International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Applications of Robots in Medical Sciences

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ABSTRACT

Human research has always been going on in the direction of reducing human intervention in every field to reduce human errors. In Medical field, too, robots have been in application since the first surgical robot, PUMA 560, was used in 1985 in a stereotaxic operation, in which computed tomography was used to guide the robot as it inserted a needle into the brain for biopsy. Medical robotics are mainly categorized into 3 types: a) Macro robotics which mainly deal with large size robots like automated wheelchairs, b) Micro robotics which are mainly used in advanced surgical techniques like Minimally Invasive Surgery (MIS), c) Bio robotics which mainly deal with simulating biological systems. Telesurgical robotics has appeared as the first area of medical-surgical robotics to reach true global clinical adoption as a workable solution for robot-assisted minimally invasive surgery (RAMIS). The specific human-in-the-loop control, wherein the skilled surgeon is always held accountable for the clinical outcome obtained by the robot-actuated invasive equipment, is the reason for its promising performance (still at a low percentile total market penetration). In this paper, we are going to discuss the several types of robots which are implemented in the medical field till today and the advancements made in them in some of the major fields in which they are employed, like Robotic Laparoscopy, MRI-guided surgery, Radiosurgery, Soft Robotics, Minimally Invasive Surgery etc.

Keywords: MIS, RAMIS, Medical Robotics, Laparoscopy, Surgical robot, Soft Robotics, Radiosurgery

1. Introduction

Robotics is one of the most advanced fields today. There are many situations where Robots are used as alternatives for human labour as human intervention can lead to human errors. And the one field where human errors can be fatal is the medical field. So, there have been many advancements in Robots used in medical sciences. Many innovative technologies are being developed using medical robots as base such as Minimally Invasive Surgery (MIS), Robotic laparoscopy, orthopaedics etc. Medical robots are also invaluable players in non-pharmaceutical treatment of disabilities.

In recent years, flexible electronic interfaces and soft robotics have attracted tremendous attention in this field due to their high biocompatibility, functionality, conformability, and low-cost. The earliest roboticists started investigating the use of robot manipulators for surgical procedures just more than 30 years ago. Hospitals implemented the first commercial systems twenty years ago. Millions of procedures have been carried out thanks to the growth of the field of medical robotics over the last ten years, which has resulted in the installation of thousands of robotic surgical systems in hospitals throughout the globe. Robotics researchers have increasingly concentrated on what the future generation of medical robots might like since it has become obvious that current healthcare systems embrace surgical robots.

Other aspects of medicine are also being investigated, so their focus is not just on surgical robots. The history of the discipline is thoroughly covered in the literature, but the original purpose of medical robots was to enable surgeons to operate on their patients remotely and/or with more accuracy. The early initiatives can be linked to uses in orthopaedic and neurosurgery. Twenty years ago, a transatlantic cholecystectomy was done as the first true long-distance telesurgery. Although the field's early development was somewhat erratic, as is to be expected with the launch of any completely modern technology, robot - assisted surgery has matured to the point that the health care sector is now willing to invest significantly in research and development.

2. Literature review

In “A decade retrospective of Medical robotics research from 2010 to 2020”, P. E. Dupont et al., discussed the most advancing technologies in the medical field in the past decade and the various new Robotic equipment invented. [1]

A platform for cooperative study on developments in surgical robotics is the Raven-II. Seven universities have started using this platform for research. Dual 3-DOF spherical positioning systems on the Raven-II system allow for the attachment of swappable four-DOF instruments. To make software development as simple and efficient as possible, the Raven-II program is implemented on open standards like Linux and ROS as discussed by B. Hannaford et al. [2]

A telerobotics study platform that makes open-source hardware and software available for total access to all control levels was presented by P Kazanzides et al. The electronics use an FPGA to provide a dispersed I/O and centralised computation architecture, where low-latency I/O is carried out via an IEEE-

