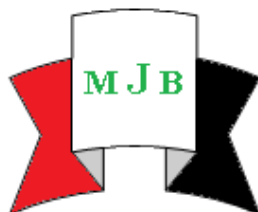


Robotic Surgery and Tele-Surgery: A Review Article

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Review Article



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Abstract

Objective: To highlight the history, development, and current applications of robotics in surgery.

Background: Surgical robotics is a recent technology that holds a significant promise. Robotic surgery is often regarded as the new revolution, and it is one of the most talked about subjects in surgery today. Up to this moment, however, the need to develop and obtain robotic technology has been largely driven by the market. There is no doubt that they will become an important tool in the surgical pyramid, but the extent of their use is still evolving and totally dependent on the standard of development of human being.

Methods: A review of the literature was undertaken using internet and medical literatures . Articles describing the history and development of surgical robots were identified as were articles reporting data on applications

Results: Several centers are currently using surgical robots and publishing data. Most of these early studies report that robotic surgery is feasible. There is, however, a paucity of data regarding costs and benefits of robotics versus conventional techniques.

Conclusions: Regarding its global use , robotic surgery is still in its infancy. Its current practical uses are mostly confined to smaller percentage of surgical procedures worldwide .

Robotic surgery is a new and exciting emerging technology that is taking the surgical profession by storm. Up to this point, however, the race to acquire and incorporate this emerging technology has primarily been driven by the market. In addition, surgical robots have become the entry fee for centers wanting to be known for excellence in minimally invasive surgery despite the current lack of practical applications. Therefore, robotic devices seem to have more of a marketing role than a practical role. Whether or not robotic devices will grow into a more practical role remains to be seen.

Our goal in writing this review is to provide an objective evaluation of this technology and to touch on some of the subjects that manufacturers of robots do not readily disclose. In this article we discuss the development and evolution of robotic surgery, review current robotic systems, review the current data, discuss the current role of robotics in surgery, and finally we discuss the possible roles of robotic surgery in the future. It is our hope that by the end of this article the reader will be able to make a more informed imagination about robotic surgery than before reading.

Key Word: Robotic Telesurgery, Advanced Model Of Surgery, Minimally-Invasive Surgery.

جراحة الإنسان الآلي والجراحة بالتحكم عن بعد

الخلاصة

الهدف: تسليط الضوء على تاريخ التطور وتطبيقات العصر الحالي للجراحة الآلية وجراحة التحكم عن بعد لاغناء الكوادر الطبية باساسياتها ومستجداتها.

الخلفية: الجراحة الآلية هي مستجد تقني يوعد بالكثير من الامل ولحد هذه اللحظة لا يوجد شك في ان هذا المجال سيصبح ادات اساسية في تشكيل الهرم الجراحي المستقبلي.

الطريقة: مراجعة المصادر الطبية وشبكة الانترنت والمقالات التي تعنى بهذا المجال وتطبيقاتها العملية وتحديد فوائدها من عدمها ودراسة تطبيقاتها الجراحية الحالية .

النتائج: هنالك مراكز عديدة تستخدم الجراح الالي للاجراء تداخلات الجراحية البسيطة منها والمعقدة لنشر معلومات موثقة عن الموضوع والنتائج الاولى تشير الى ان هنالك قلة في المعلومات في ما يخص الكلفة والفوائد بصورة متيقنة بالنسبة للجراح الالي مقارنة بالجراحة الاعتيادية ولكن مما لا شك فيه ان الجراحة الالية وجراحة التحكم عن بعد هي باتساع مستمر وفي طريقها الى ان تثبت نفسها كبديل ناجح للجراحة الاعتيادية. وسرعة تقدمها يعتمد بصوره اساسيه على مدى تقدم البنى التحتية للبلد .

