ROBOTIC SURGERY

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INTRODUCTION

Robots are commonly used for automobile assembly, and drug screening and program data analysis by the pharmaceutical companies. When compared to human beings, surgical robots are more reliable, provide greater precision, and have better three dimensional spatial accuracy. Successful applications of robots in neurosurgery and orthopedic surgery have encouraged research investigations in other disciplines of medicine. [1,2,3]

Currently, four types of robots are mainly utilized in medicine: (a) neurosurgical navigation to localize intracranial tumors, (b) precise placement of total hip prosthesis by orthopedic surgeons, (c) intraoperative maneuvering of the laparoscope using the AESOP robotic arm, more recently, (d) endoscopic coronary artery bypass surgery. Also, in conjunction with current telecommunication technologies, surgical teleconsulting, teleassistance, and telemanipulation have been investigated to facilitate higher learning, information exchange, and to deliver surgical expertise.

Herein, after a brief historical review, we discuss the recent advances in robotic research and preliminary clinical applications. In addition to applications of robotic technology across various surgical subspecialities, the emerging urologic literature in this regard is reviewed. Finally, the future of robotic surgery in the modern era will be discussed.

VARIOUS CURRENT AVAILABLE ROBOTS

Currently available telemanipulator systems are ARTEMIS [4] (Advanced Robotic Telemanipulator for Minimally Invasive Surgery), Green Telemanipulator Surgical System [5] (SRI International, Inc, Menlo Park, CA), da Vinci™ Surgical System [6] (Intuitive Surgical, Inc., Mountain View, CA), AESOP [7] (Automated Endoscope System for Optimal Positioning, Computer Motion, Goleta, CA) and Zeus™ Microsurgical Robotic System [8] (Computer Motion, Goleta, CA).

ARTEMIS (Advanced Robotic Telemanipulator for Minimally Invasive Sugery) is a first prototype of an endoscopic manipulator system that was developed in 1995 in Germany for the minimally invasive abdominal surgery.[9] This system incorporates robotic technology using " master-slave manipulators" and has two main components: the surgeon console with endoscopic monitors (master) and the instruments station (slave). Using computer communication software, two master devices at the surgeon console control two slave arms which are placed at the O.R. table. Two slave arms with steerable instruments are capable of 6 degree-of-freedom (DOF) of motion. In addition, surgeon's view is afforded by an endoscopic 3D monitor as well as two additional monitors to display views of the two slave arms and various system data.

Green Telemanipulator Surgical System (SRI International, Menlo Park, CA) is a prototype, four DOF remote-control telesurgical system that was developed in 1995 by Green and associates as a Pentagon-funded project which was initially designed to perform the surgery at the battle field without risking the surgeon.[5] The system consists of a surgeon's console, an electronic control module, and a remote patient unit. A high resolution stereoscopic video image is displayed on a mirror surface and the surgeon controls conventional instrument handles attached to servocontrolled motors located under the mirror. The remote site is connected by coaxial cables, and has identical robotic manipulators fitted with interchangeable surgical instruments. The system is equipped with visual, auditory, and haptic feedbacks.

The daVinci ™ Surgical System (Intuitive Surgical, Inc., Mountain View, CA) is a spin off of the prototype Green Telemanipulator Surgical System from SRI International.[6] This system was further modified and refined for nonmilitary applications by Intuitive Surgical. The da Vinci ™ Surgical System consists of two primary components: the surgeon's viewing (3-D visualization) and control console and the surgical arm unit that holds and manipulates the detachable surgical instruments.

One arm holds an endoscope and the other two hold a variety of "Endowrist" instruments. Endowrist (tiny computer enhanced mechnical wrists) instruments provides the dexterity of the surgeon's hand and wrist at the operative site through 1 cm ports. The system incorporates a six-degree of freedom with additional seventh-degree of freedom at the instrument tip. Also, Intuitive's "motion-scaling" software allows surgical precision and fine motor control by scaling hand movements and eliminating natural hand tremors.