1394a (FireWire) bus at rates up to 400 Mbits/sec while all control calculations are conducted in a familiar development platform (Linux PC). The mechanical parts are from first-generation da Vinci ® Surgical Systems that have been discontinued. With 11 research institutes now using this system and more installing it, a research community is being built around a shared open-source platform for hardware and software. [3]

Although the usage of robots has been growing for around 75 years, the medical industry as a whole has only just begun to grasp its potential. This first-person account traces the growth of robots for the clinical society, the contribution of military medical research, and many of the key initiatives that helped robotics achieve its present level of accomplishment. [4]

Telerobotic systems' quick development opened the door to new uses outside of the industrial and nuclear fields. Surgeons can now execute medical procedures from remote locations, away from their patients, thanks to medical telerobotics. Telesurgery solutions facilitate the production of perfect surgical circumstances and offer a high degree of flexibility and general performance improvement. The initial attempts to create telesurgical devices adapted the concept from space exploration, where the demand for unique robotics for intrusive treatment even under severe circumstances, like weightlessness, emerged. Following the same principle, telesurgical devices on Earth first targeted military uses before moving on to civilian ones. Globally, more than 1.5 million patients receive telerobotic care each year. [8]

Robots have had a significant influence on laparoscopy, neurosurgery, orthopaedic surgery, emergency response, and many other areas of medicine since they were first utilised in medicine in 1985. This article covers the capabilities of contemporary medical robot systems and offers a history of medical robots. It largely focuses on commercial products systems while also mentioning a few notable research initiatives. Trends that suggest future capabilities of surgical robots may be seen by comparing robotic systems across disciplines and time, such as greater intraoperative imaging use, enhanced mechanical arm design, and tactile feedback to assist the surgeon. [13]

3. Robotic Laparoscopy

When it comes to surgeries, there are a variety of ways to approach it. One method is robotic laparoscopy. With this method, a robot is used during the procedure. While it is not a popular approach for many surgeons, it is definitely worth looking into if you are going to have a surgery. Surgery can be scary for patients, so having a robot to perform the surgery alleviates a lot of that fear. The subfield of medical robotics known as laparoscopic robotics may be the most developed and, undoubtedly, the most lucrative. Three areas have shown advancement in the last ten years: clinical, commercial, and academic. Clinical research has accounted for an increasingly generous part of laparoscopic robot research. For various surgical procedures, many studies compare the effectiveness of the robot with conventional (often manual laparoscopic) approaches. Examples include research on hysterectomy, rectal cancer resection, radical prostatectomy, and radical cystectomy for bladder cancer.

Commercially, the da Vinci robot produced by Intuitive Surgical has continued to evolve over the past ten years [1]. This system features enhancements to the instrument coupling, the ability to mount endoscopic and laparoscopic instruments on any arm (earlier models had a dedicated endoscope arm), and semi-automated arm and patient cart positioning. At least 50 new instruments have been made available for the da Vinci over the past ten years. According to their annual report, the da Vinci has also seen a sharp increase in use, with more than 1.2 million procedures carried out in 2019.

Radical prostatectomy, a radical cystectomy for bladder cancer, the excision of rectal cancer, and hysterectomy are just a few of the procedures that laparoscopic robots are used for. Robotic versions of manual medical tools such as catheters, bronchoscopes, uteroscopes, and colonoscopes are known as continuum robots [2]. In addition to device implantation in the brain and microsurgery within the eye, non-laparoscopic robots have been created for a variety of uses. Soft sleeves that help the heart contract have been made using soft robotics, and they have also been used to rehabilitate the hands for daily activities. When a person has mobility limitation or has had a limb amputated, assistive wearable robots are employed to supplement or replace arm and leg movements.

