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A Comprehensive Overview of Robotic Surgery

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ABSTRACT

In this comprehensive review, the field of robotic surgery is discussed. The review focuses on robotic surgery, its applications within cardiac and gynecological sectors, its advantages and disadvantages, and its future outlooks. Robotic surgery has become an industry leading innovative technology offering better patient outcomes, reduced complications rates, reduced recovery periods, and improved control which allows for robotic surgery to be a viable option for expanding surgical capabilities on a global scale. Even though there are major economic challenges, the advantages which robotic surgery offer are more than the disadvantages. As such, robotic surgery has the potential to become the most utilized medical technology in the world.

Introduction

Robotic surgery in the modern day is an essential component of the medical field, and has been for the last 20 or so years. Since the introduction of the Da Vinci robot in 1999, many medical fields have changed the method by which they operate to ensure safer and better patient outcomes. As a result, fields such as cardiology and gynecology have shifted towards the use of robotics to enhance patient outcomes, improve recovery time, and to ensure satisfactory results. Robotic surgery has generally been advantageous due to its ability to provide the surgeon with superior dexterity, precision, and control. Moreover, robotic surgery has also been adopted widely because it reduces complication rates and recovery duration, therefore improving patient outcomes and as a result patient satisfaction. In a study conducted by Emma Long et al. it was found that over 91% of patients that undergo a robotic procedure (Gynecologic Oncologic procedures) would recommend robotic surgery as a modality (Long and Kew). However, some argue that the economics of robotic surgery do not make sense for implementation on a wide scale. In a study, Chetna Bakshi et al. found that the average cost of bariatric laparoscopic surgery was 8955 USD while its robotic counterpart cost an estimated 15319 USD (Bakshi et al.). As a result, robotic surgery has not been applied on a global scale yet, but it is apparent that robotics have become a necessary aspect of medicine and that this technique must be adopted globally in the future ensuring the continuity of innovation.

History of Robotic Surgery

The history of robotic surgery is engraved with a variety of technological advancements that have revolutionized the field of surgery and created limitless opportunities. The first surgical robot was used in 1985, known as PUMA (Programmable Universal Machine for Assembly), the robot was utilized for neurosurgical biopsy which took place at Memorial Sloan Kettering Cancer Center. The robot was later repurposed for urologic and prostate operations at the Robotics Center in Imperial College. In 1993, a company known as Computer Motion was founded by Yulun Wang which developed a new robotic system known as AESOP, which allowed the surgeon to control the position and orientation of a laparoscope using a foot pedal (and was later replaced by voice commands in 1996) rather than needing an assistant to position it allowing the surgeon greater dexterity and control. It was first introduced into clinical use in 1994, 4 generations were developed with each one integrating new features (Aesop 1000/Aesop 2000/Aesop

3000/Aesop HR) (Luiz et al.). Furthermore, in 1998 a new system was introduced into clinical use known as the ZEUS surgical system developed by Computer Motion, the first clinical case revolved around the use of the robot for coronary artery grafting. The robot comprised of 3 arms, one that controls the endoscope and two that manipulate interchangeable surgical instruments and offer up to 4 degrees of maneuverability. The console used an electromechanical interface which digitized inputs and scaled them (Damiano and Maniar). Later on in 2001, the robot was used in performing the first transatlantic cholecystectomy, it utilized advanced technologies at the time such as fiberoptic technology and asynchronous transfer mode to enable a 10 mb/s transfer rate along with a latency of 150 milliseconds allowing the robot to be used in a teleoperation where a surgeon in New York operated on a patient in Strasbourg, the procedure lasted 54 minutes and was successful (Luiz et al.). Moreover, in 2003 Computer Motion was acquired by Intuitive surgical in a number of long consecutive legal proceedings and as a result the ZEUS system was discontinued in favor of the Da Vinci Surgical robot. The Da Vinci surgical robot was first approved by the FDA in 2000 and constituted many major technological advancements, the robot introduced the use of a 3D High-Definition camera, 4 robotic arms, and Endo-wrist instruments. Later on, many new variations of the Da Vinci were released offering various improvements, the most prominent being the Da Vinci Xi which offered many new features such as setup automations, a touchscreen, 3D vision with up to 10x magnification, wireless connectivity, firefly fluorescence imaging, and integrated table motion (Luiz et al.).

