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A Review on Robotics Used in Biomedical Surgery

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Abstract: In terms of advancing surgical techniques, robotic surgery, which has been around for more than 20 years, is a revolutionary development. The last ten years have seen a rise in the usage of robotics in medical treatments. In an effort to develop smaller, more effective, and less expensive equipment, researchers are ready to achieve record heights as robotic surgery becomes more and more common. Robotic surgery has been successfully used in many hospitals throughout the world and is gaining recognition on a global scale. In this article, we examine robotic surgery's development and progression, current robotic systems, limitations as well as current statistics, and current roles of robotics in surgery, and finally, we discuss the possible roles of robotic surgery in the future.

I. Introduction

A. Robotic Surgery as a trend

Surgery is being enhanced by robotic technology thanks to its increased precision, stability, and dexterity. Robots employ image data from computed tomography and magnetic resonance to direct devices to the treatment location during image-guided procedures. It also requires sensors to register the patient's anatomy with the preoperative picture data, which necessitates novel algorithms and user interfaces for planning treatments.

Remotely operated robots are used in minimally invasive procedures to enable the surgeon to operate within the patient's body without creating significant incisions. In order to maximise dexterity under these access restrictions, specialized mechanical designs and sensing technologies are required.

With robotic surgery, doctors may perform a range of difficult procedures with more control, accuracy, and adaptability than is possible with conventional techniques. Minimally invasive surgery, which involves procedures done through small incisions, is usually linked to robotic surgery. Occasionally, it may also be used during different kinds of open surgery. [2]

B. Advancement in Robotic Surgery

From early computer-aided design/manufacturing systems to contemporary master-slave robotic systems that copy the surgeon's precise actions onto robotic tools in the patient, robotics has come a long way. [3]

In 2010, there were more than 300,000 robotic surgeries performed worldwide, including 98,000 radical prostatectomies assisted by robots. With more practice, port placement has been improved to prevent arm collisions and speed up surgery. Improved three-dimensional camera magnification allows for better intraoperative structural identification. [4]

Recently, a number of robotic surgical systems were commercially produced and FDA-approved for use. These include the comprehensive master-slave surgical robotic systems Da Vinci (Intuitive Surgical Inc., Mountain View, CA) and Zeus (Computer Motion Inc., Santa Barbara, CA), a voice-activated robotic endoscope, and the AESOP system (Computer Motion Inc., Santa Barbara, CA) (Computer Motion Inc., Santa Barbara, CA). [5]

Fig -1 Da Vinci System

Fig- 2 AESOP 3000

C. Significance of Robotic surgery over Traditional method

Robotic surgery has effectively solved the drawbacks of conventional laparoscopic and thoracoscopic surgery, enabling the completion of intricate and advanced surgical procedures with higher precision and a minimally intrusive method. The surgeon is sitting comfortably on the robotic control console, which lessens the physical strain on the surgeon compared to the awkward positions needed for laparoscopic surgery. [5] The operating surgeon is given a 3-dimensional vision that improves depth perception in place of the flat, 2-dimensional image received by the standard laparoscopic camera; camera motion is steadily and conveniently controlled by the operating surgeon using voice-activated or manual master controls [6]. Additionally, using robotic arm tools offers a greater range of motion than using conventional laparoscopic tools, enabling the surgeon to carry out more difficult surgical procedures.

D. The software architecture used in robotic surgery

Robotic surgery is based on the concept of minimally invasive surgery (MIS), in which a robot replaces or supports a surgeon in performing surgical operations [15]. Research papers [16, 17] depict a robotic system doing operation planning and execution with manual takeover when needed. One method [18] enables the integration of several components such as sensors and imaging devices that helps the surgical system in performing surgery. Our findings allow us to infer that the increasing complexity of contemporary and practical robotics increases the significance and necessity of effective software architecture design for designing and improving commercial robotic systems in a reliable and efficient manner [19]. The technologies used might have a big influence on the robotic driven world in the near future, such as robotic surgeons [16], unmanned [20], and self-driving automobiles [21]. Furthermore, mission essential robotics are developing as a human substitute for performing simple and demanding activities such as hazardous waste cleaning [22], rescue missions [23], and space exploration [24]
The robotic surgical software architecture is divided into three layers: drivers of the hardware, master-slave control, and human-machine interaction. The hardware drivers is an important factor in the software system as it facilitates the real-time hardware control. The master slave control is the most important in the robotic surgical software. And the human-machine interface software takes precedence over all other software.