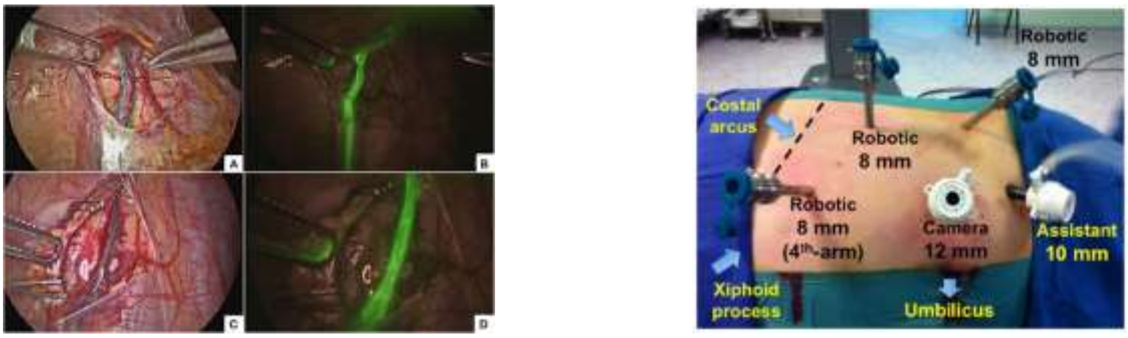

Fig. 1 - (a) Operating Procedure; (b) Robot Assisted Radical Prostatectomy.

4. MRI-Guided Surgery

Employing medical imaging to direct surgical operations has several documented benefits. A description of numerous such examples was created by a research consensus panel from the Society of Interventional Radiology. As MRI gives better soft-tissue contrast and spatial resolution, using it to guide therapies has distinct benefits over using CT and ultrasound for the viewing of soft tissues [3]. Additionally, MRI offers concurrent imaging of soft tissue and interventional tools (such as needles and catheters), allowing for interactive adjustment and control of the interventional strategy. Additionally, MRI has the ability to sense a wide range of physiological signals, such as oxygenation, flow, temperature, strain, and others as a multiparametric imaging technique.

The ability to improve accuracy is one of the main advantages of MRI-guided robot-assisted procedures. Because of closed-loop control and well-coordinated multi-axis motion, robotic aid may increase positioning precision and repeatability. To make sure that the operative plan is carried out as intended, intraoperative MRI may specifically measure tissue movements and tool deflection.

To dynamically modify intervention tactics, imaging can help with instrument monitoring and motion compensation. As a striking example, Hatiboglu et al. discovered that in more than 40% of documented glioma surgery instances, the surgeons revised their surgical strategy based on newly acquired data from intraoperative MRI. Additionally, robot-assisted treatments with MRI guidance can considerably enhance ergonomics. The closed-bore scanner makes manual interventions difficult and, in some situations, impossible from an ergonomic standpoint. The distance to the isocenter of a conventional closed-bore MRI scanner is 75–90cm, with a bore diameter of 60–70cm [4]. Additionally, while extending into the bore, it is challenging to view intraoperative MRI. Although there have been more low field open scanners developed for surgical interventions, their field strength and picture quality are inferior to that of an adoption of high field closed-bore diagnostic scanner. Between MRI-guided and fluoroscopy-guided treatments, Fernández-Gutiérrez et al. examined the ergonomic procedural differences.