Applications of Robotic Surgery

Due to the enhanced dexterity and precision which robots offer; robotic surgery has many key advantages which allows for its use as a versatile tool in many different surgical aspects. As such, systems such as the Da Vinci Xi robot have been instrumental in many surgical fields including Robotic kidney surgery, Robotic prostate surgery, Robotic colorectal surgery, Robotic cardiac surgery, Robotic coronary artery bypass, Robotic Gallbladder removal, Robotic Hysterectomy, Robotic Kidney transplant, Single-site robotic gallbladder surgery, Robotic Kidney removal (total or partial), Robotic Head-and-neck surgery, Robotic Joint replacement surgery. Thus, surgical robots are being used in many key areas of operative medicine, and their ability to offer the surgeon extreme precision while reducing risks and potential for human error have allowed them to become the predominant choice for most surgeons and patients (The Surgical Clinic).

Cardiac Robotic Surgery

Cardiac robotic surgery involves the use of small incision by which robotic arms can access the chest cavity to perform a cardiac procedure. The main advantage of cardiac robotic surgery is the ability of the patient to avoid a full sternotomy which can drastically decrease the required amount of postoperative care and the recovery duration. Cardiac robotic surgery has also been proven to include fewer complications resulting in less pain and less bleeding post-operation. The two main operations which have become dependent on robot assistance are mitral valve repair/replacement surgery and coronary revascularization surgery. Robotic mitral surgery was first performed in 1998 using the Da Vinci Xi system, it later obtained approval from the FDA in 2002. It was mainly adopted as the gold standard due to the fact that robotic mitral surgeries involved less incidence of atrial fibrillation and pleural effusion in comparison to surgeries involving full/partial sternotomies and mini-thoracotomies. Moreover, robotic surgery has been used in coronary revascularization surgery such as in TECAB procedures (totally endoscopic coronary artery bypass) whereby the left internal thoracic artery is harvested and then grafted onto the left anterior descending artery. The first TECAB procedure using a robot was performed in 1998 by Loulmet using the Da Vinci system. Currently, over 1000 cases have been recorded, and of the past 326 cases record a mortality rate of 0.6% was recorded, a 2% rate of stroke was recorded, and a perioperative myocardial infarction rate of 2.5% was recorded. Over 80% of cases were attributed as

a success, however, 14% of cases converted to an open procedure due to complications. Therefore, it is apparent that robots in cardiac procedures offer a higher rate of efficacy than traditional methods of operation (Harky and Hussain).

Gynecological Robotic Surgery

In 2005, after preliminary success was shown with myomectomy and hysterectomy at the University of Michigan, the Da Vinci robot was the first robotic surgical system approved for use in gynecology by the FDA. Its main uses include: robotic myomectomy, robotic hysterectomy, robotic resection of endometriosis, robotic sacrocolpopexy, etc. The field of gynecology has largely shifted towards dependence on robotic-assisted surgery due to the advantages affiliated with robotic procedures. In gynecology, robots utilize much smaller incisions which leads to a lower mortality rate. Moreover, the use of robotics in surgery causes less postoperative pain and decreases recovery time (Sinha et al.). Therefore, robotics have become an integral part of gynecological surgery, and have become a valid treatment option for many patients ("Gynecologic Robotic Surgery | Conditions & Treatments | UT Southwestern Medical Center").

Training and Education

There are two main pathways which are relevant to the training and education of robotic surgeons. Firstly, a surgeon can obtain a Master of Science in Robotic Surgery, this is a degree which features a comprehensive curriculum that will provide the surgeon with the necessary skills to perform robotic operations, this degree is offered by many institutions such as Advent Health University ("Online Master of Science in Robotic Surgery"). The other pathway involves a trained surgeon enlisting in an online course provided by the manufacturer of the robot to obtain certification in its use. These training pathways involve comprehensive curriculums, practical training, and training in instrument use which all contribute to the surgeon's skill set. One such online program is the Da Vinci Xi training course, the course consists of 4 main phases. The first phase introduces the surgeon to the system by allowing them to test drive it, it also involves reviewing the procedure for the planned operation along with completeing live observations of previously done operations. The second phase involves all technological skills training, it is conducted through two stages, one online stage where surgeons are certified through an electronic assessment, and a second stage where surgeons are certified by an Intuitive surgical representative in person. Phase 3 is named as the initial case series plan where the surgeon must complete two of the following activities per week in retrospect of the timeline relevant to the procedure itself: Assist in a da Vinci procedure, perform a da Vinci procedure, complete a da Vinci Technology Skills Drills session, complete a da Vinci Skills Simulator session, or review a da Vinci Surgery procedure video relevant to the planned da Vinci procedure. Phase 4 is named as continuing development where a surgeon must perform at least two of the following activities: Surgeon lecture program, complex da Vinci procedure observation, Complex da Vinci procedure video review, da Vinci surgery webinar, and/or Peer-to-Peer consultation via Surgical Congress. The previously mentioned certification course is only a means of certification offered by the manufacturer and does not replace any means of certification required by the institution that the surgeon works at nor does it represent clinical competence (Diaz et al.).

