Invited Review Article

Transforming urology: exploring the innovations and utilizations of robotic systems

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Abstract

Robot-assisted surgery represents the pinnacle of minimally invasive surgical techniques, surpassing laparoscopic surgery in its efficacy. This study aimed to evaluate the current status of robotic surgery in urological practice, examining its advantages and disadvantages. A literature review was conducted using PUBMED and the pertinent articles in the field of urology selected. Various single-port and multiport robotic platforms, such as Da Vinci, Versius, Hugo RAS, Revo-I, Senhance, Mantra, Avatera, hinotori, and MicroSurge, are discussed along with their respective pros and cons. Details of the 4 robotic platforms used in our centers are also included. With an influx of diverse medical surgical robots entering the market and a competitive drive to establish the next standard of care in robotic surgery, it is inevitable that robotic surgery will soon become economically comparable to laparoscopic procedures.

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Introduction

Robot-assisted surgery currently stands as the epitome of minimally invasive procedures, boasting a distinct advantage over its predecessor, laparoscopic surgery. With technological advancements, it naturally progresses the evolution of minimally invasive techniques. The integration of high-resolution three-dimensional magnified vision, a multi-degree range of movements, tremor dampening, and instrument miniaturization enhances the dexterity and precision of surgeons, further improving the safety and efficiency of surgical techniques. These advancements build upon the already established benefits of laparoscopic surgery.[1] Commercial approval of robotic surgery by the FDA began in 2000[2], primarily with the da Vinci robotic systems from Intuitive Surgical, which dominated the market for nearly two decades. Now, as many of Intuitive Surgical's patents expire, we are entering a new era where numerous competitors are vying for a share of the robotic surgical market.

Our objective is to assess the current status of robotic surgery in urological practice, including its advantages and disadvantages in today's application landscape.

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Materials and Methods

A non-systematic literature search was conducted using PubMed/MEDLINE with the keywords "robotic surgery," "robotic surgical system," "da Vinci system," and "robotic urology." A similar search was also performed using Google Scholar. The search was specifically narrowed down to literature pertaining to urological surgery. Furthermore, relevant information was sought from the official websites of various robotic companies.

Information regarding different robotic systems

Da Vinci

Intuitive Surgical Inc. has achieved remarkable success with the introduction and sustained presence of the da Vinci Surgical System, solidifying its dominance in the robotic surgery market for the past 21 years.[3] To date, there have been four distinct generations of robotic surgical systems that have been actively operational, functioning primarily as telemanipulator systems.[4]

The da Vinci Si, X, and Xi models are characterized by their shared features, including four robotic arms mounted on a single patient cart. (Figure 1) The surgeon operates from a confined closed console, which houses finger loop controllers equipped with Endowrist Technology. Notably, all instruments utilized in these models have an 8 mm diameter, enabling seven degrees of freedom.[2] Presently, the Si system is undergoing a phase-out process and is being succeeded by the newer Xi system, which was launched in 2014. Similar to its predecessors, the Xi system boasts additional features such as a dual console, slender robotic arms, articulating instruments, and an 8 mm port hopping camera, facilitating the execution of multi-quadrant procedures.[5]

The most recent advancement is the da Vinci Single-Port (SP) system, which received FDA approval in May 2018. Its application has been documented in a variety of urological procedures, including renal surgery.[6] The da Vinci Single-Port (SP) system has been utilized in radical perineal and transperitoneal prostatectomy procedures,[7,8] and cystectomy.[9]

The SP platform comprises a 360-degree rotating boom and a single robotic arm designed to fit into a 25 mm multichannel cannula. This configuration allows for the deployment of a fully articulated 3D endoscope and three wristed 6 mm instruments, all of which fan out to prevent collisions within the surgical field[4] (Figure 2).

