Innovations in laparoscopy: current trends and prospects for the development of surgical techniques

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Abstract
The article examines current trends and prospects for the development of surgical techniques in laparoscopy with an emphasis on innovation. The latest technologies and methods used in laparoscopic surgery, such as robotic surgery, improved video systems, three-dimensional visualization and telemedicine solutions, are highlighted. The authors analyze the benefits of these innovations, including more accurate and effective procedures, shorter patient recovery time, and reduced risk of complications. The challenges facing the introduction of new technologies, including the need for staff training and the high cost of equipment, are also considered. It is concluded that innovations in laparoscopy play a key role in modern surgery and have the potential to significantly improve patient outcomes in the future.

Keywords
Laparoscopy, Innovations, Surgical techniques, Current trends, Development prospects.

INTRODUCTION

Laparoscopy is a minimally invasive surgical procedure and allows surgeons to visualize internal organs on a large screen, which makes it possible to perform various surgical procedures [1]. This surgical procedure is characterized by a low degree of tissue injury, allows you to reduce pain after surgery and achieve a faster recovery of the patient. The use of laparoscopy reduces the risk of blood loss, infections and other complications associated with open surgery. Laparoscopes provide good visualization of internal organs thanks to high-quality cameras and optical systems, which allows surgeons to perform operations more accurately.

Laparoscopy is used for a wide range of surgical procedures, including gallbladder removal, appendicitis, gastric and small intestine surgery, hernia repair, etc. This method is becoming more common due to its advantages and the possibility of application in various fields of surgery.

Laparoscopic instruments and methods are constantly being improved, since the ability to perform minimally invasive operations is crucial in modern medicine. The shift from open surgery to minimally invasive surgery over time eventually led to the use of robotic devices that either assist or completely replace surgery on the patient's side with a separate console. Although robotic surgery has been praised for its surgical results, some situations limit its use, such as cost-effectiveness or physical space constraints.

The purpose of the study is to consider current trends and prospects for the development of surgical techniques with an emphasis on laparoscopy.

MATERIALS AND METHODS

While writing the paper, an assessment of existing studies, publications and clinical reports related to the application of innovations in endoscopy was carried out. New technologies and innovative techniques have been studied, such as robotic systems, improved video images, various manipulators, etc., as well as clinical data and observations obtained from doctors and sur-
geons applying innovative techniques in practice. The analysis of statistical data related to the results of the use of innovative techniques, including data on efficacy, safety and outcomes for patients, was also carried out. In the process of writing the study, comparative and analytical research methods were used.

RESULTS

The development of minimally invasive surgery began in the early 1900s, when D. Kelling performed a laparoscopic procedure in vivo for the first time [2]. However, this method of performing surgical operations was not widely used at that time due to the fear of specialists of possible risks of postoperative complications. And only in the late 1970s of the twentieth century, Dr. K. Nezhat began using video cameras during surgical procedures, after which laparoscopic surgery began to be taken more seriously and began to be considered as a promising area of surgical development [3].

At the present stage, laparoscopic surgical operations are no longer unjustified. The decision on when to perform the operation in an open, laparoscopic or robotic manner depends on various factors. The type of technique used also depends on the procedure (cholecystectomy, hysterectomy, etc.), the severity of the indications (disease progression, low/high risk) and surgical experience. Complications during surgery can change the technique, for example, the transition from laparoscopic surgery to open surgery in case of severe adhesions or the choice of another technique in case of complex anatomical changes [4].

Specific instruments are required for each type of surgical procedure. All methods of laparoscopic surgery require the use of an illuminated endoscope or laparoscope, which allows you to observe the picture in the human body during the operation. Advances in this field are currently associated with the use of three-dimensional (3D) cameras to improve surgical results. Trocars are used to gain access to the abdominal cavity by puncturing the muscles and fascia of the abdominal wall with a sharp edge, allowing other instruments to pass through a channel in the core.

Many different methods are used for laparoscopic access. The two main methods are the open entrance or Hasson entrance, in which the trocar is inserted before the trocar is inserted, and the closed entrance or insertion of the Veres needle, in which insufflation is performed before the trocar is inserted [5].

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Robotic surgery became widespread in the 1980s, and the first available surgical system was the da Vinci system. She uses the master-subordinate console, which allows the surgeon to operate remotely from the operating field. Today, this system is used for an increasing number of surgical procedures [6].

The system in question uses a binocular endoscopic camera and an eyepiece display on the console to create a stereoscopic image, providing the same sense of distance as in open surgery. Surgical instruments are equipped with a wrist-type mechanism driven by a wire, which allows performing various movements similar to the movements of a surgeon's hand in open surgery [7]. In addition, the surgeon can intuitively control the robotic arm through the main device on the control console, which allows for complex operations. Thanks to the control technology, the tremor of the operator's hands is filtered and scalable movement becomes available, which ensures an accurate and safe operation that is difficult to achieve with conventional surgery.