AESOP (Automated Endoscope System for Optimal Positioning, Computer Motion, Goleta, CA), the first robotic enhancement technology system introduced in 1994, is a six-degree of freedom robot capable of maneuvering and positioning the laparoscope under the direct control of a surgeon. [7] AESOP incorporates Computer Motion's speech recognition technology, allowing surgeons to directly control the robot using simple verbal commands. The device consists of a "read-only memory" computer, a robotic arm that is attacheds to the O.R. table holding a camera, and an interface for manipulation consisting of either a hand control or a foot control. AESOP incorporates two important safety features. To protect the patient from erroneous lateral movements of the laparoscope, the fourth and fifth joints are passive. Also, to prevent excessive torque on the laparoscope, an instrument coupling device is designed to release the laparoscope if the force of greater than 5 lbs are applied.

Zeus™ Microsurgical Robotic System (Computer Motion, Goleta, CA) was developed initially from a NASA space project in which prototype was designed to remotely repair space station out in the space. The system has three major components: three interactive robotic arms, an ergonomically enhanced surgeon console and a dedicated computer controller. [8] This system incorporates activated robotic force-feedback and automated speech recognition technologies. One robotic arm (AESOP) holds an endoscope and is controlled by the remote surgeon's voice commands. The other two arms manipulates a variety of custom-built, purpose-designed laparoscopic instruments under direct surgeon's control. Surgeon is seated at a mobile, ergonomically correct console that incorporates a high resolution video monitor and has two attached robotic handles. Activation of robotic handles is initiated by stepping on a foot pedal, a built-in, fail-safe feature to prevent untoward movement of the instruments. Surgeon's hand movements are controlled by handles that resemble conventional surgical instruments. Using computer controller, the movement of the instrument handles are precisely interpreted, filtered, downscaled and translated by electromechanical interface to the robotic arms and instruments. A fail-safe system is incorporated by the computer controller which continuously monitors each movable joint of the robotic system to prevent inadvertent movement of the instruments.

CURRENT SURGICAL APPLICATIONS

Success of neurosurgery and orthopedic surgery research have recently paved ways to develop surgical robots in cardiac surgery, urology and other fields of medicine. In neurosurgery, robotic technology was applied to improve surgical accuracy and spatial registration in three main areas: neurosurgical navigation, stereotactic surgery, and robotic assistants. [10,11] Puma 200 robot was used to hold and manipulate surgical retractor in the resection of thalamic astrocytomas in six children. [12]

The Lausanne Research Group developed a new robot " Minerva", which utilizes real-time CT scan data to designate corresponding coordinates to perform stereotactic procedures, such as a tissue biopsy, an aspiration, stimulation, electrode implantation or other procedures. [13]

In orthopedic surgery, robots known as "The RoboDoc Surgical Assistant System (Intgrated Surgical Systems, Inc, Sacramento, CA) were utilized to precisely execute the femoral canal for the placement of cementless total hip prosthesis. [14] Conventional reaming allows only 18-20% of prosthetic surface to contact with the bone. The robot can provide the accuracy of less than 0.4 mm which gives about 90% surface contact. In a controlled, randomized US study with 136 hip replacements (65 ROBODOC and 62 control), no differences were found in the Harris hip scores (79.9 for ROBODOC group and 80.3 for the control) or the Short Form Health Survey outcomes questionnaire.[15] Hospital stay was similar (8.2 days for the ROBODOC group versus 7.5 days for the control group), but surgical time (258 minutes for the ROBODOC group versus 134 minutes for the control group, $p<.0001$) and blood loss (1189 cc for the ROBODOC group versus 644 cc for the control group, $p<.0001$) were surgical time was longer & blood loss in the ROBODOC group.

In general surgery, the ARTEMIS was initially tested to perform remote telepresent laparoscopic cholecystectomy in a phantom model while master and slave sites were 1.3 km apart linked by a fiber-optic cable. After initial system and safety evaluation, the system was employed to perform mobilization of the sigmoid colon and ligation of sigmoid vessels for laparoscopic sigmoidectomy in a porcine model.[15] The surgeon performed the surgery while sitting few feet away from slave robot. This system is designed as an integrated teleoperation and telepresence system for planning, training and performing different minimally invasive surgical procedures. However, it was learned that changes in the flexible tip section were necessary as well as further improvements in the area of slave mechanics and the control system before clinical application. In the latest publication, the ARTEMIS has been undergoing reevaluation for the application in minimally invasive cardiac surgery. [16]

