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# Research on the Progress of Autonomous Technology in Robot Assisted Surgery

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***Abstract:*** Since the introduction of robotics technology into the operating room in the mid-1980s, doctors and researchers have been seeking to integrate higher intelligent technologies with robotic systems. Compared with conventional surgeries, surgical robot systems with higher intelligence often require higher security and accuracy, and can make decision adjustments through matching perception systems and the current surgical stage. Although a fully autonomous surgical robot system is still some distance from true clinical use. But with the accumulation and development of technology, robot intelligence technology with semi autonomy and partial doctor participation in decision-making will gradually be introduced into the operating room, providing a better platform for clinical surgery. This article mainly summarizes and prospects the current progress of robot assisted surgery and related intelligent technologies.

## 1. Introduction

Robot autonomy refers to the completion of some or all tasks by intelligent robot systems in the execution of tasks, often used in industries, services, and other fields. The rational introduction of intelligent technology in robot assisted surgery has always been a concern for researchers and clinical doctors. Robot assisted surgical operations must ensure safety and accuracy. Therefore, robot assisted surgery systems need to fully perceive the environment and patient status, and be able to make decisions in different situations to adapt to changes in the environment. In surgical procedures, some tasks that are relatively easy to implement have been applied, such as reducing hand tremors. However, some autonomous operations, such as robot assisted cardiac ablation or tumor resection, currently need to be carried out under the control of doctors. The current development of artificial intelligence is far from achieving fully autonomous surgery. However, semi-autonomous robots, with their advantages of automatically performing repetitive operations, help doctors focus their attention on important surgical tasks, thereby ensuring and improving surgical treatment effectiveness. Research and technology related to achieving intelligent operation tasks of surgical robots. Examples include robot design and control, integration of medical image processing, real-time signal processing, artificial intelligence, and machine learning. This article will introduce these technologies separately.

## 2. Types and related systems of surgical robots

### 2.1 Autonomous surgical robots

#### 2.1.1 The category of autonomy

As the foundation of autonomous categories, automation technology has a wide range of applications in surgical robots. According to the degree of user interaction, it can be divided into direct/bilateral teleoperation, shared control or Supervisory control. Yang Guangzhong and others analyzed the intelligence level of medical robots [1]. Medical robots are divided into six levels: non autonomous, auxiliary autonomous, task autonomous, conditional autonomous, highly autonomous, and fully autonomous. At the same time, in the discussions and technical reports of the ISO/IEC joint working group, autonomous robot technology was similarly divided into six levels [2].

#### 2.1.2 Advantages of autonomous surgical robots

Autonomous surgical robots can perform autonomous processing of some surgical tasks during the surgical process. Surgeons excel in making high-level decisions about patient management. But not all have the ability to perform high-precision tasks. Especially factors such as hand shaking caused by fatigue after prolonged operation can easily reduce the stability of fine surgical tasks. Overworked doctors often experience problems such as lack of concentration and may also lead to human decision-making errors. Autonomous robot operation avoids the occurrence of such problems and can ensure the standard and quality of surgical treatment process.

Compared to traditional manual surgery, robotic surgical systems can provide greater flexibility [3]. The widely used Da Vinci robotic surgical system has been clinically validated [4,5]. The endoscopic robots and catheter robots assisted by medical image navigation technology (Hansen Medical System) have the potential to locate the robot end to complete related surgical operations without the need for clinical doctor control [6]. Not only does it reduce the time spent by doctors on learning related procedures, but it also helps surgeons avoid radiation generated by X-ray machines and other fluoroscopy equipment [7, 8].

The autonomy of robot assisted surgery also has certain advantages in hospital admission and treatment of patients. Compared to traditional laparoscopy, Da Vinci robots require more skilled technicians during the surgical process. For example, intraoperative assistants need to perform operations such as tissue retrieval, suturing, aspiration, and disinfection. If the robot system can independently complete the above operations, on the one hand, it can improve surgical efficiency and allow doctors to invest in more surgeries. On the other hand, skilled surgical personnel can be reassigned to other areas of the hospital, further improving the operational efficiency of the hospital.