Robotic surgery not only replaces traditional laparoscopic surgery, but also allows for complex operations that are impossible with laparoscopic surgery. Recently, instead of adapting robots to existing operations, on the contrary, surgical techniques adapted for robots have been developed and published. In accordance with the direction of development of minimally invasive surgery, the da Vinci SP device was developed and entered the market, which can perform operations with a single hole [8].

In addition to being used in surgical procedures, Da Vinci is used for educational purposes as a virtual reality (VR) surgical simulator. This is due to Da Vinci's ability to visualize the operating field in three dimensions on the main console.

The first operation performed using the da Vinci robotic system was performed in Brussels, Belgium, in 2000, after it was introduced to Europe in 1997. A study conducted in 2001 examined the clinical feasibility of the da Vinci system, performed 146 operations with 11 types of interventions, discussed the
timing of operations and the preferred position of the trocar and the driven lever. The study recognized the need to improve both system protocols and system design, but praised da Vinci’s ability to improve ergonomics, for example, to reduce a surgeon’s tremor [9].

Despite the advantages of the da Vinci system, experts point out that it is necessary to improve traditional laparoscopy due to the limitations of cost-effectiveness, training or customization. An assessment of the cost of robotic surgical systems has been carried out, which has shown that they can become more cost-effective; however, the current financial climate limits opportunities [10]. The Da Vinci system has certain advantages that allow it to improve the results of surgical operations; Therefore, efforts should be made to discuss and compare the specific benefits of improving traditional laparoscopy.

The success of the da Vinci system has led to the development and introduction to the market of many subsequent surgical robots: from multiport surgical robots that work through multiple incisions on the body to single-port surgical robots that work through a single hole, following the philosophy of minimally invasive surgery. In addition, flexible surgical robots have appeared, which have a flexible structure and perform operations or procedures through natural human openings.

Laparoscopic surgery is successfully developing in many surgical fields, where the da Vinci surgical system provides robotic care and allows the surgeon to work outside the operating field in a comfortable environment. Being the most advanced robotic surgical system currently available, it dominates the surgical discipline. Many complex procedures require the use of da Vinci to perform complex and tedious operations. There are many studies evaluating the use of da Vinci for a specific procedure, testing its feasibility, or examining several cases to verify its effectiveness. For example, one group of researchers demonstrated the ability of a robotic system to simplify hysterectomy by performing a typical procedure using a da Vinci robot. In this experiment, EndoWrist® instruments were used, which provided the surgeon with greater feedback and, thus, reduced the effect of support: there is a consequence of the turning point of the surgical instrument, which causes the surgeon’s hand to move in the direction opposite to the end of the surgical instrument [11]. All this makes it possible to increase the level of non-intuitiveness of laparoscopic surgery.

Although da Vinci is able to reduce the effect of support, there are still noted limitations, such as the lack of tactile feedback.

Another study notes that robotic assistance is used in various procedures in addition to hysterectomy. The authors indicate such operations as myomectomy, endometriosis surgery, sacrocolpopexy, appendage surgery, tubal reanastomosis and cerclage [12]. The review discusses each of these indications and notes either the same effectiveness when using robotic assistance, or improvements. Some of the improvements were to expand the ability to perform more complex procedures, improve ergonomics when working with obese patients, and improved 3D visualization of the surgical field.

Another group of specialists discussed a new extraperitoneal approach to radical prostatectomy, which allows for the complications arising from conventional transperitoneal access. The researchers also discussed the use of only one assistant during robotic laparoscopic radical prostatectomy, which was different from the traditional use of two assistants in previous procedures [13]. The only assistant had to stand next to the robot, whose three arms were controlled by a surgeon sitting at a console outside the sterile field. Experts came to the conclusion that the presence of a robotic system in any conditions will reduce the number of necessary assistants.

A third group of specialists evaluated the da Vinci system in terms of the error rate measured by system failures and the transition to open surgery, and found that the system is reliable and safe, since none of the failures resulted in injury to the patient.

A case of using the da Vinci system for cholecystectomy was also described, and this description argued in favor of wider use of the system, since the benefits were large enough to promote this system for use in more complex diseases[14]. Another group of authors discussed several cases of cholecystectomy and came to the same conclusion, since laparoscopic cholecystectomy is highly standardized and widespread. One of the unique disadvantages mentioned in this article was the size of the robotic system, which made it difficult for the surgical team to move around the operating room [15].

Let’s consider different approaches to performing surgical operations using the laparoscopic method.