Another group from France in May 1998 reported two Nissen fundoplications by using remote robotic technique, the Mona robot (Intuitive Surgical, Mountain View, CA). [17] Mona robot is an earlier experimental version of da Vinci™ Surgical System. Robotic system was placed about 3 meters away from the patient and the surgeon operated while sitting at a console. The Mona device utilizes 3 robotic arms, surgeon console with a 3D monitor, and a computer controller. Surgeon's operative maneuvers were processed in computer signals, relayed by a 5 m long cable and translated into articulated robotic arms at the operative site. Computer allowed to scale down the amplitude of motion by a factor of 1 to 3 or 1 to 5. Operating time was 4 ½ hours, and 1 ½ hours, and blood loss was minimal in these two patients. The patients were discharged the first postoperative day without any complications.

In the obese patient, freedom of the trocar movement and instrumentation during laparoscopy can become significantly restricted due to the thick layers of abdominal fat. Same group in 1999 evaluated Mona robot to demonstrate the advantages of robotic surgery in a morbid obese patient.[18] Laparoscopic gastric banding procedure (adjustable silicon gastric banding) was successfully performed remotely at a distance from the patient. Articulation near the tip of the instruments allowed greater degree of freedom which perfectly translated the surgeon's wrist movement through computer interface even in an obese patient. Operative time was about 90 minutes, blood loss was minimal and the patient was discharged on the second postoperative day.

Also, another group from France in late 1999 reported the world's first laparoscopic cholecystectomy using Zeus Robotic Surgical System. [19] Two surgeries were performed as a part of European study to assess the feasibility of using a computer-enhanced technology in the abdominal surgery.

While most centers and researchers were investigating surgical robotic technologies in macrorobotics, few others were developing new applications using miniature robots. A new concept of colonoscopy was reported by Dario P et al in 1999 using computer-assisted colonoscopy on a miniature robot. [20] This robot features an innovative inchworm-like locomotion capable of semiautomatic propulsion, affords visualization, and biopsies tissue samples. It is controlled by a thin and flexible umbilical cable to external control unit which relays pneumatic actuation signals to the robot by the endoscopist. In vitro experiment using a prototype has shown strong potential for possible future applications in endoluminal diagnosis and therapy.

Robotic enhancement is also utilized in downscaling and filtering of the tremor of the surgeon's natural hand movements into microscopic scale. In opthomology, Yu et al developed a robotic ultramicrosurgical system and instruments for specific intraocular applications. [21] In preliminary animal study, the authors successfully performed intravascular (<70 um) drug delivery, intraretinal manipulation of electrode with minimal damage, and implantation of microdranage devices.

Das and colleagues developed Robot Assisted MicroSurgery (RAMS) system to assist microsurgeons in manipulating surgical instruments more precisely.[22] RAMS is a six-degrees-of-freedom telerobotic system which consists of mater robot, slave robot, and real-time computing system with a graphical user interface (GUI). The system components include mechanical, electronics, servo-control and configuration and user-interface software. In a pilot study, RAMS required a longer time to perform precision position task. When the tremor filter was set to limit hand motion to below 5 Hz, most of the subjects performance were degraded. Also, when the 30-Hz tremor filter was applied, the group composed of ophthalmology surgeons did not have a significant advantage whereas the group of medical students and Jet propulsion Laboratory (JPL) robotic engineers had a significant advantage. The opthalmology surgeons did not have a significant performance improvement when comparing the RAMS system to the manual mode.

Robotic applications in the endoscopic-assisted coronary artery bypass grafting (CABGs) have been very intense and swift. There are currently two commercially available robotic systems specifically designed for coronary artery bypass grafting (CABGs). One is Zeus™ Robotic Surgical System [8] and the other da Vinci Surgical ™ System.[6] Currently, these two systems lead major thrust for endoscopic CABGs. In October 1999 the group at the London Health Sciences Centre in London, Ontario, Canada has successfully performed the world's first endoscopic beating heart coronary artery bypass grafting (CABGs) using Zeus Robotic Surgical System.[23] Soon after in January 2000, German group reported another totally endoscopic coronary artery bypass procedure on a beating heart using the da Vinci ™ Surgical System.[24] Novel computer software was employed to facilitate synchronization of the patient's EKG with instruments and filter out the motion variations in beating heart resulting virtual still image. Despite limited data, initial experience of robotic application in cardiac surgery has been so far encouraging with reduced morbidity, especially that is associated with conventional open surgery: the large incision and the heart-lung machine. Given the large number of CABGs procedures performed annually in U.S.A., endoscopic CABGs looks very promising. Currently, both systems are under phase 1 clinical trail authorized by FDA.