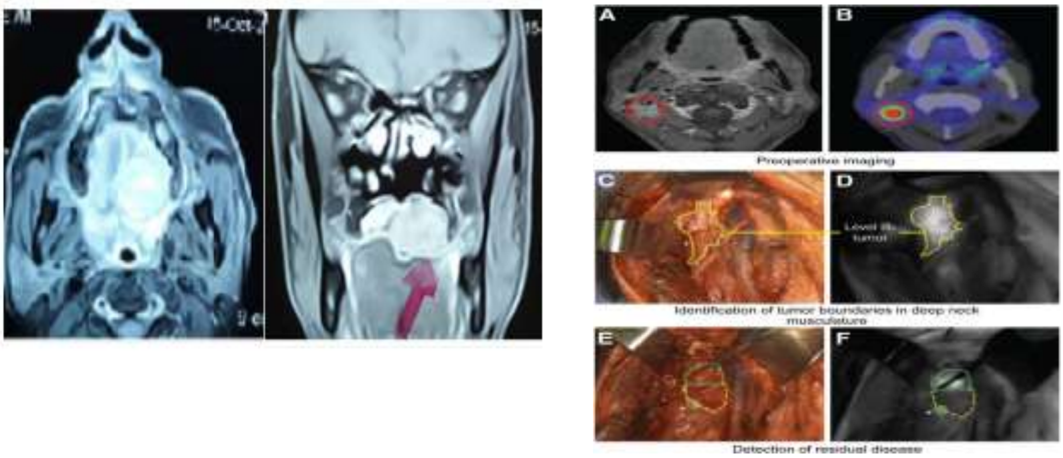

Fig. 2 - (a) Axial & coronal MRI of palatal mass; (b) Disease detection.

5. Radiosurgery

Focused beams of ionizing radiation are aimed at the patient during radiosurgery, a form of therapy (not surgery), largely used to treat malignancies [5]. High-dose radiation is supplied to the tumour while the epithelial layer receives much less radiation by orienting the radiation through the tumour at different angles. Before real-time tissue monitoring, radiosurgery was essentially restricted to employing stereotactic frames attached to the cranium with bone screws to treat the brain. Systems are now marketed because actual tissue tracking is practical. The goal of radiosurgery is to treat diseases of the brain, spine, and nervous system with a high level of precision through the use of focused beams of radiation. This technique is able to focus on small target areas with minimal damage to surrounding tissues.

A prosthetic arm having a linear accelerator, a six-degree-of-freedom robotic patient table termed the RoboCouch, as well as an X-ray image processor that can simultaneously capture images in two perpendicular orientations in real time are all components of the frameless radiosurgery system known as the CyberKnife (Accuray Inc.) [6]. The two concurrent intraoperative X-ray pictures are used to register a high-quality preoperative CT image but are insufficient to offer a clear description of the tumour. The premeditated radiation dosage can then be administered using a variety of orientations by the robotic arm. A frameless system with a linear accelerator, the Novalis using TrueBeam STx (BrainLab Inc. and Varian Medical Systems, formerly Novalis and Trilogy, first FDA certification 2000) uses micro-multileaf collimators for beam shaping [7].

Intraoperative X-rays are compared to CT scans similarly to CyberKnife, and epidermis fiducials are visually monitored in real-time. Cone beam CT is also a part of the delivery system. The patient is positioned on top of a robotic sofa with six degrees of freedom. The Cyberknife radiation source offers more flexibility in how it can be positioned around the patient than the Novalis, which can also shape the beam of radiation and claim a lower out-of-field dosage.

Fig. 3 - (a) CyberKnife model; (b) Left Trigeminal Neuralgia scan.

6. Soft Robotics

It is difficult to pinpoint the robotics breakthrough that gave rise to the discipline of soft robotics in medicine. Robotics built on soft principles, naturally flexible structures, and intelligent materials have always been intricately linked to biomimetics and bioinspiration. The research on intelligent materials that may be used to fabricate soft robots or to give soft robots actuation and sensing abilities, from the macro-scale through to the nanoscale, has been prompted by the rising interest in bioinspired robots with flexible bodies [8]. Even though it has not yet created paradigmatic instances of medical robotic systems, the discipline of soft robotics is guiding the research and development of the majority of medical instruments. Parallel to this, research in soft substances and cutting-edge manufacturing techniques is being encouraged by soft robotics, which may lead to unanticipated developments in biomedical applications.

As an illustration, the majority of research on prosthetic skins with sensing devices has been done for soft robots and other soft devices. If one looks at the literature from the past ten years [1], there are a lot of fundamental reviews and surveys on soft and bioinspired robotics for many applications (including medicine, in which the issue of intrinsic safety is highly relevant), as well as a lot of papers and reviews on innovative smart materials where conventional silicon-based technologies for detection are supplanted by silicone-based innovations with smart behaviour. Excluding materials articles and survey papers from the last ten years' most-cited papers, two categories of medical works may be distinguished: One consists of portable soft robots for human enhancement or rehabilitation, which have been discussed in earlier sections.