Ethical Considerations

Robotic surgery carries many ethical issues that have been in dispute for some time. Firstly, the issue of malpractice can become complicated with the involvement of a robot. As such, it has been determined that all fault should fall on the operating medical team in case of malpractice unless the poor surgical results is a direct result of technical failure. This allows for robots to be used responsibly allowing the provision of the finest care to the patient, while also preventing surgeons from shifting blame to third parties in case of poor surgical results occurring as a direct product of malpractice. Secondly, the issue of data security and privacy must also be discussed, as teleoperations have also become

more prominent the transfer of data safely while ensuring the privacy of patients is of the utmost importance. As a result, healthcare institutions and surgical robots' manufactures must take extreme measures to protect patient information, this can be done through substantial encryption protocols, implementation of firewalls, and the implementation of secure data access methods. As such, patient data will be protected. Thirdly, healthcare intuitions must also address the rudimentary ethical considerations of robotic surgery, patients must provide consent clearly stating that they consent to the robotic operation. Moreover, patients must be given all the necessary information to make an informed decision, as if a doctor were to withhold information this may causes serious ethical conflictions. Lastly, healthcare institutions operating a robotics program must ensure that the physician performing the procedure has the required certification and training from both the institution and the manufacturer of the robot, and that the robot itself is free of any defects and has undergone sufficient and timely maintenance procedures to ensure that it can operate on a human being (Welp).

Conclusion

In conclusion, robotic surgery has made significant advancements over the years. From the development of PUMA in 1985 to the creation of the first single-incision robot in the Da Vinci SP (Luiz et al.). Due to the many advantages which robots continue to offer; they have become a widely sought after technology in many areas of the world. Robotic surgery has not only reduced patient complications but has also improved patient outcomes, and as a result robotic surgery has become the industry standard of medical procedures in many different medical fields (Reddy et al.). Moreover, patients have also become much more comfortable with robotic surgery as robotic surgery has been proven to outweigh its disadvantages, and it has also been proven to be safe. Therefore, surgeons are also orienting themselves to paths where they can obtain robotic surgery certification in order to provide patients with many options and to provide healthcare institutions with versatility. In short, robotic surgery is an essential medical field and will continue to grow in order to realize future outlooks such as remote surgery or even autonomous surgery.

Future Outlooks

In the realm of robotic surgery there are many future possibilities which will allow for major breakthroughs in patient care and operative results. One such breakthrough is the potential of fully autonomous robotic systems. It has been theorized that fully autonomous surgical robotic systems are possible and that the integration of artificial intelligence along with machine learning can allow for the use of extremely accurate and effective algorithms that can accurately predict surgical outcomes in real-time and as such determine the most effective method that can be used to achieve the desired operative result. However, due to the ethical concerns which may arise due to the implementation of autonomous robotic surgical systems, medical experts have largely preferred the idea of integrating artificial intelligence systems within the procedure by allowing them to aid the primary physician, but by leaving all key decisions to the physician in charge ethical boundaries can be preserved and surgical errors as a result of technical failure can be prevented (Yeisson Rivero-Moreno et al.). Moreover, another technological advancement which can be implemented into robotic surgical systems is the integration of virtual reality and augmented reality technology into the visualization components of surgical robotics. This will allow the surgeon to have extremely accurate and precise visualization, and this will also allow the surgeon to overlay 3d models of organs, real time patient data, and essential procedure details further aiding the surgeon in performing the procedure and further ensuring success (Iqbal et al.). In addition, the possibility of adaptable remote surgery is also an extremely exciting aspect. Robotic surgery could be used in low-resource environment such as in war-ridden countries to give patients access to high-standard care and increase survival rates. Remote surgery has also been a subject of interest to militaries as to preserve the lives of surgeons and allow them to operate on injured patients while being far away from any type of danger, this will not

only serve to protect the doctor but it will also allow the patient to receive the best care from the most suitable doctor based on his/her injuries (Mohan et al.).

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