Robotic applications in urology were initially focused in two main procedures: transurethral prostatectomy and percutaneous renal access. In the late 1980's a robotic system was developed by Davies et al at the Imperial College in London to perform a transurethral resection of the prostate (TURP). [25] The original design used a six-degrees of freedom robot, a cutting and resecting instrument, and a personal computer. Several modifications were required before a clinical trial. These include reducing operative software and downsizing to a four-degrees of freedom, a motorized safety frame and a metal stop. In a clinical trial with 5 patients, this robotic system successfully performed the entire transurethral resection of the prostate except hemostasis which had to be maintained manually. [26]

However, it was learned that a reliable method of monitoring the progress of the robotic TURP was prerequisite for an effective robotic system. Arambula et al in 1999 reported an automated prostate system using the genetic algorithm technique which includes real-time intraoperative imaging of the prostate and automatic identification of the contour of the gland on each image without any human intervention. [27] Based on 22 different ultrasound images, an average error of 6.21 mm was reported. According to Arambula et al, it has been reported that an estimate error during prostate measurement during robotic surgery should be less than 2.0 mm. Although the authors couldn't recommend clinical use of an automatic prostate recognition scheme due to a long processing time (49 min), they described a novel idea of using a genetic algorithm and a constrained prostate model to automatically identify prostate. The application of real-time soft tissue tracking and_modeling would resulted in a significant benefit to the patients by reducing the failure rate or complications related to the incomplete TURP.

Application of robotic system in image-guided percutaneous renal access was also investigated by the group at the Imperial College, London.[28] This system uses a passive five-degree-of-freedom manipulator, access needle end effector, C-arm guidance and a personal computer. Personal computer provides registration between the manipulator and C-arm coordinate systems and displays the access needle's trajectory on each fluroscopic image. At initial experiment, a target accuracy of less than 1.5 mm was reported. However, fluroscopic image-guided systems, unlike CT scan, produced imaged distortion which requires an image calibration algorithm for accurate spatial identification of the organs.

Another experimental system for percutaneous renal access was developed at Johns Hopkins, but it used active robot to manipulate needle using a biplanar fluroscope.[29]

Using this system, Cadeddu et al reported a success rate of 83% in ex vivo porcine kidney model and 50% in situ renal access of live porcine at the first attempt of placing a needle into a targeted calyx. [30] Low success rates were attributed to kidney or needle displacement by the advancing needle, and rib interference. In an attempt to make user friendly, Stoianovici et al developed a simple device with a passive six-degree-of -freedom arm and an active needle insertion driver with a low radiologic profile.[31] This system allows the surgeon to improve accuracy and the safety of the procedure.

A group at the Politecnico of Milan, Italy developed a robotic system to perform a transperitoneal prostate biopsy. [32] Utilizing external video camera and TRUS with the robot, this system demonstrated a target accuracy of 1-2 mm in positioning the biopsy needle in animal models. Rovetta and Sala reported first remote prostate biopsy but, its use was mainly confined to research due to difficult techniques, high cost and long set-up time. [33]

As minimally invasive surgery became more complex, the demand for more accurate and precise positioning the endoscope by an assistant surgeon was required. Recent introduction of minipulator technology in endoscopic surgery brought in a purpose-built robotic arm "AESOP" the first FDA-cleared medical robot for laparoscopy which was introduced to maneuver and position a laparoscope under the direct control of a surgeon.[34]

At Johns Hopkins, AESOP was used to assist in a variety of laparoscopic urologic procedures with a considerable success. Partin et al successfully completed 82% of 17 cases using one or two robots with a single surgeon. However, human intervention was required in three cases in which excessive bleeding required fine camera control. [35]

In another study, Kavoussi et al evaluated the effectiveness and accuracy of robotic versus human laparosocpic control in terms of inadvertent contact with instruments or tissue, inadvertent movement of camera, and inadvertent rotation of camera. Authors concluded AESOP was better as compared to the human assistance during surgery. [36] Up to now, more than 50,000 cases have been performed using AESOP in the United States. In latest version, AESOP 3000, is equipped with a second joint which allows more space for an assistant.