### 2.2 Commercial robot systems

Since the commercialization of AESOP1000 in 1994, several surgical robots have been successfully commercialized (as shown in Figure 1). At present, some commercial surgical robots adopt shared control and supervised autonomous systems, which have achieved a certain degree of autonomy. However, the surgical tasks performed by such products are usually routine and require a high level of involvement from doctors before and during surgery. This type of product combines the advantages of robots in computation and mechanization with the scene understanding and high-level intelligence of surgeons. Therefore, it has been successfully applied in clinical practice. The Probot, developed in 1991 at the Imperial College of Technology in the UK, is one of the earliest autonomous surgical robot systems to be applied in surgery. This robot is designed for transurethral prostatectomy [9]. During robot surgery, doctors can stop the robot from performing unexpected actions by controlling the Manual fire alarm activation [10, 11].

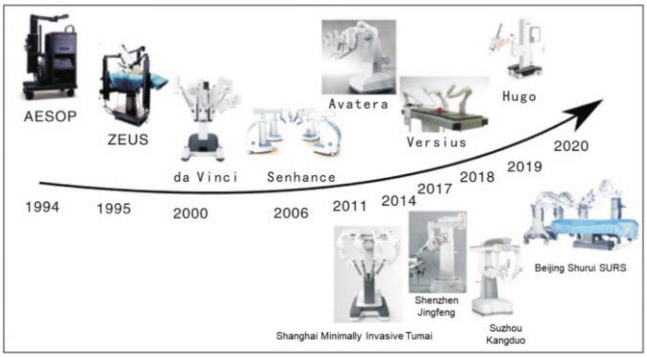



Figure 1 Some commercialized robotic surgical systems at home and abroad

The Acrobot system was developed by Imperial College of Technology in 1991 and commercialized by Acrobot Limited [12]. Unlike Probot, the Acrobot system allows doctors to directly control the system during operation. And during the surgical process, the robot's movement can be limited to a pre designed safety area. If the doctor's operation exceeds the safe area during the surgery, there will be some resistance to avoid further incorrect operations [13,14].

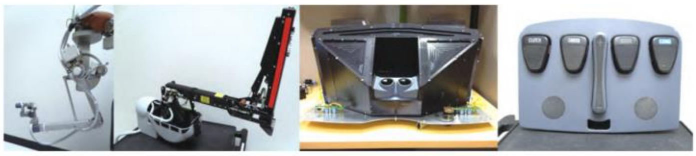
ROBODOC and CyberKnife systems are supervised autonomous surgical robot systems used in clinical applications such as orthopedics and stereotactic radiosurgery, respectively. Both robots utilize preoperative imaging data for surgical planning and are able to perform surgical planning without external interference during surgery (except in emergency situations). The difference between these two robots lies in how to solve the registration problem between preoperative images and intraoperative patients [15]. The ROBODOC system requires patients to be fixed and preoperative images to directly generate surgical plans. Cyber Knife uses real-time imaging and tracking technology to develop surgical planning. Therefore, it can solve problems such as displacement caused by patient breathing movements [16,17].

In recent years, Chinese surgical robots have also developed rapidly. In 2014, MicroPort Robot (Group) Co., Ltd. began to independently develop domestic surgical robot system. As of 2021, it has become the second clinically applicable single hole endoscopic surgery robot in the world. At the same time, it has completed all clinical trials for registration, becoming the first domestic endoscopic surgery robot that has completed multi center registration of clinical trials in the field of Urology. Established in 2017, Shenzhen Jingfeng Medical Technology Co., Ltd. has developed rapidly in three technical directions, namely, multi hole Laparoscopy robot system, single hole Laparoscopy robot system and ultra-high-definition stereoscopic endoscope, and has entered the clinical trial stage in 2021. Suzhou Kangduo Robot Co., Ltd., founded in 2014, mainly focuses on the research and development of laparoscopic Minimally invasive procedure robots. At present, it has been conducting animal experiments and clinical trials. Founded in 2014, Beijing Shurui Co., Ltd. has become the first enterprise in China that can independently and completely develop the third generation Minimally invasive procedure robot system relying on the core technology of the new generation of flexible continuum manipulator. A large number of animal experiments have been completed and clinical registration is underway. With the improvement of technology and clinical development, commercial surgical robots will gradually be widely used in clinical scenes such as gynecology, interventional medicine, orthopedics, and Neurosurgery.