الاستنتاج: عالميا الجراحة الالية مازالت في مرحلة الطفولة والاستعمالات الجارية هي في اتساع من العمليات البسيطة الى العمليات المعقدة ولكن لحد هذه اللحظة فان العامل المحدد للسرعة في انتشار هذا النوع الجراحة يعتمد بصورة اساسية على السوق التقني والكلفة العالمية لهذه الجراحة علما بانها فيما يخص الجراحه العامه فان هنالك الكثير من العمليات تجرى حاليا في المراكز العالمية مثل رفع المرارة , وطي الطرف القوادي للمعدة , وعمليات السمنة , وعمليات الاورام . كلها تجرى حاليا بواسطة الجراحة الالي وبصورة امينة.

Nomenclature

The word "robot" was first used by Czech writer Karl Capek for his 1920 play, R.U.R.

Rossum's Universal Robots, in which artificial workers eventually overthrow their creators. But contrary to popular opinion, Karl Capek didn't invent the word "robot". He wanted to call the workers "labori" but his brother, cubist painter and writer Josef Capek, suggested they be called "robots". The Czech word "robota" means "forced work or labour".[1,2]

Robotics For Surgery

Definition: Robot - “A reprogrammable multifunctional manipulator, designed to move material , parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks (Robot Institute of America) .A powered computer controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a range of surgical tasks (B Davies 2000).[3]

Introduction

Robots are being used in increasingly complex surgical procedures. However these robots are not autonomous machines that carry out simple, pre-programmed instructions . Operating theatre robots are designed to supplement a surgeon's abilities,

translating human movements into incredibly steady and accurate robotic movements, which, in turn, manipulate instruments to aid delicate operations. [4] But minimally invasive procedures, using instruments controlled by humans, have their limitations. For one, instruments are not in the surgeon's direct control, being manipulated by assistants. And the instruments' positioning within the body is subject to human tremors and fatigue, which makes working on minute structures difficult and dangerous.[5]Patients of conventional open heart surgery for example need, on average, two weeks recovery in hospital, followed by two to three months rest before they can resume normal physical exercise -this is how long the sternum takes to heal - and even then the patient is left with massive scarring. [6] Heart surgery carried out by robot-controlled endoscopy, on the other hand, means for a drastically reduced recovery time of three to four days in hospital and then a further two weeks before normal activities can be resumed . [7] General Surgery has seen an evolution over the last several decades toward minimally invasive approaches to procedures that were classically performed though large open incision. The former assumption in the surgical world that “a big surgery requires a big incision” is no longer true. The benefit of

significant reductions in the size of incisions is clear to surgeons who appreciate fewer wound complications and to the educated public who value less post-operative pain and rapid return to normal activities. As incisions and access ports become smaller and fewer, the tools to enable complex tasks through these ports are being developed. Robotics is one of the primary tools being incorporated into the surgical environment. [8] Besides the apparent advantages, there are some serious challenges of robotic healthcare that must be dealt with. The primary difficulty with teleoperation over large distances or beyond Earth orbit is communication lag time. Even in the case of intercontinental teleoperation—assuming the usage of commercial communication lines—latency can be in the order of several hundred milliseconds. While military satellite networks show better performance, these are not accessible for regular use.[9] Surgery robot control communication protocols must be robust and false-tolerant, while advanced virtualization and augmented reality techniques should help the human operators to better adapt to the special challenges. A novel virtual reality based, extended surgical environment control concept is proposed. [10]

To meet safety standards and requirements in space, a three-layered architecture is recommended to provide the highest quality of telepresence with the provisional exploration missions. Today's extreme telesurgery concept may well find a way to common civil applications for the benefit of many patients. [11] Surgical robots offer many advantages in the area of minimally invasive General Surgery and have made significant contributions to the field in the last twenty years. Robotics was first introduced to the General Surgery

operating room in the form of surgeon controlled robotic arms for laparoscopic camera manipulation. More recently, robotic surgical systems that allow the surgeon to operate from a remote console have been introduced. Significant challenges remain for the field including the cost-effectiveness, safety, training, and adoption. However, the benefits of robotics in the operating room are becoming clear and further development will see the maturation of a field with significant promise to improve patient care.[12]

