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The Role of Surgical Robotic Systems in Operative Urology

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Abstract: The paper provides information about currently existing robotic surgical systems used in operative treatment of urological diseases. The possibilities of surgical robots for the treatment of such diseases as prostate cancer, benign prostatic hyperplasia, and urolithiasis are reflected.

Key words: robot, robot-assisted surgery, urology.

Introduction: It is impossible to imagine modern life without the participation of robotic systems in it, from a robot vacuum cleaner in our apartments to robots working in space and participating in the most labor-consuming surgical interventions. In the healthcare system, and in particular in urology, there is a whole galaxy of robotic solutions. These include robotic laboratory and transport systems. There is a growing trend towards the use of robot-assisted surgical interventions in various areas of surgery. One of the leading places in the list of surgical specialties using robotic assistance is urology [1,2,3].

One of the most sought after and best known today is the da Vinci surgical robot. The da Vinci Surgical Robot System was made possible by Intuitive Surgical Inc., which made it possible for civilian use of a prototype surgical robot being built for the military. Currently, the da Vinci system is the undisputed leader in the field of robotic surgery. It was originally developed for robot-assisted coronary surgery and was first used for this purpose at the Heart Center in Leipzig [2]. Up to now, the following modifications of the system have changed: da Vinci 2000, da Vinci S, da Vinci Si and da Vinci Xi.

The da Vinci system consists of three components (Fig. 1):

1) surgeon console;
2) patient cart;
3) vision cart - optical system.

The surgeon console is the control panel for the entire system and the workplace of the operator, who controls three manipulator instruments and the patient cart camera using two joysticks and foot pedals.

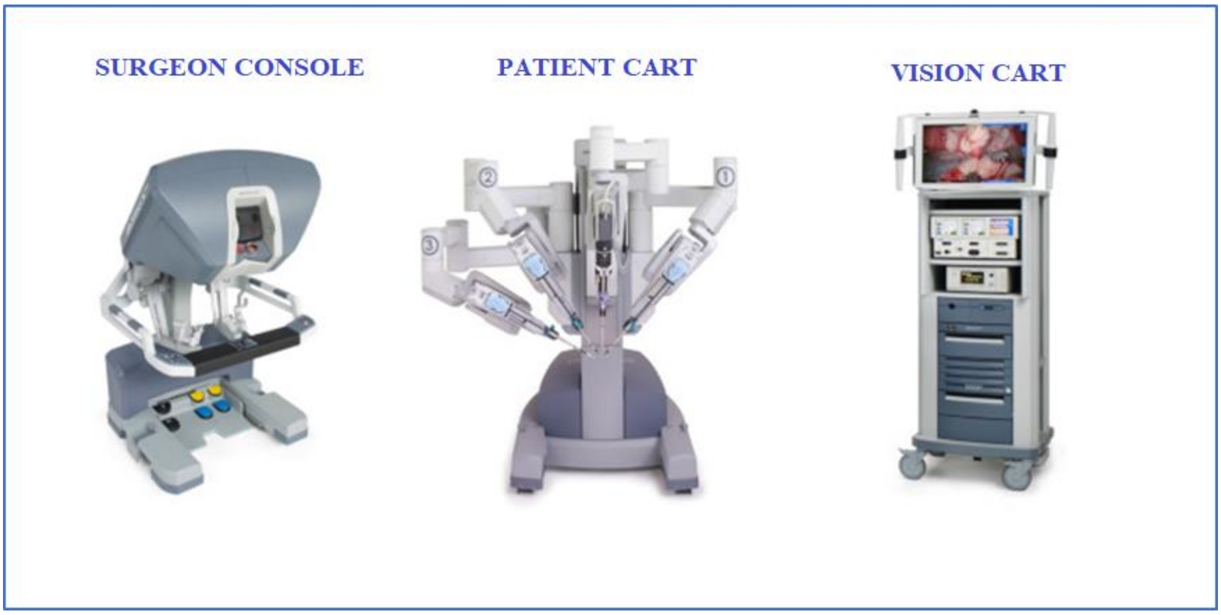

Fig. 1. Components of the da Vinci robotic system.

The movements of the surgeon's hands are completely copied by joysticks and transferred to the manipulators in such a way that the tremor is leveled and the possibility of precise dissection is provided. The process of coagulation (mono- and bipolar), switching between working manipulators and camera, as well as focusing of the optical system is provided by foot pedals. The surgeon has the ability to remotely control the system, i.e., the console can be located outside the operating room [2,4].