Transluminal endoscopic surgery with a natural opening is a special method that prevents scarring
because the endoscope is conducted through natural openings such as the mouth or urethra. The advantage of a transurethral port compared to a transgastric port is a reduced risk of infection, improved visualization of anatomical structures, anesthetic safety due to proximity to the respiratory tract and improved healing after closure.

The specialists also assessed the possibilities and features of the Percuvance™ percutaneous surgical system (PSS). Percuvance™ is a surgical instrument that can be inserted into the skin without a trocar, which reduces the size of the incision and is usually less invasive. Experts condemned the possibility of using PSS in nerve-sparing laparoscopic colposacropexy, in which vaginal prolapse was successfully corrected. Despite the effectiveness of operations using this surgical system, researchers noted disadvantages such as long working hours and improper handling of devices, however, it was concluded that it was possible to overcome these disadvantages through product updates and training of specialists [16].

The Senhance ® system is another robotic platform that works similarly to the da Vinci system, but has an additional eye movement tracking function, which makes it possible for the laparoscope surgeon to move without making physical movements. The researchers looked at the benefits of the system, including improved tactile feedback and ergonomics, as well as cost savings through reusable tools. However, disadvantages were also highlighted, such as a limited number of tools, problems with a bulky console, limitations related to the necessary calibration for eye tracking, as well as limitations related to the procedure. However, the relative novelty of the system suggests the possibility of improving it during modernization.

The Medrobotics Flex ™ system, a computer-controlled flexible endoscope, has been tested for transloral surgery on several cadaveric models and for surgical purposes. When used on several cadaver models, its flexibility allowed for greater access to visualization of the larynx and nasopharynx. It has been reported that this system has better tactile feedback than other robotic systems due to its flexible and compact components [17].

As more and more cases of robotic surgery are accumulated and analyzed, more neutral studies of the effectiveness of surgical robots are emerging. The disadvantages of robotic surgery include the high cost and extended operation time. Although there are some procedures, such as prostatectomy, where robotic surgery has clear advantages, there are also increasing reports of no clinical differences or benefits for patients compared to traditional laparoscopic surgery for relatively simple procedures such as cholecystectomy and right-sided colectomy.

Currently, the market for laparoscopic surgical robots is dominated by the Da Vinci system of Intuitive Surgical Inc. However, with the recent expiration of key patents, various companies are developing and launching laparoscopic surgical robots. It is expected that as more robots compete in the market, the cost of surgical robots will decrease. Robotic technologies are constantly evolving, providing safer and better operations. In recent years, instead of improving the mechanical performance of robots, research and development has focused on user interfaces to provide surgeons with extensive and accurate information and simplify their work. In addition, research is continuing in the field of autonomous surgery using robots.

DISCUSSION

A number of innovative technologies have led to significant progress compared to traditional laparoscopic surgery and have contributed to the widespread adoption of robotic surgery. These are cable-operated manipulators that provide multi-stage freedom of movement inside the abdominal cavity, a main device with remote control that allows intuitive manipulation of surgical instruments as if they were made by the hands of a surgeon, and, finally, visualization technology that provides a clear three-dimensional image [18].

Robotic surgery is directly different from traditional laparoscopic surgery in terms of functionality, as it is an articulation mechanism driven by a wire. The articulation mechanisms with a cable drive can be miniaturized to a diameter of less than 8 mm, and the drive unit manipulates a surgical instrument. Various types of mechanisms have been developed and patents have been registered, including wrist-type mechanisms and snake-like mechanisms of continuous action [19]. Since the mechanisms of robotic surgical instruments are very small to request sensors and receive feedback from them, modeling is essential to ensure sensitive drive characteristics. Rope motion models and real-time compensation algorithms have been studied to prevent phenomena such as sagging when the rope loses tension and the backlash increases.
Flexible surgical robots have a tendon-sheath mechanism (TSM) to compensate for the length of the wire when the bending path changes. TSM hysteresis modeling and compensation methods have been studied, and recently artificial intelligence has been used to improve the accuracy of the model.

Improvements to the mechanism are constantly being explored to ensure more stable movement and a larger payload with smaller diameters.

The main device installed on the da Vinci control console allows the surgeon to control the robot as intuitively as if he were sitting in a chair and holding surgical instruments, such as forceps. The main device can also generate reaction forces or damping in order to sensually transmit information to the operator about an acceptable workspace and the peculiarities of the position of the robot arm [20]. Control algorithms can filter the physiological tremor of the operator and implement scalable movements to ensure a safer and more accurate operation. This is an important factor that directly affects the performance and usability of the device, since it is held and controlled by the operator. This technology is constantly being studied to implement advanced features such as tactile feedback, while providing a degree of freedom of operation appropriate to the characteristics of each surgical robot.