Device Drivers

Device drivers typically interact with hardware by encoding control values and instructions into hardware codes before sending them to hardware devices and decoding device codes from hardware devices into values that may be used by master-slave control software. The input and output signals are digitally controlled by drivers, while master haptic device drivers talk to PHANToM Omni haptic devices (POHD). Motor drivers link with the motor-driven components. The remaining drivers, with the exception of the POHD drivers given by Sensable, are written by the authors. To provide real-time hardware control, these device drivers have the greatest priority in the system. The device drivers' modular structure allows the programme to be easily expanded and maintained. If any of the hardware devices are updated, only the related hardware drivers must be modified without having to rewrite the entire code.

Master-Slave Control Software

Enabling master-slave tele-operated control is the function of the master-slave control software. It includes the modules for controlling the motion of the manipulator, haptic devices, data logging, and error detection. Depending on the type of work, these modules' control periods change. The control period of error detection is the slowest, whereas the control period of haptic devices, for instance, is to maintain a smooth control response for the user. The maximum communication frequency between the computer and the motor driven devices limits the control rate for manipulator motion control to 30Hz. At the moment, the haptic device control module is primarily utilized to get information on the operator's hand movements; no force is output to the operator. Because the slave lacks a force sensor, the haptic output feature is reserved. The surgical simulation module, which will provide virtual 3D training for surgeons and assist them operate the robot system expertly and rapidly, is kept for future development. The slave manipulators' movements are accomplished by commanding the motors installed in the manipulators' joints to move in accordance with the target locations provided by the master devices via the surgeon's operation. Figure xx depicts the joint position closed-loop control diagram for each joint. The input is the provided joint position, which is derived using inverse kinematics from the master's supplied position. The motor controller measures and decodes the position of the feedback joint from the hall sensor in the motor. The present position control algorithm is a standard proportional-plus-derivative control strategy (PD). The PD controller receives the joint angle error as input and outputs the velocity control code to each motor controller. According to the output control code, the motor driven unit changes the motor velocity.

Figure 3: Joint Position Closed-loop Control

Human-Machine Interface Software

The human-machine interface includes functions such as data display status and error display, work mode selection, manipulator operation, parameter setting and graphical display of manipulator motion, and surgical simulation for training. The human-machine interface of the current prototype is made up of a number of modules, including, among others, the OpenGL display module, the data display module, the status and error display module, the control button module, the user assistance module, the parameter setting module, and the programme debug module. The surgical simulation is still under development. The software may be loaded with multiple modules depending on the application to achieve various display interfaces for both the user and the programmer.

E. AI and Big Data Analytics for Robotic Surgery

Image-guided techniques, such MIS, interventional radiology, and surgical endoscopy, are altering not just how we provide care for patients but also how we do surgical research [25]. Indeed, whether radiological or endoscopic, the pictures guiding these treatments provide a natural resource for comprehensive, direct, and unbiased information about intraoperative events. These digitized pictures are far more useful and dependable than operator-dictated post-operative notes, and if properly studied and quantified, they might shed light on OR occurrences and educate on safety initiatives. Additionally, data generated data generated in the operating room, such as anaesthesia monitors, OR device use, additional intraoperative imaging, environmental cameras and microphones, as well as patient clinical histories and outcomes stored in electronic medical records, imaging studies stored in picture archiving and communication systems, can be added to this visual information on surgical procedures [26]. Processing of the available digital data online might provide operators with quick and highly detailed input to improve patient care. These surgical big data may reveal the surgical process's advantages and disadvantages through offline analysis that could be addressed with a system approach [27]. To extract meaning from surgical big data, which is by definition too large and complex to be assessed using conventional statistical methods, machine and deep learning are needed [28]. These powerful computational approaches identify complicated patterns in data automatically, discover how to produce predictions without explicit programming, and increase their performance as data sets get larger. Deep learning has become one of the key analytical methods driving the recent boom in artificial intelligence thanks to these qualities as well as cutting-edge performance in computer vision and natural language processing tasks like directing an autonomous car or naturally answering queries. The surgical big data availability and expanding accessibility of potent AI techniques may allow for the offline analysis of the surgical process to accumulate detailed knowledge and the online processing of the surgical process to extract timely and useful insights for feedback to surgical staff. This is what Surgical Data Science aims to achieve, a cutting-edge field that leverages data and advanced analytics to raise the bar for interventional healthcare's quality and safety [29].

