes such as blood loss and length of stay were not significantly different between the groups. Therefore, it was concluded that while it was feasible, at the time of the study there was no clear clinical benefit to robotic Nissen fundoplication.⁵⁶ In 2002 another study looked at 40 consecutive, non-randomized patients. The results were almost identical to the 2001 study, but the author remarked that current level of robotic surgical expertise may be a huge confounding factor to the results.⁵⁷

Urologic surgery

The benefits of minimally invasive surgery coupled with the benefits of robotic surgery make it amenable to being tried and adapted by other fields. One such field is urological surgery because of the depth of pelvis makes it harder to access and also because the structures that are significant in the field are very small.⁵⁸ This is the main limitation to the use of traditional laparoscopy as guiding the instruments into the desired location is a challenging feat. The first robot-assisted prostatectomy was done in 2000. The daVinci was approved for this type of surgery in 2001, before that vast majority of the procedures were done open.⁵⁹ There was a prospective, nonrandomized trial of robotic radical cystoprostatectomies, and the robot group had similar operative times (160 minutes vs. 163 minutes), significantly decreased blood loss (153mL vs. 910mL), shorter post-operative catheterization times (7 days vs. 14 days), quicker return to urinary continence (44 days vs. 160 days), faster mean return time of erection (180 days vs. 440 days). In addition the complication rate was lower in the robotic group (5% vs. 20%).⁶⁰

Robotic surgical systems have been used successfully in nephrectomies and adrenalectomies.⁶¹ It was first documented as a case report in a paper in 2001 where a 77 year old female underwent a nephrectomy for a non-functioning hydronephrotic kidney. This study showed it was possible to use robotics to surgically remove a kidney.⁶²

The adaptation of robotics to the field of urology made the treatment for uteropelvic junction obstruction less invasive⁶³. Between June 2001 and February 2002, 9 patients underwent an Anderson-Hynes dismembered pyeloplasty using the daVinci robotic system. The study found that it was feasible to do the procedure robotically and this resulted in favorable operative times, complication rates, and success rates.⁶⁴ A paper in 2013 looked at robotic assisted radical prostatectomy. The preferred method of approach was the transperitoneal, retrograde approach which allowed for athermal dissection of the neurovasculature and necessitated minimal dissection at the neck of the bladder. This study showed lower in-hospital mortality, complication rates, and need for transfusions. Also the time needed in hospital for recovery was lower, but procedure cost for the robotic surgery was higher than for laparoscopic or open approach⁶⁵.

Orthopedic surgery

ROBODOC surgical system (Integrated Surgical Systems, Inc., Sacramento, CA) in 1992 was utilized to craft precise fittings in the femur to accommodate fittings for hip replacements. In 2002, computer placement of the acetabular socket versus manual alignment was compared and it was found that the robotic approach offered far greater accuracy.⁶⁶ One robotic system that proved successful was the Acrobot (Imperial College, London, UK) which underwent the first series of clinical trials in 2002 where it did a series of 7 total knee replacements. After that, in 2004, there was a randomized, double-blinded study between the Acrobot and conventional knee replacement that showed that the robotic system allowed for consistent and accurate placement of the prosthetic implant that simply was not present in the conventional method. All 13 of the robotic knees were within 2 degrees of the desired orientation whereas only 6 of 15 of the conventional knee

replacements were within this degree of accuracy⁶⁷. Historically the clinical and radiological outcomes of orthopedic surgery have improved over time and this has led to an increased utilization⁶⁸.