The second category consists of surgical and interventional robots as well as their component parts. Three parallel subtopics may be found in surgery and intervention: Soft, bioinspired, or responsive components, which can function as standalone devices or could be incorporated into more conventional systems, including soft devices for treatment or intervention, in which the entire conventional equipment is substituted by a soft robotic layout, at both the macro and micro scale [9]. For surgery and endoscopy, various intriguing designs of modular devices with variable stiffness have been created and advanced to the preclinical or cadaver test stage. By simply varying the rigidity of the various parts, surgical manipulators may be transformed into octopus' arms or elephant trunks with the potential to do multiple jobs with a single arm. With the invention of soft-body capsules for conducting targeted medication administration, as already shown, relevant findings have also been obtained by using soft robotics technology to gastrointestinal capsule endoscopy.

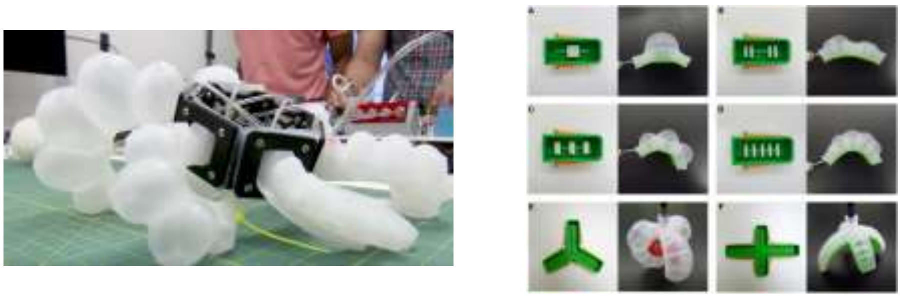

Fig. 4 - (a) Soft Robot prototype; (b) Movement Range.

7. Minimally Invasive Surgery

Although the precise creator of the concept of tele robotic surgery has not been found, some early pioneers at the U.S. National Aeronautics and Space Administration (NASA), the U.S. Department of Defense, and the Defense Agency for Advanced Research Projects (DARPA) established the foundations and the late 1960s saw the beginning of the domain's foundations, influenced by the remote controls used in nuclear power–Facilities and space development. Because of this, the first FDA-cleared product has achieved tremendous commercial success [10].

In 2000, it was clear that RAMIS system, an innovative system that numerous further studies and businesses focused on developing custom systems with minimal to no divergence, named da Vinci was developed. The former was passed by intuitive [11]. Computer Motion (Goleta, California, USA), a rival, in 2003, and their Zeus Robotics Surgical System was discontinued [10]. The several types and adaptations of these systems were examined in a recent analysis by Moglia et al. The advancement of surgical automation and the incorporation of force sensing into laparoscopic tools, along with novel robot architectures designed to minimize procedural invasiveness, were among the early efforts that Dupont et al. identified as the most significant advancements of the previous ten years. The DVRK, an open hardware and software platform developed first by Laboratory for Computational Sensing and Robotics (LCSR) at Johns Hopkins, Worcester Polytechnic Institute (WPI), and partners with funding from the Intuitive Foundation (https://www.intuitivefoundation.org/dvrk/), is arguably the most noteworthy recent achievement on the research platform front [12].

The most crucial aspect of a robotic system's applicability is likely its autonomy. The level of autonomy (LoA) idea, which was first put forth for the automobile sector, has also begun to be used in medical robotics to help identify and assess system capabilities. It expands on the traditional paradigm of task analysis along the generate-model-plan-execute cycle, an overarching autonomy notion seen in everything from mechatronics to image-guided interventional systems. Considering a large control loop frequency, the traditional surgical CAD/CAM control schematic is essentially applicable for even RAMIS systems. This proves that the core idea that digital information, through diagnostic imaging, image analysis, and robotic execution, allows accountable, measurable systems design, and quality management ideas in CIS, is entirely true in the case of RAMIS as well.