The da Vinci system receives images using a binocular endoscope and presents them as stereoscopic images on the console eyepiece display, allowing surgeons to immerse themselves in the operation without the need for evaluation. Stereoscopic images help the surgeon to perform surgical techniques and improve the quality of surgical results.

In addition, Intuitive Surgical Inc. has developed the FireFly™ feature, which allows you to view superimposed fluorescent images on a robotic endoscope. A fluorescent substance such as indocyanine green (ICG) is injected into the body to provide visualization and identification of critical areas such as lymph nodes or thyroid gland during endoscopic surgery [21].

However, along with the advantages of using robotics in laparoscopy, experts note a number of disadvantages. The main negative assessment of surgical robots that are used during laparoscopic operations by medical personnel is that they are inconvenient. There is a need for robots that perform tasks exactly according to the surgeon’s intentions, without too much interfering with existing methods, surrounding equipment or medical personnel. In addition, recent research areas are aimed at reducing the number of human errors and increasing the comfort of surgical operations by providing surgeons with a large amount of real-time information that conventional equipment cannot provide. Therefore, human-robot interaction technologies, such as image guidance and tactile feedback, have been mainly studied recently.

Technically, the ultimate goal of research in the field of surgical robotics is autonomous surgery. As with autonomous vehicles, the degree of autonomy is divided into levels from 0 to 5. Currently, soft tissue surgical robots are at level 1, as they are controlled remotely using control technologies. Research is underway to automate relatively simple procedures to reduce the burden on medical staff. Recent advances in artificial intelligence have a great impact on autonomous surgical methods [22].

One of the characteristics of laparoscopic surgery is the ease of obtaining high-resolution images in real time during surgery. Recently, the convergence of artificial intelligence technologies and image processing technologies has led to advanced research results. Surgical instruments and organs are recognized and segmented on the screen, and their position can be assessed. Various information can be extracted and quantified from surgical images to evaluate the operation, and VR (virtual reality) can be used for surgical training. Image processing techniques open the way to future advances in autonomous surgery [23].

AR (augmented reality) technology, which extracts important information from images obtained by MRI (magnetic resonance imaging) or CT (computed tomography) before surgery and combines it in real time on the screen during surgery, is also being explored to provide the operator with information beyond fluorescent images. Image matching is a technology that is already used in surgical robots on hard tissues, but soft tissue surgery requires a more sophisticated technique that takes into account tissue displacement.

Tactile feedback technology, which transmits the force exerted by the tip of a surgical robot to the main device held by the operator, is an ongoing area of research. Since laparoscopic surgery uses elongated surgical instruments, it “relies on sensations” that are less sensitive compared to open surgery. Currently, surgical robots are not able to transmit to the operator the sensitive reaction forces created by the pressure of surgical instruments [24]. The size of the surgical instrument is too small to install the sensor on the tip,
and there is not enough space for wiring. Surgical robots with a wire drive are modeled similarly to systems with long spring dampers and have high hysteresis, which makes it difficult to extrapolate small forces at the tip when the wire is stretched [25].

Recently, researchers have been working on miniaturizing sensors that can be attached to surgical instruments to directly measure force and feedback. Other approaches include indirect strength assessment and feedback based on other information that can be obtained from the environment [26].

Autonomous surgery is a complex and advanced technology that requires a combination of technologies such as the design of reliable mechanisms, path planning, control algorithms, as well as perception and localization [27]. Research is currently underway on the automatic maneuvering of endoscopic cameras using algorithms to track multiple instruments during surgery to achieve optimal images. Methods are also being explored to help the surgeon by autonomously retracting tissues to expose organs for easier access. In one of the works, a technique for automatic suturing for intestinal anastomoses was developed and the results of surgeons performing them manually were compared with laparoscopic surgical instruments, robotic surgery and autonomous surgery on animal models. Although there are still many problems to be solved, researchers are taking up the development of autonomous surgery technology.

**CONCLUSIONS**

Surgical robots for laparoscopic soft tissue operations have proven themselves to be successful professional service robots for minimally invasive surgery. In the modern period, the dominance of the Da Vinci system of Intuitive Surgical Inc. Gradually becoming a thing of the past, there is also a diversification of robots, including soft tissue surgical robots and micro-surgical robots. However, all innovations introduced into surgical practice are often criticized for their high cost compared to traditional laparoscopic surgery and lack of clinical superiority or benefit to the patient. To overcome these problems, it is necessary to continue research and development of surgical robots, including expanding their capabilities and improving the user interface.

Communication between medical staff and engineers is crucial for the development of surgical robots. In particular, if developers do not have a good understanding of the medical field and the regulation of payment for medical services, it is difficult to make a decision that will be successful in the market. Surgical robots are expected to continue to evolve in the coming years due to the increasing workload of medical staff and the demand for higher levels of care from patients.

**REFERENCES**