II. Application of Robotics Surgery

Robotic equipment is thought to have greater dexterity and range of motion than humans conducting minimally invasive, or laparoscopic, surgery. This enables surgeons to perform procedures on hard-to-reach body parts and get a clearer look of places that are occluded. Compared to utilizing conventional magnification, the robotic system's high-definition, 3-D viewer enhances the surgeons' ability to see the surgical site. [7]

A. Robotic Surgery used in Oncology

In order to combat a disease that has affected and impacted so many people, researchers are deploying robots in a variety of domains related to cancer research, including surgery, radiation therapy, biopsy, and many other vital areas. Nanobots are tiny "robots" with sizes between 1 and 100 nanometers. Nanobots are being used in a variety of medical and healthcare procedures, including the treatment of cancer and the opening of blood vessels, according to scientists. [8]

B. Robot in Cosmetic Surgery

Despite major technical breakthroughs in surgical robotics in recent years, only a tiny number of surgical specialties have benefited significantly from these technologies. Although surgical robotics and computer-assisted systems in the operating room were used in around 85% of radical prostatectomies performed in the United States in 2013, the area of plastic and reconstructive surgery has used them much less frequently. [8]

Plastic surgeons have investigated the viability of incorporating robots into clinical practice because of the potential to improve the practical skills needed during surgery and combine these with imaging modalities. Robotic microsurgery for plastic and reconstructive operations is possible, according to a number of clinical investigations.

C. Robots used in Thoracic Surgery

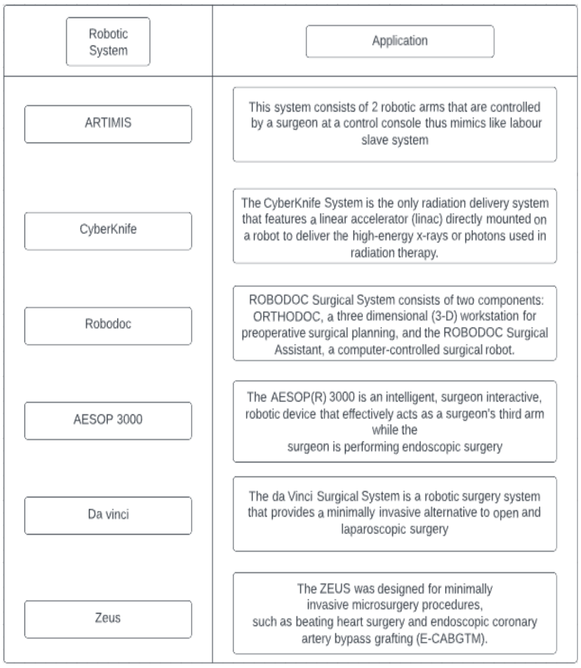

Fig 4 - Types of Robots Used in Biomedicine Surgery

Many significant common thoracic surgical operations have currently been successfully carried out by general thoracic surgeons using the robotic technology, and its use in general thoracic surgical practice is continuing to spread across numerous institutions. The increased acceptance of robotic technology in thoracic surgical cases is due to a number of factors. Robotic technology provides a steady platform and is less invasive than open surgery. The da Vinci Surgical System is a medical treatment option that uses a robotic surgery system to create a minimally invasive alternative for laparoscopy and some open surgeries.