Another avenue where robotics has been useful in the field is precision fracture repositioning. Conventional approach was to drive pins into ends of the bone and then manipulate then into position, often under great force and then attach them to an external fixator. The robotic approach allows for greater accuracy in positioning and allows for greater control of the ends of the bone. In 1998, use of FRACAS which also for computer guided fracture fixation was documented.⁶⁹

Microsurgery

One of the major benefits of robotic surgery is the scale that it can be done at. There is a limit to the scope of actions of a human hand and actions involving smaller movements simply cannot be done. Robotic surgery and the development of PUMA, AESOP, and ZEUS are all part of the timeline of miniature robotic surgery. Between 1997–2002, Johns Hopkins developed a system through which a specific calyx of the kidney can be operated upon. The accuracy of this system was lacking with 83% on a porcine model and 50% in live animal trials due to constant movements and needle deflection. Once the daVinci surgical suite was developed, the 3D immersion technology along with the 7 degrees of freedom allowed for more accurate miniature surgeries. The newest model of the daVinci suite offers HD visualization with greater magnification powers which allows greater range of motion and positional capabilities. Some of the procedures that are now available that in the past were not possible are vasectomy reversals, sub-inguinal removal of a varicocele, and removal of innervations of the spermatic cord. In fact during a case involving deinnervation of the spermatic cord, there was damage to the testicular artery. Using microsurgery the artery was repaired and no testicular atrophy was noted at 6 months post-op. Now there is even a probe that allows for 100x magnification which allows for greater visual prowess.⁷⁰

Future of Robotic Surgery

Robotic surgery is a popular topic in today's patient and physician community, since it seems that every day it is being used for a different indication than before, or there is a new type of robotic surgery. For example, recently the University of Illinois started to use robotic surgery to treat head and neck cancers by using a transoral surgical approach.⁷¹ While the present is certainly interesting, it is the future of robotic surgery that is truly exciting. Currently, the feasibility of using a robotic surgeon to do tele-surgery (the surgeon is in a whole different location than the patient) is being evaluated. Another area of research and development is shrinking the robot or manipulators used. There are many applications to smaller surgical robots/manipulators. One example is a robotic cardiac catheter that is being developed that will allow a physician to place it more precisely and have more control of the catheter once it is placed. At its extreme, nanorobots small enough to enter the blood stream and then identify and then deal with diseased cells. Also, robotic systems are being developed that allow surgery to be done through microscopic incisions. The current

application being envisioned is in neurosurgery where the size of incision is directly correlated to amount of brain tissue lost⁷².

One major limitation to robotic surgery is the lack of tactile feedback. Surgeons are dependent on haptic feedback, but robotic systems do not allow for the feeling of temperature, pressure, tension, and vibrations. The newest robotic models that are currently in development are trying to address this problem by providing the surgeon continuous, real-time sensory feedback.⁷³

Another avenue of growth in the field of robotic surgery is tele-surgery where the surgeon is not in the same location or even in the vicinity of the patient being operated on. In 2001, using the ZEUS system, a surgeon in New York City was able to successfully complete a robot-assisted laparoscopic cholecystectomy on a patient in Paris, France.⁷⁴ Currently, the daVinci system theoretically does allow for teleoperation, but the communication relay that the system uses is short-distance (same room). There have been trials using modified daVinci consoles to do teleoperations on non-human subjects. One study attempted to perform 4 right nephrectomies on porcine models using a daVinci system where the attending surgeons were either 1300 or 2400 miles away from the “patient.” It showed that while it was feasible the distance and the latency time between action and reaction posed a significant challenge to the surgeon and caused inferior outcomes.⁷⁵ Another study was done using the daVinci system, but instead of public internet, relied on Bell Canada’s Core Network which is a significantly faster internet connection. The robot was used to complete porcine pyeloplasties. Results showed that even with the latency period and delay in action-reaction, robotic surgery over a distance was feasible and the procedures were completed successfully.⁷⁶

Currently, the robot is dependent completely on human control. Attempts are being made to be able to program the robot. In the short term the goal is to be able to program areas based on imaging which are danger areas that the robot would not allow to be infringed. This would help prevent some surgeon error. Also, attempts are being made to shrink the scale and allow for even better microsuturing to eventually allow for suturing below the limits of human eyesight. In the long term time frame, adding an AI component to robotic surgery is envisioned.⁷⁷ Maybe in the future, surgeons will just have to identify the two boundaries of an organ or location of interest, and the robotic system will automatically suture and tie the two together.

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