Telesurgery allows expert surgeons to perform life-saving procedures without having to travel to remote corners of the globe. The capability of remotely teleoperating a surgical robot offers many possibilities for providing critical care, particularly considering that life-saving procedures that are commonly done in the developed world are often out of reach for a large segment of people. Surgeons would also be able to provide vital medical care to injured soldiers while avoiding dangerous exposure in an active battle field.[13]

Applications Of Robotics In General Surgery

To date, the majority of published clinical experience using robotic technology has consisted primarily of retrospective case reports and case series. Robotic surgical systems have been used in many different surgical disciplines including Urology, Cardiac Surgery, Gynecology, General Surgery and Pediatric Surgery. Telerobotic surgical techniques have been applied to a rapidly growing list of General Surgery procedures. Highlights of selected procedures are discussed below.

1- Cholecystectomy

The introduction of laparoscopy about 30 years ago revolutionized the treatment of

gallbladder disease. [14] Since then the laparoscopic cholecystectomy has become the standard of care and one of the most common laparoscopic procedures performed today. It is thus no surprise that the first robotic surgical procedure performed on a human was a laparoscopic cholecystectomy in 1997 by Himpens, Leman, and Cadiere. [15] Since that time, many clinical series have been published documenting experiences with robotic-assisted cholecystectomy. [16] All of these studies have shown few intra- or postoperative complications confirming the feasibility and safety of using the da Vinci[®] robotic system to perform laparoscopic cholecystectomy. [17]

2- Fundoplication

Telerobotic fundoplication, like cholecystectomy, also has been used by many centers to initiate their clinical experience with telerobotic gastrointestinal surgery. There are several series in the literature demonstrating that robotic fundoplication is feasible and safe with a low conversion rate and an acceptable morbidity rate, however similar to robotic cholecystectomy, robotic fundoplications resulted in longer operating room times. [18-20] Several randomized control trials of robot-assisted versus conventional laparoscopic fundoplications have been published. Most of these show similar results to the studies mentioned above, in that the procedure is feasible, and the outcomes are similar to conventional laparoscopy. Some argue that the small field of operation and the importance of suturing for repair of the hiatus and construction of the fundoplication makes this procedure an ideal application for telerobotic surgical systems. [21]

3-Heller Myotomy

The role of robotic technology in assisting minimally invasive Heller

myotomy is more apparent. Laparoscopic Heller myotomy is a difficult operation to perform, with a steady rate of esophageal perforation occurring (approximately 7%) even for very experienced surgeons. [22] The published telerobotic Heller myotomy series, in comparison, have demonstrated extremely low rates of esophageal perforation. [23,24]

4-Bariatric Surgery

Robotic surgical systems are being used to assist in a variety of bariatric surgical procedures. Cadiere and colleagues. [25] were the first to enter this area, performing a gastric banding procedure in 1999. Since then telerobotic surgical techniques have also been reported for biliary pancreatic diversion with duodenal switch, as well as various elements of laparoscopic Roux-en-Y gastric bypass procedures. [26,27]. All studies demonstrate the feasibility and safety of performing robotic bariatric procedures. Mohr and colleague. [28] Developed a totally robotic Roux-en-Y gastric bypass technique. They reported telerobotic operations were accomplished significantly faster than the laparoscopic operations and suggest that their results point to the potential superiority of telerobotic bariatric surgery. In general, authors suggest that the robotic surgical system may enhance performance particularly in superobese patients. The strength of the robotic arms, as well as the additional degrees of freedom in motion offered by the wristed instruments appears to overcome the problems generated in these patients by their thick abdominal walls.

Robotic Telesurgery

In most of the cases, mechatronic systems and cameras are the remote hands and eyes of the surgeon, and therefore key elements of the operation. Out of the 370 international

surgical robotic projects listed in the Medical Robotic Database ,there are several dozens with the capability of teleoperation.[29] In general, robots can be involved in medical procedures with different level of autonomy. [30] Systems that are able to perform fully automated procedures—such as CT-based biopsy or drilling—are called autonomous, or supervisory controlled. (A human supervisor would always be present to intervene if deviation occurs

compared to the surgical plan.) This can be combined with the classic tools of image guided surgery, once the robot is registered to the patient. When the robot is entirely remote-controlled, and the surgeon is absolutely in charge of the motion of the robot, we call it a teleoperated system.