Initially, the surgeon and robotic team work together to place the robot in the most ideal position for the procedure, strategically placing the robotic arms. A very small 3D camera and dime-sized surgical instruments are placed inside the patient through tiny incisions. The camera gives the surgeon a magnified 360-degree view of the operative field. Using the console's hand and foot controls, the surgeon remotely moves the robotic arms attached to surgical instruments. Surgical technicians are positioned at the operating table to confirm the correct placement of the surgical instruments. [10]

III. Limitation to Robotics Surgery

A. Instrumentation

The majority of instruments compatible with the da Vinci are considered to be too large for tne manipulation of delicate tissue normally seen during microsurgery. Success has been observed by utilising the da Vinci's Black Diamond Micro Forceps for operating on small vessels and nerves [12]. Yet, lack of a comprehensive set of appropriate microsurgical instruments means that handling sub millimeter tissue and equipment is challenging and time-consuming process. The majority of instruments compatible with the da Vinci are considered to be too large for the manipulation of delicate tissue normally seen during microsurgery. Success has been observed by utilizing the da Vinci's Black Diamond Micro Forceps for operating on small vessels and nerves

The majority of Da Vinci-compatible instruments are thought to be too large for the precise manipulation of delicate tissue often seen during microsurgery. The da Vinci's black Diamond Micro Forceps have been used with success to operate on small veins and nerves. Components that are common to microsurgical techniques when employing a surgical robot instead of traditional microsurgery, routine tasks like dissecting blood arteries, attaching vascular clamps, and handling thin sutures become more challenging. The variety of surgical tools does not fully address the range of tissue encountered during microsurgery in addition to the large instruments. Numerous procedures involving the upper or lower limbs need the manipulation of several tissues with distinct properties, including skin, arteries, and bones. There is currently no robotic system available that offers the instruments required to carry out treatments involving all types of tissue. Since both soft and hard tissues are involved in some procedures, surgical robots alone cannot be used to complete them. Robotic utilization is also ineffective due to the extensive use of macroscopic and microscopic procedures during reconstructive surgery. The da Vinci surgical robot offers an endoscopic 3D imaging system that can digitally zoom in up to ten times. Sadly, when compared to surgical microscopes, the Da Vinci surgical robot's picture quality and magnification fall short of expectations. [10]

B. Cost

Investing in surgical robotics demands large financial resources because one surgical robot can cost more than $2 million. There are additional direct and indirect expenses that are necessary to run the system and create a secure setting for robot aided surgery. If costlier treatment alternatives are linked to higher outcomes or long-term income growth, hospitals may benefit from offering them. Very few plastic surgery departments are currently willing to invest in robotic-assisted surgery without a rise in patient turnover and cost-effectiveness.

C. Education

With surgical robots, the entire treatment is frequently carried out by a single surgeon who is also in charge of the system as a whole. As a result, there are few opportunities for assistants to participate in operations involving robots. Surgeons' exposure to surgical robotics and opportunity to develop their skill set may be limited by their lack of active participation.

Multiple surgical robots might be a safer choice when instructing nascent surgeons. In addition to giving the main surgeon a helper throughout the process, this enables students to develop the skills required for robotic microsurgery.

Since movements and handling of delicate tissue differ greatly from those of conventional microsurgery, the skills required to successfully operate in such situations with a surgical robot do not simply translate. [11]

D. Surgical Workflow

However, some degree of ambiguity will always exist, and it could be challenging to forecast which operations provide adequate surgical access and which do not. As a result, there is a chance that surgeons may need to alternate between robotic and traditional surgery while performing a procedure to get the desired outcome. It is absolutely possible to transition during an operation; however, it is a difficult and drawn-out process that depends on the operating room staff's knowledge with surgical robots.

Surgical robots must consider uncertainty during microsurgery and be able to provide a seamless and speedy transition between traditional and robotic microsurgery in order to maximize surgical workflow. [12]

E. Gateway of Fear

In general, the idea of having a robot operate on you scares you because of its autonomy and lack of precision. However, to some extents, this is true since the robot is unable to build a system of segregation within a sensitive area of the patient, which discourages some people from having robotic surgery.

IV. Robotics Surgery as Pre-cursor to Biomedical

Many hospitals are now using robotic surgery, a continually evolving technology that allows surgeons to perform precise operations from a distance. Robotic surgery will be the way of the future of surgery since it offers total precision in the procedure and less stress for the patient. The quick development of robotic technology has opened up new possibilities for biomedical and engineering in healthcare. For instance, the precise positioning and manipulation skills of a micro-Nano robot allow us to investigate the fundamental problems at the cellular scale.