### 2.3 Research Robot System

Surgical autonomy is committed to improving the safety and reliability of the system, and has gradually become a research hotspot in this field, attracting the attention of many researchers. The open-source robot system provides a good platform for promoting the development of research in this field. It is particularly important to use open-source research platforms to simulate surgical processes and test new technologies before truly entering clinical trials. This section will introduce several mainstream open-source surgical robot platforms.

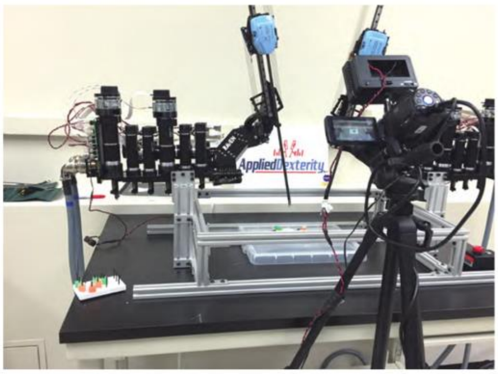
The Da Vinci Research Kit (referred to as "D VRK" for short, as shown in Figure 2) is an open-source control system based on the first generation of Da Vinci surgical robots [18]. The research tool is hardware provided by Intuitive Surgical in the United States. The system includes two main segment operators (Masters) and two robotic arms (Slaves) that enter the patient's body and 1 high-resolution endoscope and foot pedal equipment. At present, more than thirty universities around the world have owned this platform and have conducted research on autonomous surgical tasks such as debridement and tissue cutting based on this platform.



(Source: https: //www.intuitive-foundation.org/dvrk)

Figure 2 Da Vinci research kit

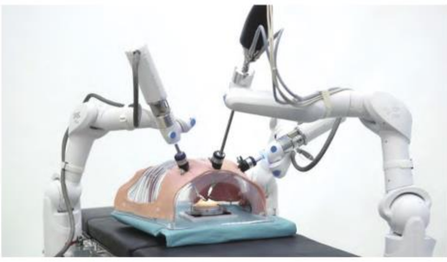
Raven II surgical robot platform is an open-source robot platform developed by the University of Washington for laparoscopic Minimally invasive procedure (as shown in Figure 3). Currently, Applied Dexterity is responsible for its commercialization and management. Unlike d VRK, the original intention of the Raven II system is to encourage interdisciplinary and interdisciplinary cooperation among researchers to improve the intelligence and stability of the platform [19]. The Raven II system includes two-line driven laparoscopic arms that can be independently installed on both sides of the surgical site and enable collaboration among four robotic arms in one space to complete the surgery. At present, the Raven II surgical robot system has been installed in nearly 18 universities and research institutions around the world and has been used for autonomous research on fourth class surgical tasks such as tumor ablation and debridement [20].




(Source: http: //applieddexterity.com)

Figure 3 Raven II surgical robot platform

The Miro Surge system developed by the German Aerospace Center is also a research platform dedicated to laparoscopic Minimally invasive procedure (Figure 4). Most components of the system, including position sensors, are installed on the robotic arm. The overall weight of the robotic arm is relatively light, and it can be installed on ceilings or even walls, with good adaptability and versatility. Although Miro Surge is able to perform some autonomous surgical procedures, its research team has not yet made any attempts or promotions related to it [21].



(Source: https: //www.dlr.de)

Figure 4 MiroSurge surgical robot platform

In addition to the above research platforms, there are also research groups using industrial or collaborative robotic arms to carry out research on the autonomy of some surgical procedures [22, 23]. This type of robotic arm provides certain support for high-level autonomous operation in terms of operability, but it is difficult to apply to clinical practice. However, the algorithms and related research developed around specific clinical needs still have certain significance and value. And it can be flexibly applied to different robot assisted surgical platforms. Thus, further promoting the development of autonomous technology for surgical robots applied in different clinical scenarios. At the same time, this also puts forward higher requirements for the structure, driving, perception, and control of robot systems.