If we compare between traditional and Telesurgery in their basic character and properties we may notice the following [31].

Traditional Surgery	Telesurgery
Tri-dimensional	Two-dimensional
Profound cognitive input	Limited cognitive feedback
Tactile feedback	Tactile feedback –ve
Stereoscopic vision with depth perception	Binocular vision without depth perception
Time lag –ve	Time lag +ve

1 - First telesurgery systems

Funded by the DoD, the first prototype of telesurgery robot was developed at Stanford Research International (SRI) (Menlo Park, CA) called the Green Telepresence System. [32]It was assembled by 1991, primarily aimed for open surgery. The idea to use it with MIS came with the rapid spread of laparoscopic technique. A series of ex-vivo and invivo trials were performed by 1995.[33] NASA Jet Propulsion Laboratory (JPL) (Pasadena, CA) also started to develop a system in the early times, and by 1993 they created the RAMS (Robot-Assisted Microsurgery System), targeting high-precision ophthalmic procedures.[34]

2-Commercialized systems

The most well known commercialized robots are the da Vinci Surgical System from Intuitive Surgical Inc. (Sunnyvale, CA) and the discontinued Zeus from Computer Motion Inc. (Santa Barbara, CA). While these robots inherited the structure and features that make them capable of performing telesurgical operations,

most commonly they are used for on-site surgery. Their primary advantage is easing the complexity of laparoscopic procedures, providing better visualization, control and ergonomics to the surgeon, and higher precision to the patient.[35]

The Surgeon Console

The da Vinci system consists of a master console that connects to a surgical „manipulator” with two instrument arms and a central arm to guide the endoscope. Two „master” handles at the surgeon’s console are manipulated by the user. The position and orientation of the hands on the handles trigger highly-sensitive motion sensors and translate to the end of the instrument at a remote location .The surgeon sits comfortably at a master console located at a distance from the patient with eyes focused down toward the operative site mirroring an open surgical technique and the slave unit provides „tele-presence” within the abdomen or chest for micro instruments manipulation [36]. Superior ergonomic design allows surgeon to become immersed in the

operative field. A 10 mm high-resolution 3D 0° or 30° endoscope (with two three-chip charge coupled device – CCD cameras) is used for better perception of depth and optical resolution. The endoscope is held by the central four DOF manipulator of a remote centre design, similar to the slave tool manipulator. The camera manipulator is capable of positioning the tip of the endoscope in 3D by working through the fulcrum made by

the port incision at the body wall. This Navigator Camera Control system gives the surgeon a 3rd arm to hold and move the camera without the need for an assistant. Hand motions are captured, transformed and transmitted to tiny robotic manipulator .[37]

Development: The last decades involve the following events which represent the evolution of robotic technology summarize in the following table [3, 38-40].