Figure 1. Davinci Xi

Figure 2. Da vinci SP

Furthermore, the surgeon console of the SP system features a relocation pedal, enabling the movement of the entire robotic arm while keeping the instruments in the same position.[2]

A comparison between the SP and multiport (Xi) robotic platforms of the da Vinci system has been conducted, with the conclusion that there is no significant difference between the two platforms. Additionally, it was found that the SP platform offers advantages in both pain control and shorter hospital stays.[10]

Versius

The Versius surgical system, developed by Cambridge Medical Robotics Ltd. in Cambridge, UK, received its CE mark in 2019.[11] One distinctive feature of the Versius surgical system is its setup, which consists of five lightweight portable carts, each individually mounted with a robotic arm.[3] In contrast to most robotic platforms, the surgeon console of the Versius system features an open design. It necessitates the use of 3D polarized glasses for vision and offers haptic feedback to the operating surgeon.[2] The handheld handles of the joystick offer complete control of the system, eliminating the necessity for foot pedal controls. The instruments of the Versius system are slender, with a 5 mm diameter, and are wristed, allowing for seven degrees of freedom. This system has been evaluated in various clinical settings, with approximately 66 installations worldwide to date. The first clinical series reported in India involved its use in gynecologic and upper gastrointestinal surgeries.2 Feasibility was assessed through 30 robotic radical hysterectomies using the Versius system.[12]

Hugo RAS

The Hugo™ RAS system by Medtronic features an open console that also requires the use of 3D glasses for visualization. The system comprises independent pods, with each pod containing six hinges offering seven degrees of freedom. Notably, all system components and arms, including the surgeon console, are mounted on wheels for enhanced mobility. This system is designed to be upgradable, thereby eliminating the need for purchasing newer systems and ultimately reducing costs.[13]

Revo-I

The Revo-I system, developed by Meere Company Inc. in Yongin, Korea, received approval from the Korean Ministry of Food and Drug Safety in August 2017. Subsequently, its availability has been extended to Russia and Kazakhstan.[4] The features of the Revo-I system are akin to those of the da Vinci system. The surgeon console is enclosed, and the patient cart is equipped with four arms, each allowing seven degrees of freedom. The 3D endoscope has a diameter of 10 mm, while the instruments measure 7.4 mm in diameter and can be reused up to 20 times.[14] Chang et al. published their first human study in 2018, utilizing the Revo-I system for localized carcinoma of the prostate. The study reported no major perioperative or intraoperative complications and noted the absence of any robotic malfunction throughout the duration of the study.[14]

Senhance

The Senhance system was originally developed by the Italian company SOFAR and Tuebingen Scientific, and was initially called Telelap ALFX. It obtained its CE Mark certification in 2016.[13] Later, the system was rebranded as "Senhance" after being acquired by the US company Transenterix, based in Morrisville, North Carolina, USA, in 2015. It became the first robotic system to receive FDA clearance in 2017, receiving CE approval for use in Europe after da Vinci. The Senhance system features an open console with up to four independent arms. It also incorporates a "machine vision system," which employs eye tracking 3D vision technology, enabling the camera to move in response to the movement of the instruments.[13,15] While the Senhance system offers haptic feedback and is compatible with laparoscopic trocars and many commercially available laparoscopic instruments, it lacks the "wristed" degrees of freedom that are present in most of the newer robotic systems.[4]

Mantra

The Mantra Surgical robotic system, developed by the Indian company SS Innovations, is renowned for its cost-effectiveness and versatile surgical applications, including cardiac surgery. It comprises patient-side arm carts, a Surgeon command center, and a Vision cart. The side arm carts are individual motorized carts equipped with robotic arms featuring an Integrated Tool Interface and Instrument actuator. Each joint's actuator includes motors, harmonic drives, electro-mechanical brakes, and sensors. The Surgeon command center boasts an open console system with dual monitors: a 3D-HD monitor and a 2D touch display monitor for system control and patient-related data display. It incorporates visible active hand and foot pedal controls, as well as a head tracking system. The endoscopic camera is equipped with Chip-on-Tip technology and Motorized articulation control (four-way), providing a field of view of 75 degrees. The articulating endoscope offers the advantage of a greater range of vision, facilitating the observation of ports without moving the camera and visualizing anatomical structures without changing endoscopes. The system includes over thirty 9 mm SSI MUDRATM Endo-Surgical Instruments designed for multi-specialty procedures, including the NADI (Automated Anastomotic Connector) for coronary bypass surgery, Multi-fire Clip Appliers, and a Cardiac Endo-Stabilizer.