Kavoussi and collegues further pursued the use of AESOP robotic arm during telerobotic surgery. The actual laparoscopic procedure was performed by the primary on-site surgeon and assistant while the laparoscope was telerobotically controlled by a remote surgeon who is located 3.5miles away at other hospital. [36,37] Based on a similar technique, a laparoscopic adrenalectomy was successfully telementored recently from Baltimore, Maryland to Innsbruck, Austria. However, robotic-assistance was limited to remote manipulation of the laparoscope by a telementor surgeon. [38]

Currently, there are two main systems for robotic-assisted surgery in urology, The Green Telemanipulator Surgical System and the Zeus™ Robotic Surgical System. The Green system is designed for use in open surgery whereas the Zeus system for laparoscopic surgery.

The ability to remotely perform actual robotic operation hasn't been evaluated until 1996 by Bowersox and colleagues. [39] The authors initially investigated the use of telepresense technology in the management of the trauma patient in a battle field. They utilized the Green surgical telemanipulator system to remotely perform vascular anastomosis. However, the increased operative time negated the use of telepresence technology for resuscitative surgery. In 1998, same group also performed first robotic-assisted remote open surgery using porcine model. [40] Various urologic procedures including nephrectomies, cystostomy closures, and ureteral anstomoses were performed without any intraoperative complications. However, placement of the retractors, suction, and suture cuttings were required manually by an assistant at the operative site.

ROBOTIC RESEARCH AT CLEVELAND CLINIC

Robotic research at Cleveland Clinic involves three main subspecialities: cardiac surgery, obstetrics and gynecology, and urology. In cardiac surgery, possibility of using robotic system for endoscopic coronary artery bypass anastomosis was first explored by Garcia-Ruiz and colleagues in a custom-made plastic model. [8] Seven coronary artery bypass anastomoses were performed using Zeus ™ Robotic Surgical System. Operative time, intraoperative incidents, surgeon's fatigue, stability and dexterity of the robotic system, and anastomotic patency were evaluated. Based on 7 coronary artery bypass anstomoses, the author reported 100% patency in all anstomoses with minimal surgeon's fatigue, high stability and dexterity of the robotic system without any intraoperative incidents.

In gynecology, Margossian et al evaluated the feasibility of performing robotically assisted laparoscopic tubal anastomosis in a porcine model using Zeus Robotic Surgical System (Computer Motion, Goleta, CA) and compared it to laparoscopy and open microsurgery. [41] Six female pigs were performed robotic-assisted laparoscopic microsurgical uterine horn anastomosis and followed up for 4 weeks. The mean total operative time was 170 minutes including robotic set-up time. Laparoscopy was associated with fatigue and pain. The robotic system was safe, more comfortable and without any intraoperative incidents. Patency was confirmed immediately after surgery, and, after 4 weeks of follow-up, eight anastomoses were still patent (67%). The author concluded that robotic assistance in laparoscopic tubal anastomosis enhances surgeon's dexterity and precision while reducing fatigue. Based on their animal study, Falcone successfully performed first robotic-assisted laparoscopic tubal anastomosis using Zeus™ Robotic Surgical System (ZRSS) in a 33 years old woman. [42] The tubal segments were approximated using two interupted 6-0 polygalactin sutures, and the anastomosis was performed using four interupted 8-0 polygalactin sutures. The total operative time was 5 hours and 20 minutes, and actual anastomotic time was 95 minutes. The patient was discharged within 24 hours after surgery.

Recently, the author successfully completed 19 robotic-assisted laparoscopic tubal anastomoses in 10 patients. [43] Mean operative time to complete bilateral tubal anastomoses was 159 minutes. A patency rate of 89% was achieved on postoperative hysterosalpingogram. Five pregnancies were reported after a mean follow-up of 12 months. Currently, the group is conducting a multiinstitutional clinical trial approved by FDA for noncardiac application of ZRSS.

