# Robotic surgery in urology: a review from the beginning to the single-site

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**Abstract:** Robotic surgery is a minimally invasive technique that is becoming increasingly popular in surgery and especially in urology. More and more major urological interventions, such as radical prostatectomy and partial nephrectomies, are evolving into laparoscopic and robotic minimally invasive techniques. Robotic surgery itself is constantly evolving in order to improve its performance and minimally invasiveness. A non-systematic literature review was performed using the PubMed/Medline electronic search engine using the following terms: "robotic surgery" or "development of robotic surgery" or "single site surgery" or "single port surgery". Although it is a very recent technology, some preliminary experiences have been presented in the literature that document the feasibility of some major urological interventions, including radical prostatectomies, radical cystectomy, partial nephrectomy and ureterocystoneostomy. Long-term oncological and functional outcomes are not yet available and require more follow-up. Anyway, the single-port robotic system has proved feasible and safe, although in small cases series. Re-evaluating the development of robotic surgery, with each innovation, it aroused great enthusiasm, leading to a great diffusion of the method before having randomized clinical trials that confirmed the effective improvement of the technique compared to the gold standard. The urological community should not miss the second chance to be able to evaluate an emerging technique based on comparative clinical studies.

**Keywords:** Robotic surgery; development of robotic surgery; single site surgery; single-port surgery

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## Introduction

Robotic nowadays represents the gold standard for numerous surgeries. Its use is transversal to several medical specialties and its diffusion is constantly growing all over the world.

What is meant by the term "robotic surgery": "*A computer-controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a range of surgical tasks*" (1).

Two types of robotic systems are currently available; indeed, they can be OFF-LINE (FIXED PATH SYSTEMS) if they perform precise movements based on pre-programmed imaging studies obtained before surgery or ON-LINE (MASTER-SLAVE SYSTEMS) in which the robot replicates the surgeon's movements in time real within the operating range and the Da Vinci robotic system falls into this second category (2).

In this review of the literature, we will try to highlight what have been the peculiarities in the development of robotic surgery in urology from the beginning till today and trying to identify what are its future prospects.

## Methods

A non-systematic literature review was performed using the PubMed/Medline electronic search engine using the following terms: "robotic surgery" or "development of robotic surgery" or "single site surgery" or "single port surgery".

Articles in English and of urological interest relating to single-site robotic surgery with a dedicated platform were selected.

## Brief history of robotic surgery

In the late 1980s, after the statements of President George H. W. Bush to want to bring man to Mars, a series of technological innovations followed. A group of researchers developed a stereoscopic 3D viewing display unit called the head-mounted display (HMD) (3). Later researchers from the Stanford Research Institute (SRI) together with a military surgeon developed a system for instrument telemanipulation (4). Unfortunately, these technological innovations were not technically ready for telepresence surgery, however, the contemporary development of laparoscopic surgery led to the development of a robotic system that could be applied to it. This aroused the interest of the United States Department of Defense which financed a research project for the development of a robotic system capable of delivering first aid to wounded soldiers on the battlefield [Defense Advanced Research Projects Agency (DARPA)] (5).

Starting from the early 1990s two main private industries (Computer Motion and Intuitive Surgical) brought the technical-scientific innovations necessary for the final development of the robotic system used today.

Computer Motion Inc. initially developed an Automated Endoscopic System for Optimal Positioning (AESOP) that used voice-controlled commands to provide hands-free intraoperative maneuvering.

Later, with the use of funding obtained from DARPA, they developed a robotic system called Zeus capable of reproducing the surgeon's movements (2).

In 1995, the Intuitive Surgical company was founded, which, after a few prototypes, developed the surgical system known as Da Vinci. This system, unlike previous prototypes that involved anchoring the robotic arms to the operating table, consisted of a patient-side cart, a stereoscopic vision, and an advanced master manipulator system. In 1997 the first robotic cholecystectomy was performed in Brussels using the "Mona" prototype (6). Subsequently, myocardial revascularization interventions were performed in Germany in 1998 (7).

On May 23, 2000, Binder and Kramer performed the first robotically-assisted laparoscopic radical prostatectomy (8).