## 3. Autonomous robot assisted surgery related technologies

### 3.1 Mechanism and Drive

#### 3.1.1 Surgical robot mechanism

The mechanisms of surgical robots mainly include Remote Center of Motion (RCM), series mechanisms, parallel mechanisms, and continuum mechanisms [24-26]. Remote Center of Motion refers to a mechanism where the output components of the mechanism can rotate around a fixed point in space. Typical RCM mechanisms include dual parallelogram RCM mechanisms and dual synchronous belt RCM mechanisms. Among them, the double parallelogram RCM mechanism has simple structure, high rigidity and precision, such as the "Shendao Huatuo" Minimally invasive procedure robot and the "Huaque I" Laparoscopy robot all use this type of mechanism. The dual synchronous belt RCM mechanism has fewer joints and links and a compact structure, such as Da Vinci Surgical System and "Revo-I" Minimally invasive procedure robot. The tandem mechanism is composed of a series of simple single degree of freedom rigid joints in series, such as the "smart hand S" robot of Tianjin University. Parallel mechanism is a closed-loop mechanism composed of multiple parallel chains, which has the characteristics of small movement inertia and precise control. LIC et al. developed a flexible parallel mechanism based on 3-PRS parallel mechanism, combined with Hyperelastic material nickel titanium alloy rod, and applied it to the natural cavity surgical robot [27]. Shen Tong and others proposed a new type of hybrid Laparoscopy robot through two decoupled parallel mechanisms. A continuum mechanism is an executable mechanism composed of materials with continuous tangent vector curves, which utilizes the elastic deformation of the material to transmit motion and force.

#### 3.1.2 Surgical robot drive

The driving modes of surgical robot mainly include rope driving, Smart material driving, fluid driving and magnetic driving [28]. As a flexible transmission, rope drive can transmit power through flexible sleeves and pulleys, with advantages such as light weight and good biocompatibility, and is widely used in various surgical robots. For example, Leonardo da Vinci Endo Wright Minimally invasive procedure robot for Laparoscopy. Smart material drive is to drive the end effector of surgical instrument through the deformation of Smart material. Typical Smart material, such as Shape Memory Alloy, can have regular shape changes when the temperature changes. Control the shape of SMA by adjusting temperature. Based on SMA drive, YUANX et al. proposed a laparoscopic Minimally invasive procedure robot. Fluid drive has the same characteristics as rope drive [29].

Due to the high flexibility of the fluid, it can drive the end effector of minimally invasive instruments through a catheter. Eastwood K et al. used miniature high-purity silicone tubing and silver-plated woven mesh to create 10 shrinkable fluid driven actuators [30]. Magnetic drive uses a moving external permanent magnet or electromagnet to drive the internal magnet, transmitting power and torque from the external unit through the abdominal wall to the internal execution unit. Garbin K et al. proposed a single degree of freedom laparoscopic tissue dilator based on Local Magnetic Action (LMA).

### 3.2 Perception and Planning

The robot perception system utilizes sensors installed to transform the internal state information and complex surgical environment of the robot from physical signals to effective data information. The obtained information is used in autonomous surgery to match preoperative planning, achieve closed-loop feedback motion control, judge system state transmission, skill enhancement learning, and other related surgical records and human-machine interaction.

Accurate positioning of surgical instruments is a necessary condition for achieving surgical autonomy and ensuring surgical safety. Because the executive end of the surgical robot often has greater flexibility, it is difficult to ensure the accuracy requirements of automated surgery by deriving its spatial position through Inverse kinematics. The most commonly used method is to obtain the position of tracking instruments through visual image processing using an endoscope. In recent years, with the rapid development of deep learning, a large amount of research has also focused on how to use deep neural networks to segment and estimate instrument pose from images.

During the surgical process, soft tissues may undergo deformation and displacement due to physiological movements such as breathing and pulse, as well as interaction with instruments. Real time localization of soft tissues is a research focus of autonomous robotic surgery operations. The current research hotspot is the reconstruction and position estimation of endoscopic visual images through visual algorithms [31]. For the periodic movement of soft tissue, Moreira P et al. and BebekO et al. proposed real-time tracking and control compensation of target soft tissue position by monitoring the Contact force of the device and using ultrasonic sensing [32].