The effect of presence is provided by an optical system consisting of two parallel cameras transmitting an isolated image for each eye. In this case, the transmitted image is three-dimensional, which allows the surgeon to determine the three-dimensional position of the patient's organs and tissues in space.

The patient console carries the working manipulators and is in direct contact with the patient during the entire procedure. Three manipulators with instruments attached to them, as well as one manipulator with a camera, are connected to the surgeon's console using a computer interface [1,3].

When preparing the patient console for surgery, all manipulators are put on special sterile covers and remain in them throughout the procedure. The latest generation DaVinci Xi system allows you to install the camera in any of the four manipulators. Robotic surgery uses EndoWrist instruments, which are modeled after the human wrist and have 6° of freedom of movement, exceeding the range of motion of a human hand (Fig. 2). The EndoWrist tool kit includes a variety of forceps, needle holders, scissors; monopolar and bipolar electrosurgical instruments; scalpels and other specialized instruments (more than 40 types in total). EndoWrist instruments are available in 5mm or 8mm diameter. An important feature is a clear restriction on the use of tools.

Fig. 2. EndoWrist technology (“endo-wrist”).

Currently, the da Vinci system is the most common robotic surgical system, with about 5,000 units sold worldwide and many publications published [5].

Uzbekistan became the first country in Central Asia, where the use of the Revo-I robotic system (South Korea) was launched in 2022. The robot was installed in the private clinic Shox International Hospital (Tashkent), where on September 28, 2022, the work of the robotic surgery department was launched. The first intervention performed on a South Korean robot was a radical prostatectomy.

Robotic surgery has shown a high degree of compliance with surgical interventions in urology. In 2001, robotic-assisted prostatectomy for prostate cancer began in Europe and is today the most frequently performed robotic procedure in the world. In reconstructive urology, robot-assisted pyeloplasty is successfully performed. Also in 2001, the first robot-assisted nephrectomy was performed, and in 2003, the robot-assisted radical cystectomy was performed. Robot-assisted operations are performed mainly on da Vinci system robots [5,6,7].

Robotic systems are actively used in the surgical treatment of benign prostatic hyperplasia, urolithiasis. The most promising robot-assisted techniques are aquablation and high-intensity focused ultrasound ablation of the prostate.

Image Guided Robotic Waterjet Ablation - AquaBeam System (Procept BioRobotics, Redwood Shores, CA, USA) uses the principle of water jet dissection to effectively ablate the prostate hyperplasia tissue while preserving collagenous structures such as blood vessels and the surgical capsule. Precise, high-velocity saline jets induce tissue ablation without heating under real-time ultrasound guidance. After completion of ablation, hemostasis is achieved by placement of a Foley catheter with slight tension, if necessary, electrocoagulation or a low-power laser is used [8].

The first data on the use of aquablation in an experiment on dogs were presented in 2015 by Faber K. et al. [9]. The AquaBeam Generation 2 robotic system for aquablation (Fig. 3 A, B, C) consists of 3 main components: an conformal planning unit (A), console (B), a motor unit and a handpiece with an integrated scope (C).

Today, specialists confirm the successful use of this technique for the treatment of BPH. In a study comparing aquablation and transurethral resection of the prostate, in both groups of patients there were no differences in changes in the IPSS (International prostate symptom score) score, quality of life (QoL) index, maximum urine flow rate and a decrease in the of residual urine volume [8].

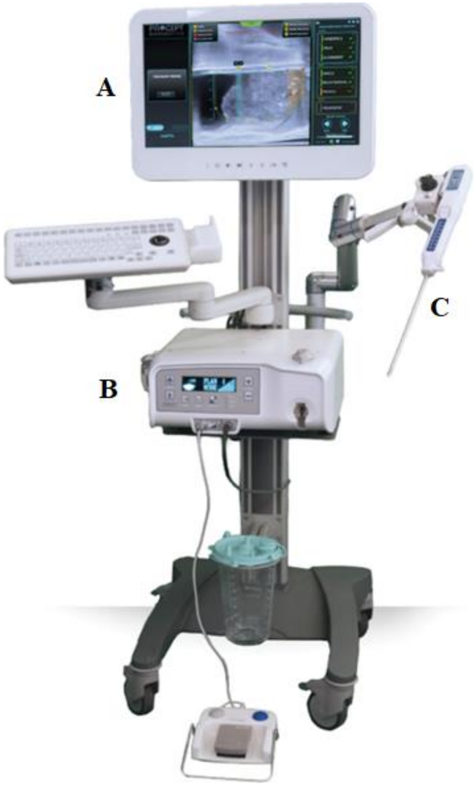

Fig. 3. General view and components of the AquaBeam Generation 2 robotic aquablation system.