In 2004 Intuitive Surgical acquired Computer Motion and assumed a monopoly on robotic surgery. Since then, the food and drugs administration has approved 5 generations of Da Vinci systems for use in urology.

Simultaneously with the development of robotic surgery, laparoscopic surgery has also undergone considerable development over the years. In fact, the two techniques have had a parallel development influencing each other with the technological improvements introduced in one or the other. From the first laparoscopic experience published in 1997 by Schuessler *et al.* (9), there has been a notable development also with regard to conventional laparoscopic surgery with the introduction of HD 3D optics, dedicated instruments for haemostasis and motorized laparoscopic instruments to have greater degrees of mobility in the space. Even in conventional laparoscopy, there has been a tendency to minimize the surgical approach with the introduction of minilaparoscopy and single-port laparoscopic surgery (LESS) (10).

The first systems introduced in the early 2000s were the Da Vinci 2000 system and the Da Vinci S system initially developed for coronary surgery but also used for urological surgery. Starting from 2009, Intuitive Surgical introduced the Da Vinci Si system by making some technological improvements such as HD video technology, finger-based clutch mechanism and indocyanine green fluorescence (Fire-Fly technology) as well as the possibility of being adapted to single-port surgery using the VeSPA system. In 2014 the Da Vinci Xi system was introduced featuring an 8-mm HD 3D camera and a slimmer robotic arm design as well as the ability to move the operating table while the robotic arms are connected which gave it the ability to be used in multi-quadrant surgery.

In the end, the Intuitive Surgical introduced the Da Vinci SP system which, by means of a telescope and flexible instruments, allows the triangulation of them within the surgical field while using a single port (11).

Some other companies have introduced robotic systems but none currently has the diffusion of the Da Vinci system in the world.

## The evolution of robotic surgery in urology

After the first surgery performed in May 2000 by Binder and

Kramer, robotic surgery has had an exponential development and diffusion in the urological field and thanks to this rapid diffusion the urologic community missed the window of opportunity to test this novel approach within an evidence-based frame. In fact, in the first years since its introduction, only few comparative studies have been undertaken that compared robotic surgery with conventional laparoscopy and retropubic prostatectomy (12).

The first systematic review on studies comparing conventional laparoscopy, retropubic prostatectomy and robotic prostatectomy comes in 2009 by Ficarra *et al.*, about 10 years after the introduction of robotic surgery. Their conclusions are not conclusive because, from the analysis they conducted, it emerges that conventional laparoscopy and robotic surgery approaches are correlated with lower blood losses and transfusion rates, but there are not sufficient criteria to prove the superiority of a surgical approach compared to others (12).

Despite these fragile initial conclusions, the spread of robotic systems has continued exponentially to become the gold standard for some types of surgery.

In fact, almost all urological surgeries were performed with the use of robotic surgery. The spread of the robotic approach in urology has also led to the development of dedicated surgical techniques that are difficult to replicate with conventional laparoscopic surgery or open surgery. In 2010 Galfano *et al.* published their initial experience with Retzius sparing surgery and, to date, this method remains the prerogative of the robotic assisted surgical approach (13).

However, we can identify some limitations to robotic surgery. As identified by Cacciamani *et al.*, some of these may be related to the characteristics of the tumor (size and surgical complexity), others to intrinsic characteristics of the patient which in some cases may lead to contraindicating the robotic approach from an anesthetic point of view (14).

The patient's position in Trendelenburg or on the side and the need for a pneumoperitoneum can lead to changes in hemodynamics, respiratory dynamics, and intracranial pressure. All aspects that must be taken into consideration during the planning of the intervention (15).

Since 2008, robotic-assisted single-site laparoendoscopic surgery (R-LESS) has been proposed as a further technical evolution in the urological field. The first series of R-LESS in urology was described by Kaouk *et al.* on three patients describing a radical prostatectomy, a pyeloplasty and a radical nephrectomy. These procedures were performed using the Da Vinci S robotic system through a single-port multi-channel platform (16).

However, the early robotic systems did not have a thin arm design and this caused numerous instrument clashing (17).

To overcome this inconvenience, the use of GelPort was introduced which allowed a better triangulation of robotic tools by decreasing arm clashing (18).