Avatera

The Avatera system, developed by avatera-medical GmbH in Jena, Germany, obtained its CE mark in November 2019, after which its primary focus has been on urological and gynecological surgeries.[2] The features of this system include four robotic arms fixed to a single cart, a 10mm endoscope, and single-use 5mm instruments aimed at reducing costs.[13] The surgeon console is an open system with microscope-like technology providing 3D-HD vision through the eyepiece. This design allows the surgeon's head to remain outside of the system, facilitating better communication with the surgical team. Additionally, the console features an integrated sitting arrangement and loop-like handles for instrument control.[13] Clinical data for the system are yet to be published.

Hinotori

Medicaroid developed the Hinotori Robot, a Japanese surgical system that obtained regulatory approval from the Japanese Ministry of Health, Labor, and Welfare. This system comprises three units: the surgeon cockpit, the operation unit (which features four arms in a single boom), and the vision unit. The arms of the operation unit allow for 8 degrees of freedom and feature a "docking-free" design for instruments, where the pivot of the instrument is set by software. The handles for controlling the instruments are wristed, loop-like handles (Figure 3).

MiroSurge

The Miro robotic surgery platform, developed by the German Aerospace Center, is a lightweight system weighing only 10 kg. Its robotic arm is designed to mimic the structure of the human arm, comprising a shoulder, upper arm, elbow, forearm, and wrist. A unique feature of this system is its moving fulcrum point, which enables surgeries to be performed on the moving chest wall during respiration. The instruments of the Miro robotic surgery platform offer seven degrees of freedom, with an additional option of haptic feedback available. While the platform was initially developed for minimally invasive abdominal and thoracic surgery, it has not advanced to preclinical or clinical studies.[4]

Single-port robotic platforms

As the conventional robotic system becomes more widely used across various surgical procedures, innovators have turned their attention to

Figure 3. Hinotori

Table 1. Experiences of robotic systems in our centers

Platforms	Advantages	Disadvantages
DaVinci Xi	• Maximum mobility and flexibility • "Firefly" utilizes a near-infrared technology (ICG)	• Large & heavy cart • Non-ergonomic neck and trunk angle
Hinotori	• Human-sized & Flexible arm design (eight axes movements) • Docking-free design (pivoting)	• Single console • Only domestic market (as of 2024)
Da Vinci SP	• Single-port with flexible camera • No collision between arms outside	• Cost (platform & disposables) • Collision & limited movement inside
Hugo RAS	• Open console with specific 3D glasses for head tracking technology • Each unit of the Hugo RAS is independent and extendible with six different joints	• Limited variety of instruments • Delayed upgrade responses to the clinical feedbacks

Robotic Laparo-endoscopic Single Site (R-LESS) surgery. This approach offers several advantages, including a reduced number of incisions, improved cosmesis, decreased postoperative pain, shorter recovery times, and a lower risk of postoperative incisional hernia.[16]

In addition to the da Vinci® SP1098 platform, several other robotic systems are undergoing preclinical and human studies. These include the Single-Port Orifice Robotic Technology surgical system (SPORT) by Titan Medical (US) and the miniature in vivo robot surgical system (MIRA) developed by Virtual Incision (US). Neither of these systems is currently available for sale or use in any country.

The SPORT system features a maneuverable patient cart with a single port of 25 mm, housing two articulating arms within it. This system is considered to be cost-effective in the future due to its replaceable end effectors in the instrument.