In addition, surgical robots need to accurately identify target tissues (such as diseased tissues) during the execution of tasks. Cheng Z et al. proposed a method of identifying different tissues by measuring the electrical properties of biological tissues to verify the feasibility of detecting deep pathological tissues [33, 34].

The research on the perception of surgical robots also includes integrating sensing information and proposing more accurate and efficient measurement methods. A study has proposed an active search perception method, which uses the measured results as a prerequisite to determine the next measurement point and optimize the region search process [35-37]. In addition, for the fusion method of multi-channel sensor information, the LI Y et al. have proposed relevant system architectures and algorithm designs [38].

## 3.3 Control and Learning

### 3.3.1 Control method

The simplest form of surgical robot control is to execute user-defined trajectories or operations without updating the plan during surgery. For safety reasons, doctors will monitor the implementation of this process throughout the entire process. This control form usually requires a precise calibration program. Therefore, it is often used in orthopedic surgery or Neurosurgery surgery [39]. Master slave control is a commonly used control mode in the existing Laparoscopy robots and intracavitary interventional robots [40]. This control method consists of two parts: the master hand and the slave hand. The doctor is usually located at the main hand end, while the end effector of the surgical robot serves as the slave hand end. The hand usually has a high degree of freedom to achieve complex surgical operations. The secondary hand can reproduce the movements of the main hand. At the same time, the position information of the hand and the surgical environment will also be transmitted to the doctor through visual feedback methods [41]. This control method enables doctors to perform surgeries remotely, reducing the harm of ionizing radiation to doctors, reducing their physical exertion, and improving the accuracy and safety of the surgery [42]. In the above two control methods, the surgical robot does not provide any assistance or guidance, only mechanically executes or replicates the doctor's commands.

Achieving a higher degree of automation helps assist doctors in better performing surgeries. Auxiliary control refers to the ability of robots to provide active assistance to doctors. In auxiliary control, surgical robots do not have the ability to perform tasks autonomously, and doctors continue to control the system. Surgical robots only provide assistance or guidance, or respond to doctors' operations. Auxiliary control has a higher degree of automation than direct control.

An example of auxiliary control is active motion compensation. The surgical effect will be affected by periodic movements such as the patient's breathing or heartbeat, so if these movements can be actively compensated for. It will reduce unnecessary contact between surgical robot actuators and the environment, thereby improving the effectiveness of surgery. Ruszkowski A et al. realized the compensation of heartbeat movement based on the da Vinci surgical robot for Coronary artery bypass surgery surgery [43]. This method can significantly reduce the surgical duration for doctors with the help of surgical robots. Yuen S G et al. modeled the motion of the mitral annulus and designed a motion compensation device based on this model to assist doctors in performing operations on the moving mitral valve [44].

With the development of image processing and visual communication related technologies, visual servo has also been applied as an auxiliary control technology in surgical procedures. In visual servo, information about surgical instruments and the surrounding environment is obtained through various imaging methods. This information will also be further used in the closed-loop control of surgical robots. Given the real-time requirements of surgical visual servo for imaging methods. The imaging methods currently available include ultrasound images, MRI, endoscopic images, X-ray, CT, etc. A representative related study currently is the movement of autonomous endoscopic cameras, such as Krupa A et al. using visual servo to automatically place surgical instruments at the center of the endoscopic image [45].

### 3.3.2 Autonomous surgery

Although the way of supervising the operation of Autonomous robot has been verified and applied in orthopaedic and Neurosurgery surgical robot systems, autonomous operation in Laparoscopy surgical robot systems is still in the exploration and research stage. With the massive accumulation of useful data during Laparoscopy and the improvement of autonomous operation standards and classifications, autonomous Laparoscopy robot programs are expected to be promoted in the future. However, there are still challenges in autonomous surgical robot technology for soft tissue or organ operating environments with physiological motion characteristics. Mainly focused on information acquisition and task execution. Therefore, a large amount of research work is being carried out around the next generation of cognitive surgical robots, in order to solve the above problems.