The medical robot opens up new possibilities for minimally invasive and highly effective clinical procedures, while the rehabilitation robot can help patients recover more quickly. The area of robotics seeks to close the innovation gap in several medical fields. These developments rely on new technology to open up prospects in the medical industry that did not previously exist. A few businesses are employing 3D printing to help make prosthesis. Others are developing more effective, lightweight robotics exploiting the advancements in motion. Last but not least, nanoscale robots are employed to fight cancer more aggressively than ever. [13]

In any situation, the "distance to the patient" tends to increase with the level of autonomy of robots in healthcare. For instance, a surgical robot that is placed very close to the patient has no autonomy and is instructed by the physician on how to behave. On the other hand, sanitation robots, who are far removed from interacting with patients directly, have more autonomy in how they choose to act in response to their surroundings.

There are several ways that robots are used in healthcare today, many of which are intended to support people in ways beyond what they can perform on their own organically and securely. These robots' uses in surgery and other branches of medicine are still expanding quickly. Robots are already commonplace in operating rooms and clinics. [14]

V. Conclusion

By enhancing and expanding laparoscopic procedures, increasing surgical technology, and bringing surgery into the digital era, robotic technology is poised to transform surgery. Additionally, it has the potential to expand surgical therapy options beyond what is now possible for humans. It will take a lot of study to figure out whether the benefits of using it will outweigh the costs involved. A greater number of prospective randomized trials assessing efficacy and safety must be conducted even if the feasibility has essentially been demonstrated. For robotic surgery to fully take hold, more study is required to assess whether it truly outperforms traditional medicine in terms of cost-effectiveness. The future of robotics in surgery is only limited by your imagination, much like the robots of popular culture.

The cutting-edge advancement in surgery known as robotic surgery will have a significant impact. This new technology allows surgeons to conduct procedures that were previously impractical to carry out using limited access approaches while also increasing their accuracy and dexterity. In order to provide a new medium for the acquisition and evaluation of surgical skills through simulation of all procedures that the robot is capable of doing, emerging technologies like virtual reality, haptic, and tele-mentoring can effectively work with surgical robots.

Reference

1. Ruhle, B. C., Ferguson Bryan, A., & Grogan, R. H. (2019). Robot-assisted endocrine surgery: indications and drawbacks. *Journal of Laparoendoscopic & Advanced Surgical Techniques*, *29*(2), 129-135.
2. Linsky, P. L., & Wei, B. (2018). Training in robotic thoracic surgery. *Journal of visualized surgery*, *4*.
3. Steenwyk, B., & Lyerly, R. (2012). Advancements in robotic-assisted thoracic surgery. *Anesthesiology Clinics*, *30*(4), 699-708.
4. Han, E. S., & Advincula, A. P. (2021). Robotic Surgery: Advancements and Inflection Points in the Field of Gynecology. *Obstetrics and Gynecology Clinics*, *48*(4), 759-776.
5. Neudorfer, C., Hunsche, S., Hellmich, M., El Majdoub, F., & Maarouf, M. (2018). Comparative study of robot-assisted versus conventional frame-based deep brain stimulation stereotactic neurosurgery. *Stereotactic and functional neurosurgery*, *96*(5), 327-334.
6. Muaddi, H., El Hafid, M., Choi, W. J., Lillie, E., de Mestral, C., Nathens, A., ... & Karanicolas, P. J. (2021). Clinical outcomes of robotic surgery compared to conventional surgical approaches (laparoscopic or open): a systematic overview of reviews. *Annals of Surgery*, *273*(3), 467-473.
7. Stewart, C. L., Ituarte, P. H., Melstrom, K. A., Warner, S. G., Melstrom, L. G., Lai, L. L., ... & Woo, Y. (2019). Robotic surgery trends in general surgical oncology from the National Inpatient Sample. *Surgical Endoscopy*, *33*(8), 2591-2601.
8. Hussain, A., Malik, A., Halim, M. U., & Ali, A. M. (2014). The use of robotics in surgery: a review. *International journal of clinical practice*, *68*(11), 1376-1382.
9. Lanfranco, A. R., Castellanos, A. E., Desai, J. P., & Meyers, W. C. (2004). Robotic surgery: a current perspective. *Annals of surgery*, *239*(1), 14.
10. Morris, B. (2005). Robotic surgery: applications, limitations, and impact on surgical education. *Medscape General Medicine*, *7*(3), 72.
11. Tan, Y. P., Liverneaux, P., & Wong, J. K. (2018). Current limitations of surgical robotics in reconstructive plastic microsurgery. *frontiers in surgery*, *5*, 22.
12. Howe, R. D., & Matsuoka, Y. (1999). Robotics for surgery. *Annual review of biomedical engineering*, *1*(1), 211-240.
13. Terra, R. M., Leite, P. H. C., & Vega, A. J. M. D. (2021). Global status of the robotic thoracic surgery. *Journal of Thoracic Disease*, *13*(10), 6123.
14. Sheetz, K. H., Claflin, J., & Dimick, J. B. (2020). Trends in the adoption of robotic surgery for common surgical procedures. *JAMA network open*, *3*(1), e1918911-e1918911.
15. Taylor, R. H., & Stoianovici, D. (2003). Medical robotic systems in computer-integrated surgery. *Problems in General Surgery*, *20*(2), 1-9.
16. Kazanzides, P., Zuhars, J., Mittelstadt, B., Williamson, B., Cain, P., Smith, F., ... & Musits, B. (1992, October). Architecture of a surgical robot. In *[Proceedings] 1992 IEEE International Conference on Systems, Man, and Cybernetics* (pp. 1624-1629). IEEE.
17. Buzurovic, I., Podder, T. K., Fu, L., & Yu, Y. (2010, May). Modular software design for brachytherapy image-guided robotic systems. In *2010 IEEE International Conference on BioInformatics and BioEngineering* (pp. 203-208). IEEE.
18. Jung, M. Y., Deguet, A., & Kazanzides, P. (2010, October). A component-based architecture for flexible integration of robotic systems. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 6107-6112). IEEE.
19. Thrun, S. (2010). Toward robotic cars. *Communications of the ACM*, *53*(4), 99-106.