Since 1997, our group have been investigating the role of telerobotic surgery in laparoscopy. In the initial experiment, the role of robotic-assisted laparoscopic urologic reconstructive surgery was explored. In 1998, Sung and Gill have evaluated the feasibility and efficacy of performing robotic-assisted laparoscopic pyeloplasty in an acute porcine model and compared it with conventional laparoscopic pyelopalsty. [44]

Five female swines were prospectively randomized to undergo unstented robotic-assisted laparoscopic pyeloplasty in 6 kidneys or conventional laparoscopic pyeloplasty in 4 kidneys. The Zeus (Version 2.0) Robotic Surgical System (Computer Motions, Goleta, CA.) was used for robotic procedures.

Three to four ports were used initially, and, later as experience was gained, 3 ports were used. One robotic arm held a 0°, 10 mm laparoscope and two additional robotic arms were placed to the operating table. The right robotic arm held a 3.5-mm needle driver and the left robotic arm a 3.5-mm needle grasper. Conventional laparoscopy was used for initial tissue dissection and transection of the UPJ. For robotic-assisted pyeloplasty, running, full-thickness pyeloureteric anastomosis was performed robotically using 5-0 absorbable suture from a remote workstation. For conventional laparoscopic pyeloplasty, manual laparoscopic intracorporeal suturing and knot-tying techniques was performed. Immediate patency and anastomotic integrity were evaluated by intravenous indigo carmine and ex vivo retrograde ureteropyelogram.

In comparing robotic and conventional laparoscopic pyeloplasty, total surgical time (115.2 versus 94.5 minutes, p=0.2) and anastomosis time (75.7 versus 64.3 minutes, p=0.3) were longer in robotic pyeloplasty. A total number of suture-bites per ureter was similar (13.0 for robotic versus 12.5 for conventional, p=0.8). Anastomosis were immediately watertight in 5 of 6 robotic and 3 of 4 conventional pyeloplasties. There was no intraoperative complications except one renal capsule tear in the conventional group.

Other than transient loss of grasping force on three occasions, no intraoperative incidents were noted. Surgeon's fatugue and tremor level during robotic-assisted suturing were reduced compared with conventional laparoscopic intracorporeal suturing.

Overall, the robotic device was accurate, stable, and reliable.

Immediately following this study, Gill and colleagues investigated the role of remote, telepresent robotic surgery in ablative urologic procedures using Zeus Robotic Surgical System. [45] Five swines were used to perform bilateral laparoscopic nephrectomy (5 robotic, 4 conventional) and adrenalectomy (4 robotic and 3 conventional) in an acute study. Intraoperative manipulations during robotic nephrectomy and adrenalectomy were performed completely telerobotically from a geographically-separate operating room. One assistant was stationed at the operating table to exchange various robotic instruments (electrosurgical J-hook, spatula, tissue dissector, scissors) at the voice command of the remote surgeon.

For robotic nephrectomy, the renal artery and vein were individually mobilized and ligated using previously inserted 2-0 silk tie. The ureter was secured and the kidney was circumferentially mobilized. Conventional nephrectomy was performed with standard laparoscopic techniques using metalic clips for renal vessel control. Both kidneys were left in the abdominal cavity at the end of the procedure. For adrenalectomy, each adrenalectomy was performed initially prior to the ipsilateral nephrectomy. For robotic adrenalectomy, J hook electrocautery was used to control the main adrenal vein as well as the adrenal gland off the renal hilum. Animals were immediately euthanized postoperatively.

Robotic nephrectomy was successful in all 5 kidneys and conventional nephrectomy in all 4. As expected, total surgical time (85.2 versus 38.5 minutes, p=0.009) and actual surgical time (73.4 versus 27.5 minutes, p=0.0002) were longer in the robotic group. Blood loss was minimal, and intraoperative complications were none in both groups.

Robotic adrenalectomy was successful in all 4 adrenal glands and conventional adrenalectomy in all 3. Total O.R. time and actual surgical time were almost twice as long in the robotic group. Blood loss was minimal and comparable between the groups. During robotic adrenalectomy, an inferior vena cava tear was encountered while dissecting the medial surface of a right adrenal gland using J hook electrocautery. A 5-0 prolene suture was immediately introduced into the abdomen through a

5 mm port by an assistant, and the caval injury was remotely repaired telerobotically with intracorporeal suturing. Blood loss was approximately 100 cc. This particular complication could have been avoided if robotic clips were available at that time. In both studies, Zeus Robotic Surgical System was accurate and reproducible.