## 4. Existing challenges

### 4.1 Technical Issues

At present, most of the technologies related to autonomous surgical robots are still in the laboratory research and development stage, and it can be expected that when these technologies are truly applied in actual surgical environments, they will face greater challenges.

Currently, most surgical robot systems still only have visual feedback and lack force feedback. So, when the contact between the surgical instrument and the patient's soft tissue occurs outside the screen area (i.e., when the doctor lacks visual feedback), it will be very dangerous. Allowing surgical robots to have the ability to perceive and provide feedback can provide doctors with a "sense of presence", thereby significantly improving the safety of surgery. But so far, even with the famous Da Vinci surgical robot system, surgeons are unable to obtain complete tactile feedback. The foundation of force feedback is force perception, which can be divided into direct force perception and indirect force perception based on different principles. In direct force sensing, a force sensor needs to be installed near the end effector of the surgical robot. This design is usually difficult to implement because it is limited by factors such as sensor size, geometry, wiring, cost, biocompatibility, and disinfectability [46]. Although relay perception avoids the aforementioned difficulties, it requires complex tasks such as modeling and calibration of the robot system, which can easily lead to inaccurate force perception [47]. In addition, the control of surgical robots is also a major challenge, and the modeling and control of continuous surgical robots is even more challenging. Continuous surgical robots can enter the human body through natural channels or small wounds, and complete specific tasks through complex channels. However, due to the nonlinear characteristics of driving methods, manufacturing materials, and the influence of uncertain external environments, the modeling, navigation, and control of continuum surgical robots are also unresolved issues [48].

Due to the fact that the external environment of surgical robots is human tissue, the uncertainty of the surrounding environment is also a major challenge. For example, the difficulty of surgery caused by unavoidable human movements, such as breathing and heartbeat. Currently, many researchers have proposed different methods to achieve motion compensation [49]. Other noteworthy challenges include the miniaturization design of surgical robot components, robot manufacturing and driving in special environments, such as MRI compatible robots, imaging technology and sensor information fusion [50-52].

### 4.2 Ethical issues and related legislation

In recent years, the development of robot assisted surgery has been very rapid, but relevant legislation is still relatively lacking. With the continuous improvement of the automation level of surgical robots, the ethical issues and related legislative needs that arise from this still need to be addressed.

During the surgical process, the safety of the patient is always of paramount importance. Therefore, in the widespread use of robot assisted surgery, how to ensure patient safety is a question worth exploring. At present, due to the fact that most surgical robots are still at a relatively low level of autonomy, they do not have the ability or authority to make decisions. Therefore, doctors remain the primary responsible person for protecting the safety of patients. Even in the face of robot systems that achieve auxiliary autonomy (Level 1) and task autonomy (Level 2), doctors need to develop surgical plans or verify surgical plans developed by robots before they perform any actions. And supervise the autonomous operation of the surgical robot throughout the entire process. In addition, surgical robots can take further safety assistance measures through hardware or software. On the basis of doctor supervision, provide "dual insurance" for patient safety. As mentioned earlier, active motion constraints can constrain the motion range of surgical robots within a pre calculated safety zone.

Similar to the problem of responsibility division after autonomous vehicle accidents, if the surgical robot with a certain degree of automation makes mistakes, its responsibility division is still difficult to define [53]. At present, surgical robots are still considered as auxiliary tools rather than individuals with independent behavioral abilities. Therefore, doctors still need to be responsible for operational errors in robot assisted surgery [54]. But with the development of automation in surgical robots, the question of who should lead the surgery and who should be responsible for the surgery remains to be discussed. If a surgical robot makes a mistake, the individuals who may be responsible include the user (doctor) of the surgical robot, the hospital, the design and manufacturer of the robot, and the insurance company. How to comply with the development of surgical robot automation, carry out corresponding legislative work, and clarify the responsibilities of all participants in the process still requires continuous attention and consideration.