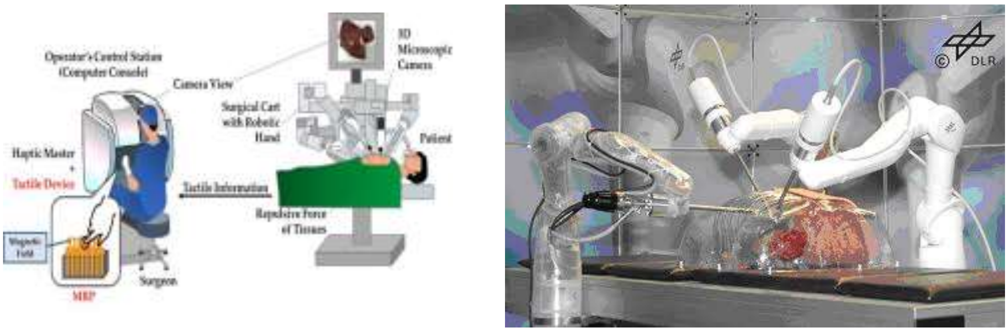

Fig. 5 - (a) RAMIS System; (b) Da Vinci Robot.

8. Orthopedics

Precise and accurate bone excision is the anticipated orthopaedic advantage of robot aid. Robotic technologies can enhance the alignment of the implant with the bone and expand the contact area between bone and implant through effective bone resection, both of which may enhance functional results and implant lifetime.

Up to now, orthopaedic robots have focused on replacing or resurfacing the hip and knee (the Renaissance system and its spine usage being the only known exception). All methods employ bone screws or pins to localize the surgical site, unlike early systems that needed the bones to be set in place. Robodoc (Curexo Technology Corp., initially by Integrated Surgical Systems), which was utilized for the first time for a complete hip replacement in 1992, provided the first robotic help for orthopaedic surgery. Robodoc has acquired FDA certification for complete hip replacement (1998) as well as a CE mark (1996) [13].

The surgeon designs bone milling using OrthoDoc, a surgical planner, and the robot in combination with preoperative CT. The patient's leg is secured to the robot's pedestal during the surgery, and a secondary clamp identifies the femoral head to cause the robot to stop if the leg moves. The milling is then automatically carried out by Robodoc in accordance with the surgical plan. Such independent motions were used in many early surgical robotics projects, raising questions regarding the safety of both patients and medical professionals.

The RIO robotic arm, manufactured by MAKO Surgical Corp and formerly known as the Tactile Guidance System, was introduced and given FDA approval in 2008[14]. In addition to patellofemoral arthroplasty, the RIO is utilized to implant medial and lateral unicondylar knee components. In keeping with the movement away from autonomous robot actions, the surgeon and the RIO both grip the surgical instrument while they navigate the operative site. The arm's low friction, as well as low inertia design, makes it simple for the surgeon to maneuver the tool, back-driving the joint actuators in the process. The arm's role throughout the milling process is to serve as a haptic device, opposing actions outside the intended cutting envelope by gently forcing on the surgeon's hand. Unlike other orthopedic systems, the RIO relies on a video system to watch bone pins and instruments intraoperatively and instantly register the anticipated operating area to the patient in the operating theatre. This is in contrast to other orthopedic systems that need the bone to be secured in place. The technology shows potential as a surgical teaching instrument in this form.

Fig. 5 - (a) OrthoDoc; (b) Applications of OrthoDoc.

9. Conclusion

Robotics in the medical field have gone far past the testing stage and are in use all over the globe for various applications. Even now, due to the COVID-19 pandemic, many hospitals are more inclined to employ robotic devices in a wide range of tasks to reduce the exposure to pathogens as much as possible. They are also helping in limiting human contact. But the key issues in medical robotics right now are automation and autonomous decision-making.

As much as human research has progressed, complete automation is still not possible for medical robots, so there is always a supervisor needed. Also, due to the lack of autonomous decision-making, medical robots lack the adaptability needed in the medical field due to the many types of variations one can observe in every case, once again needing supervision.

These are the present issues being faced and the current research directions in the field of medical robotics.

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