The MIRA system offers the unique characteristic of housing the bulk of the robotic system inside the abdominal cavity during surgery, thereby reducing the extracorporeal footprint (the motor units are housed within the arm itself). It consists of two robotic arms in a central single rod, which is inserted through a small incision of 3.5 cm and can be rotated to allow access to all quadrants of the abdomen.[3]

Conclusions

In just over two decades, surgical robots have profoundly transformed the landscape of surgical specialties, making procedures significantly more efficient and surgeon-friendly. With the influx of various medical surgical robots entering the market and the race to establish the next standard of care in robotic surgery, it's only a matter of time before robotic surgery becomes financially comparable to laparoscopic surgeries. Already, it has become an indispensable tool for delivering complex surgical care, thanks to its high levels of maneuverability, magnification, and precision.

Looking ahead, future advancements and the integration of virtual and augmented reality, artificial intelligence in data analytics, deep learning, and machine learning algorithms will further enhance the safety of the surgical applications. Simultaneously, these technologies will provide ample opportunities for surgeons undergoing training to develop their skillsets, ultimately leading to improved patient outcomes and better overall surgical care.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Ferguson JM, Pitt B, Kuntz A, Kavoussi NL, Nimmagadda N, Barth EJ, et al. Comparing the accuracy of the da Vinci Xi and da Vinci Si for image guidance and automation. Int J Med Robot 2020;16:1-10.
2. Koukourikis P, Rha KH. Robotic surgical systems in urology: What is currently available? Investig Clin Urol 2021;62:4-22.
3. Brodie A, Vasdev N. The future of robotic surgery. Ann R Coll Surg Engl 2018;100:4-13.
4. Alip SL, Kim J, Rha KH, Han WK. Future Platforms of Robotic Surgery. Urol Clin North Am 2022;49:23-38.
5. Kim DH, Kim H, Kwak S, Baek K, Na G, Kim JH, et al. The Settings, Pros and Cons of the New Surgical Robot da Vinci Xi System for Transoral Robotic Surgery (TORS): A Comparison With the Popular da Vinci Si System. Surg Laparosc Endosc Percutan Tech 2016;26:391-6.

6. Maurice MJ, Ramirez D, Kaouk JH. Robotic Laparoendoscopic Single-site Retroperitioneal Renal Surgery: Initial Investigation of a Purpose-built Single-port Surgical System. Eur Urol 2017;71:643-7.
7. Ramirez D, Maurice MJ, Kaouk JH. Robotic perineal radical prostatectomy and pelvic lymph node dissection using a purpose-built single-port robotic platform. BJU Int 2016;118:829-33.
8. Kaouk JH, Sagalovich D, Garisto J. Robot-assisted transvesical partial prostatectomy using a purpose-built single-port robotic system. BJU Int 2018; 122:520-4.
9. Maurice MJ, Kaouk JH. Robotic radical perineal cystectomy and extended pelvic lymphadenectomy: initial investigation using a purpose-built single-port robotic system. BJU Int 2017;120:881-4.
10. Vigneswaran HT, Schwarzman LS, Francavilla S, Abern MR, Crivellaro S. A Comparison Of Perioperative Outcomes Between Single-Port And Multiport Robot-Assisted Laparoscopic Prostatectomy. Eur Urol 2020;77:671-4.
11. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. Surg Endosc 2018;32:1636-55.
12. Puntambekar SP, Goel A, Chandak S, Chitale M, Hivre M, Chahal H, et al. Feasibility of robotic radical hysterectomy (RRH) with a new robotic system. Experience at Galaxy Care Laparoscopy Institute. J Robot Surg 2021;15:451-6.
13. Cisu T, Crocerossa F, Carbonara U, Porpiglia F, Autorino R. New robotic surgical systems in urology: an update. Curr Opin Urol 2021;31:37-42.
14. Chang KD, Abdel Raheem A, Choi YD, Chung BH, Rha KH. Retzius-sparing robot-assisted radical prostatectomy using the Revo-i robotic surgical system: surgical technique and results of the first human trial. BJU Int 2018;122:441-8.
15. deBeche-Adams T, Eubanks WS, de la Fuente SG. Early experience with the Senhance®-laparoscopic/robotic platform in the US. J Robot Surg 2019;13: 357-9.
16. Nelson RJ, Chavali JSS, Yerram N, Babbar P, Kaouk JH. Current status of robotic single-port surgery. Urol Ann 2017;9:217-22.