A. conformal planning unit;

B. console that contains a high-pressure fluid delivery system;

C. aquablation handpiece with motor unit [10].

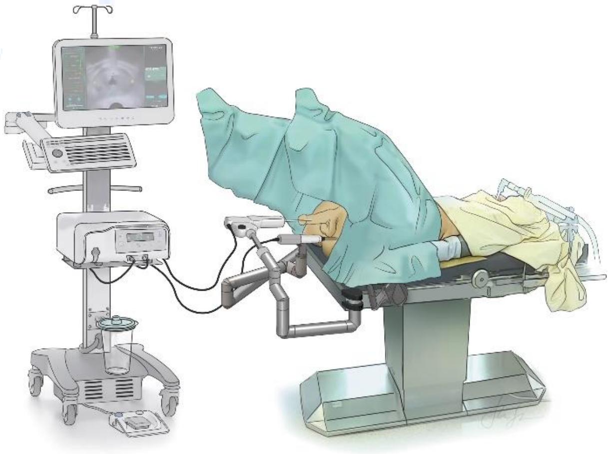

Fig. 4. The location of the manipulators in the patient's body during the aquablation procedure.

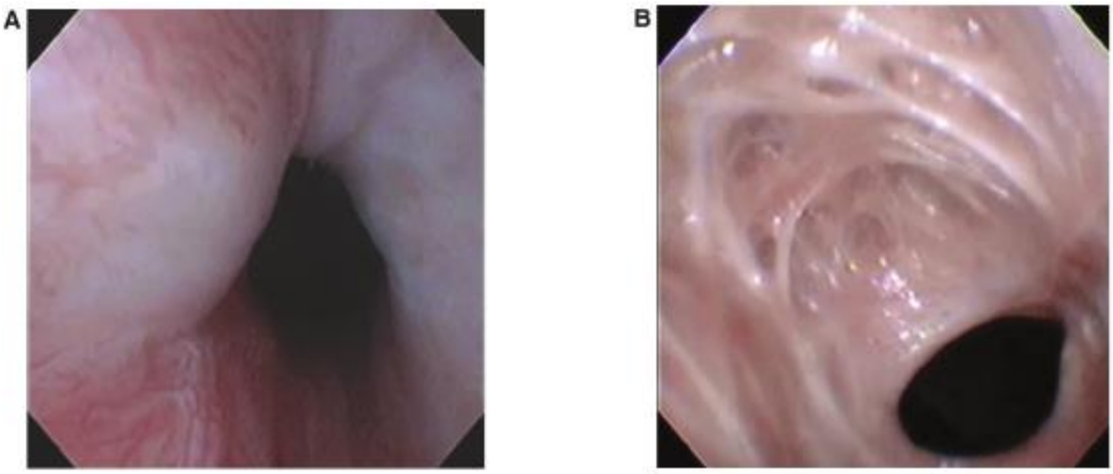

Fig. 5. Cystoscopic picture before (A) and 6 weeks (B) after aquablation. The prostatic urethra has a wide lumen, no hyperplastic tissue, collagen and muscle structures are well preserved [9].

The procedure can be performed under general anesthesia or spinal anesthesia. The patient is positioned in the lithotomy position and transrectal ultrasound (TRUS) probe is placed. After that, a handpiece is inserted just beyond the bladder neck or intravesical lobe to obtain cystoscopic access to the bladder. The end of the handpiece is located directly in the bladder before the endoscope is retracted to visualize the bladder neck, and is positioned proximal to the external sphincter. A custom-built articulating arm locks the handpiece in place to avoid displacement during procedure.