20. Antonelli, G., Baizid, K., Caccavale, F., Giglio, G., Muscio, G., & Pierri, F. (2014). Control software architecture for cooperative multiple unmanned aerial vehicle-manipulator systems. *Journal of Software Engineering for Robotics*, *5*, 1-12.
21. Berger, C. (2014). From a Competition for Self-Driving Miniature Cars to a Standardized Experimental Platform. In *Concept, Models, Architecture, and Evaluation," Journal of Software Engineering for Robotics*.
22. Parker, L. E. (1998). ALLIANCE: An architecture for fault tolerant multirobot cooperation. *IEEE transactions on robotics and automation*, *14*(2), 220-240.
23. Cepeda, J. S., Soto, R., Gordillo, J. L., & Chaimowicz, L. (2011, November). Towards a service-oriented architecture for teams of heterogeneous autonomous robots. In *2011 10th Mexican International Conference on Artificial Intelligence* (pp. 102-108). IEEE.
24. Volpe, R., Nesnas, I., Estlin, T., Mutz, D., Petras, R., & Das, H. (2001, March). The CLARAty architecture for robotic autonomy. In *2001 IEEE Aerospace Conference Proceedings (Cat. No. 01TH8542)* (Vol. 1, pp. 1-121). IEEE.
25. Satava, R. (2000). Innovative technologies. The information age and the biointelligence age. *Surgical endoscopy*, *14*(5), 417-418.
26. Mascagni, P., Longo, F., Barberio, M., Seeliger, B., Agnus, V., Saccomandi, P., ... & Diana, M. (2018). New intraoperative imaging technologies: Innovating the surgeon's eye toward surgical precision. *Journal of surgical oncology*, *118*(2), 265-282.
27. Knight, S. R., Ots, R., Maimbo, M., Drake, T. M., Fairfield, C. J., & Harrison, E. M. (2019). Systematic review of the use of big data to improve surgery in low-and middle-income countries. *Journal of British Surgery*, *106*(2), e62-e72.
28. De Mauro, A., Greco, M., & Grimaldi, M. (2016). A formal definition of Big Data based on its essential features. *Library review*.
29. Maier-Hein, L., Vedula, S. S., Speidel, S., Navab, N., Kikinis, R., Park, A., ... & Jannin, P. (2017). Surgical data science for next-generation interventions. *Nature Biomedical Engineering*, *1*(9), 691-696.