1985	Kwoh et al used Puma 560—a standard industrial robot—to hold a fixture next to the patient’s head to locate a biopsy tool for neurosurgery .
1985	Taylor at IBM was developing an industrial robot system (based on an IBM ‘Scara’ style of robot)for hip surgery. Following laboratory studies, the robot became a ‘veterinarian robot’replacing hips of pet dogs under direction of vet Dr. Hap Pal.The IBM robot was replaced by a Scara industrial robot from the Japanese company, whose Sanko-Seiki control system incorporated additional safety structures for surgery.
1988	First attempt at active motion robot in surgery. The Mechatronics in Medicine Group at Imperial College built onto Puma 560 to perform soft-tissue surgery in transurethral Resection of prostate (TURP).
April 1991	First time an active robot was used to automatically remove tissue from patients This resulted from developments based on the PUMA studies for TURP.Since that time a 2nd-generation prostate robot (called Probot) has been developed at Imperial College.
Late 1991	The modified Sanko Seiki robot system, now called ‘Robodoc’ was triedclinically on human patients.
Dec 1993	The AESOP 1000,used for holding an endoscopic camera in minimal invasive laparoscopic surgery, developed by Computer Motion was approved by the FDA.
1997	The da Vinci Surgical System manufactured by Intuitive Surgical Inc., became the first Assisting surgical robot to receive FDA approval to help surgeons more easily perform laparoscopic surgery. Jacques Himpens and Guy Cardier in Brussels, Belgium used the da Vinci by Intuitive Surgical Inc. system to perform the first telesurgery gall bladder operation.
Oct 2001	ZEUS® Robotic Surgical System from Computer Motion receives FDA regulatory clearance.(ZEUS’s 3rd arm is an AESOP voice-controlled robotic endoscope for visualization [Lanfranco et al, 2004].)
Sept 2001	ZEUS robotic system developed by Computer Motion was used in the trans-Atlantic operation.A doctor inNew York removed the diseased gallbladder of a 68-year-old patient in Strasbourg, France .
2002	A new era of robotic surgery assisted by a computer-enhanced surgical system

Miniature robots

Miniaturization using micro-electronic machine systems (MEMS) has been explored for over two decades. It has allowed scientist to create systems on

the mesoscopic scale (millimeter scale). New robots have become extremely small with entire computers, sensor systems and locomotion incorporated into a robot the size of a

small coin . The first clinical miniaturized 'robot' was the videoendoscopic capsule by Paul Swain. This is a pill size capsule inside of which is a miniature camera, light source and transmitter. The patient wears a video recorder on their belt. After swallowing, the capsule transmits images (one frame every 30 seconds) as it passively goes through the GI tract. The next generation is being researched to be able to control the direction and passage of the capsule (robotic control) and eventually add small end effectors such as biopsy forceps in order to perform therapeutic maneuvers. [41]

Cellular Surgery (Biosurgery)

Beyond mesoscopic scale is the microscopic scale and individual cells. A new technology, called femto-second lasers (or ultra-short pulsed lasers) emit pulsed laser light at 1×10^{-15} sec . When directed at a cell membrane, it is possible to create a hole (incision) into the membrane without damage, providing access into the cell. [42]

Various researchers are beginning to manipulate the individual structures within the cell; and a group in Dundee, Scotland is actually entering the nucleus and manipulating chromosomes. One might speculate that in the future, surgeons will be using such systems to actually manipulate individual genetic material or perhaps directly operate upon genes. If this were to occur, the results of surgery would be to change the very biology of the cell (biosurgery), rather than trying to remove organs or restructure tissues. Such research is now conducted by controlling the position of the laser from a workstation. Interestingly, this is very similar to what surgeons are doing today with robotic surgery, the main difference is that the scale in cellular surgery is thousands of times smaller . In addition, the researchers are using other tools, such as atomic force

microscope (AFM), to manipulate and visualize cells. These video monitors for the AFM show not only the outlines of the cells, but the actual forces between cells giving researchers a whole new way of 'seeing' the function of a cell. [43]

Conclusion

Robotic surgery is now routinely performed in specialized centers throughout the world. Da Vinci surgery offers a number of advantages over standard laparoscopy: 3D magnified imaging, tremor filtering, motion scaling and restoration of all degrees of freedom which should allow surgeons to surpass the current limitations of human performance. In the future the development of new instruments, reduction in the size of the system and improvements in ergonomics will likely result in wide spread dissemination of this technology. Medical Robotics have a bright future. Research and practice have shown that Robotic Surgery is safe, less invasive, and more accurate than surgery performed in the absence of robotics. It is still in its infancy, however so there's plenty of opportunity. Technically demanding, labour intensive, time consuming, expensive research Learning curve with similar characteristics Expensive installation, maintenance and infrastructure. Future application of robotics should include ; emergency trauma care – 1st 'Golden Hour', Battlefield surgery, Remote area assistance ,One-to-many telementoring and Space station surgery.

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