As two different robotic procedures are performed, robotic requirements for robotic-assisted pyeloplasty were precise in a limited area which required a downscale of 3.5:1 at the instrument tip. Whereas in robotic-assisted nephrectomy and adrenalectomy, the further placements of the ports from each other and a upscale of 1:3 to 1:2 at the instrument tip were necessary since wide excursion of the instruments were required to mobilize the kidney and the adrenal gland.

In both studies, certain limitations in the current robotic system and its end-effectors (instruments) were noted. The lack of adequate tactile feedback was obvious. To eliminate the spatial disorientation and simultaneously coordinate hand-eye movements by the remote surgeon, haptic feedback need to be introduced seemlessly with the visual feedback. Also, some of the robotic instruments were suboptimal. Recent improvements in Zeus Robotic Surgical System have addressed some of the issues including: (a) articulating instrument tips with a 5 mm shaft diameter, (b)optional 3-D visualization which is available in flat screen or in headset., (c) improved tactile feedback in the grasping motion, (d) on-line touch screen display of the view of a second scope, in addition to the main scope view on the monitor, (e) low profile of the system on the O.R. table which allows the use of an assistant during surgery, (f) easy steam sterilization of all system components, (g) improved voice recognition system for surgeon's voice control of the scope and visual field. To add to the current lists of robotic instruments, a robotic suction-irrigation device and a robotic clip-applier need to be developed to perform more effective robotic-assisted surgery.

In addition, further pursuit of concept for robotic, telepresent surgery is warranted as many issues still remain unresolved before actual clinical application of telepresent surgery. Currently, latency is the biggest huddle in delivering telepresence surgery.[46] Instantaneous transmission using very high bandwidth communication channels is crucial to perform telesurgical procedures. In a recent article by Fabrizio and colleagues, the authors evaluated the effect of time delay on surgical performance during telesurgical manipulation. The study was designed in two parts: (a) to determine the numbers of robotic movements required to perform specific tasks, (b) to evaluate the number of errors during a remote telepresence manipulation between Baltimore and Singapore (9000 miles away). It was recommended that time delay should be less than 700 msec in order to successfully complete the task. [47] Furthermore, novel software program incorporating haptic or force feedback technology needs to be developed. This technology will provide virtual tactile feeback that will dramatically enhance the surgeon' s performance. In near future, this technology in incorporation with CT or MRI-generated 3-D images will become indispensable tool for surgical education and training. The surgeon or trainees could practice complex surgical procedures using virtual model before it can be safely and effectively applied to the patient.

FUTURE DIRECTIONS

The potential benfits of surgical robots are considerable. Further advances in device technology are needed to provide high degree of freedom in confined spaces, to position the devices more accurately, and to perform various microsurgical procedures. Miniaturization of robotic technology will create new waves of delivering minimally invasive healthcare. In addition, there is a significant need to augment human surgical sensorimotor skills with the computerized capabilities of robotic technology to enable remote telemanipulation with sensory, tactile, and force feedback with improved precision and dexterity to a microsurgical scale. To realize direct telepresence surgery, high-bandwidth telecommunication technology must be developed to support the human clinician and the computers controlling the robotic system. Application of novel patient anatomy and surgical software in virtual settings incorporated with telepresent surgery will impact various facets of medicine and revolutionize surgical practice. Furthermore, robotic systems must be developed as a user-friendly, cost-effective and compatible with current O.R. environments. Appropriate guidelines for the patient safety and legal issues concerning medical ethics need to be intergrated into the current medical practice.

CONCLUSION

Technology today has been evolving at a dramatic speed. Especially, we have witnessed quantum development in the area of robotic enhancement technology (RET) in the last decade. Incorporation of RET with advanced telecommunication technologies is most recent intergration in medicine in which there lies tremendous potential growth and applications in the delivery of the modern health care. However, there remains still many areas which need to be further improved and evaluated before clinical application are realized. As a new millenium directsus, we have yet to witness the full potentials of our partnership with the robot.

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