After the handpiece and the TRUS probe are installed, marking of the area of future tissue ablation is performed using mapping software. In aquablation it is possible to change the depth of exposure up to 25 millimeters, and the resection angle varies within 225 degrees. Complete ablation of the transition zone of the prostate is performed by delineating the prostate using the Aquabeam program. Then, under the control of a foot pedal, a high-velocity jet of saline is delivered. The computer system automatically adjusts the flow rate in each direction to vary the depth of penetration and remove the hyperplasia tissue as intended during the mapping step. In order not to damage the external urethral sphincter, there are protective mechanisms to ablate only the targeted area. After ablation is completed, hemostasis can be achieved either by electrocoagulation or by tension with a balloon catheter. After the procedure, a three-way catheter is inserted and the bladder is flushed. Patients can be discharged the next day after catheter removal [9,10].

Another robotically assisted procedure is HIFU (high-intensity focused ultrasound). The method is based on the formation of a high-intensity ultrasonic beam, which is focused in certain areas by a special transducer. The temperature in the zone of action of focused ultrasound fluctuates within 100°C, which leads to immediate coagulation necrosis of all cellular elements within the influence of a focused ultrasound beam [11].

HIFU has been successfully used as an alternative minimally invasive treatment for prostate cancer. As a minimally invasive treatment option for patients with BPH, transrectal application of high-intensity focused ultrasound was proposed in 1992 [12,13].

The Sonablate®-500 system is an advanced system for HIFU treatments that includes a console, a digital thermal printer, a flat screen monitor, two transrectal probes with two transceivers with different focal lengths, an articulated probe handle and a cooler module.

Fig. 6. Equipment for ultrasound ablation of prostate hyperplasia Sonablate®-500 [13].

The HIFU procedure is performed under spinal anesthesia after the patient is placed in a lithotomy position. A 16-18 Ch Foley catheter is inserted into the bladder. Then the bladder fills up. A high-frequency sensor placed in a balloon filled with degassed water at room temperature or cooled is inserted into the rectum. It provides visual control of the prostate against the background of the catheter and selection of the ablation zone. Cooling of the rectal wall is carried out using a special device - a cooler. The ablation zone is marked with ultrasound and the burning sequence is determined. After marking, the ablation procedure begins directly. At the same time, high-intensity ultrasonic beams dot-burn out an area of hyperplasia or tumor tissue (in prostate cancer) [13].

Flexible robotic ureteroscopy for urolithiasis. Modern endourological treatment methods for urolithiasis, including percutaneous interventions, ureteroscopy, retrograde intrarenal surgery (RIRS), are carried out, along with ultrasound and optical, under radiological navigation. Obtaining uroscopic images before the intervention, during the procedure, and at the end of the procedure for the purpose of monitoring have a potential adverse effect on the health of the endourologist, given the number of interventions he performs. It is impossible not to take into account the fact that there are special protective devices for protecting the surgeon from radiation, but complete protection cannot be guaranteed. The situation is completely different when the operator is distanced, protected from X-ray exposure and performs all the necessary manipulations outside the irradiation zone [14].

In 2012, the world's first endoscopic robot Avicenna Roboflex appeared, which was developed by ELMED™ for retrograde intrarenal surgery (RIRS) and flexible laser ureterorenoscopy (FURLAS) procedures (Fig.7). Avicenna Roboflex is a system that allows the fragmentation and destruction of stones from various parts of the urinary tract through the natural urinary tract without incisions or punctures. The advantage of the system is the ability to perform these procedures in an ergonomic sitting position, without a lead apron and outside the radiation area. All functions (forward-backward, rotation, deflection) of the flexible endoscope can be controlled using the system touch screen and the manipulator control tools on the console [14,15].

In 2017, Klein J.-T. et al. published the results of a series of cases using Avicenna Roboflex in 395 patients, while the authors note the safety of the technique and ease of implementation in routine practice [16]. Along with Avicenna Roboflex, today the range of robotic surgery of natural orifices is represented by such systems as the French surgical robots Nîmes and Ily, the South Korean «Easy Uretero», etc. [17].

Fig. 7. Endoscopic robotic system Avicenna Roboflex.

Conclusion. Robotic-assisted surgery has taken its rightful place in the arsenal of methods of surgical treatment of urological diseases. The use of robots in urology provides significant advantages over open and even laparoscopic surgery in terms of invasive intervention and patient rehabilitation. Further use of surgical robots will be determined by randomized clinical trials, as well as the development of new robotic platforms and technologies.

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