## 5. Clinical application

The surgical robots currently put into clinical application can be roughly divided into four categories according to the application scenarios: orthopedics, cardiovascular (catheter intervention), Neurosurgery and Laparoscopy robots. The automation of surgical procedures is still in its infancy. The collection and analysis of information, the formulation of surgical plans, and the execution of surgeries are important stages that still require a lot of research and accumulation. In clinical applications, it is particularly important to develop treatment plans based on preoperative imaging data of patients and match them based on the characteristics of the patient's organizational structure. However, from preoperative to intraoperative stages, the patient's organizational structure may experience some deviation due to physiological movements or movements, causing great difficulties in matching preoperative and intraoperative information. The early application of autonomous robotic surgery in orthopedic settings is due to the fact that bones are generally considered non deformable structures and easy to manipulate. The autonomous surgery of robots for soft tissue operations is still in the research stage. Mainly due to the susceptibility of soft tissue deformation, multiple methods need to be used during surgery to match and adjust the formulated surgical plan in real-time with the actual soft tissue environment. Compared with orthopaedic surgery, it involves more peripheral blood vessels and Nervous tissue. With the further development of technology, autonomous surgical robots targeting soft tissues will also be tested and applied in more clinical scenarios.

## 6. Conclusion

It is the ultimate goal of the development of surgical robots to enable surgical robots to have operating skills similar to or even beyond human surgeons, and it is also a necessary condition for full Autonomous robot surgery. In order to achieve the goal of full Autonomous robot surgery, researchers in the fields of doctors, robots, artificial intelligence, etc. need to work closely together to promote interdisciplinary cooperation. In order to achieve this goal, leading research teams and scholars in various industries are conducting further research work. The directions involved include two aspects: software and hardware.

In terms of software, it mainly relies on the breakthrough technological achievements made in the field of artificial intelligence in recent years. Such as Rote learning, deep learning, computer vision, virtual reality/augmented reality, etc. The areas to be improved include the robot's ability to perceive the environment, especially complex environments, and the ability to learn surgical skills from human doctors based on this. The existing surgical robot's perception ability still relies mainly on simulating and expanding the information required for human operations. For example, three-dimensional vision, force perception, and tactile perception. The autonomous operation and decision-making of future surgical robots require precise modeling, detection, and prediction of all possible operating environments. This places higher demands on existing perceptual abilities. Strong perception ability is an important foundation for surgical Robot learning to learn the surgical skills of human doctors. The surgical skills of surgeons can be essentially divided into lower-level operational skills and higher-level cognitive skills. Operational skills mainly involve the execution of specific surgical steps, which are relatively easy to model and learn under the observation of multimodal sensors. Cognitive skills mainly involve operational processes, intraoperative decision-making, and handling unexpected situations. Compared to operational skills, it is more difficult to model and learn. The skill learning ability of future surgical robots at these two levels will directly determine their level of autonomy during the surgical process. For example, progress in surgical robot operation skills and progress in cognitive skills.

In order to adapt to the development and needs of software, autonomous surgical robots have also put forward higher requirements for hardware in terms of multimodal sensors and flexible operating instruments. On the basis of further improving the accuracy of traditional sensors, the development of new sensors will enable surgical robots to have a deeper and more comprehensive perception of the operating environment. For example, Optical coherence tomography Angiography (OCTA) for blood vessel detection and GPS system for instrument positioning. In addition, the learning of surgical skills for surgeons also requires the collection and fusion of as many types of sensor information as possible, as well as the analysis and learning of multimodal sensor data through artificial intelligence technology. At the level of surgical operations, the development of new surgical instruments will alleviate the burden of controller design and improve the efficiency of specific traditional operations, thereby improving the feasibility and reliability of autonomous operations. The flexible surgical instruments currently in the research hotspot make it possible for minimally invasive or non-invasive surgery to reach the operating area through complex pathways. In the future, robot assisted flexible surgical instruments with more precise and comprehensive perception and planning functions will make surgical operations more efficient in complex environments. Thanks to the improvement of computer computing power and mechanical design accuracy, robot assisted instruments can achieve miniaturization and compactness without affecting operational accuracy and dexterity. Thus, expanding its application range. In addition, because it is not limited by the physiological structure of the human hand, the mechanical structure and control design of the surgical instruments of the full Autonomous robot can be more flexible. For example, the mechanical structure adopts a multi degree of freedom and parallel hybrid structure, while the control adopts methods such as separating the execution unit and power unit (wireless communication and wireless power transmission).

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