In the following years, further technical advances were introduced that allowed a further improvement in robotic docking and instrument triangulation. On the one hand, the introduction of a new multi-channel laparoscopic port with associated curved cannulae that allowed robotic instruments, equipped with flexible ends, to be crossed at the level of the fascia (VeSPA system). On the other, an improvement of the software able to eliminate the "reverse handedness effect". That is, the need to maneuver the left instrument with the right hand and vice versa (19).

Despite these technological innovations, R-LESS surgery remained bound to some intrinsic limits such as external clashing, loss of triangularization of the instruments and poor accessibility for the assistant that made it a surgical technic under development (20).

To overcome these drawbacks, our group, while waiting for a robotic platform dedicated to single site surgery, introduced the use of a hybrid R-LESS which involved the use of a home-made multiport and with an additional standard robotic trocar (21).

More recently, Intuitive Surgical's introduction of a robotic platform dedicated to single-port surgery has led to further development of R-LESS. First the SP999 system and then the SP1098 system made it possible to articulate the robotic instruments, produced through a single-port access, within the operating field, allowing them to be triangulated correctly (22).

Although it is a very recent technology, some preliminary experiences have been presented in the literature that document the feasibility of some major urological interventions, including radical prostatectomies (23-26), radical cystectomy (26,27), partial nephrectomy (26,28) and ureterocystoneostomy (26,29) (*Table 1*).

Long-term oncological and functional outcomes are not yet available and require more follow-up.

## The robotic-assisted single-port laparoendoscopic surgery (SP)

The SP is a recent and very promising technological innovation. It combines the already consolidated advantages of robotic surgery such as optical magnification, the

**Table 1** Da Vinci SP platform-assisted operations performed in the literature

| Author | Year | Title | Operation | N |
|---|---|---|---|---|
| Agarwal *et al.* (23) | 2019 | Initial experience with da vinci single-port robot-assisted radical prostatectomies | SP radical prostatectomy | 49 |
| Kaouk *et al.* (24) | 2019 | Robotic urologic surgical interventions performed with the single port dedicated platform: first clinical investigation | SP radical prostatectomy | 3 |
| Bertolo *et al.* (25) | 2019 | Pure single-site trans-perineal robotic radical prostatectomy: first clinical report using the SP® surgical system | SP perineal radical prostatectomy | 1 |
| Kaouk *et al.* (28) | 2019 | Pure single-site robot-assisted partial nephrectomy using the SP surgical system: initial clinical experience | SP partial nephrectomy | 3 |
| Kaouk *et al.* (27) | 2019 | Single-port robotic intracorporeal ileal conduit urinary diversion during radical cystectomy using the SP surgical system: step-by-step technique | SP radical cystectomy and intracorporeal diversion | 4 |
| Kaouk *et al.* (29) | 2019 | Robot-assisted surgery for benign distal ureteral strictures: step-by-step technique using the SP® surgical system | SP ureteroneocystostomy | 3 |
| Dobbs *et al.* (26) | 2020 | Single-port robotic surgery: the next generation of minimally invasive urology | SP radical prostatectomy | 24 |
| | | | SP partial nephrectomy | 6 |
| | | | SP radical cystectomy | 1 |
| | | | SP Ureteral reimplant | 2 |

abolition of tremor and the possibility of using endowrist® manipulators with a further step in minimally invasive surgery. This actually leads to less postoperative pain, a lower chance of hernia and a better cosmetic result.

With the development of a dedicated platform, the initial drawbacks associated with the use of a standard platform adapted to single-port surgery, such as external and internal clashing and loss of triangularization, have been reduced.

All the instruments pass through a single door of 2.5 cm in diameter and within the operating field acquire the triangularization necessary to improve the workspace and reduce clashing between the endowrists.

In fact, the endowrists designed for SP surgery have been equipped with two movable joints, a wrist that allows the rotation of the instrument and an elbow that allows it to flex within the operating field in order to obtain a correct positioning within the same.

Thanks to these technological advances, single-port surgery takes on the characteristic of multi-quadrant surgery. However, the need to obtain a triangularization of the instruments within the operating field raises the need to have a suitable distance between the entry point of the instruments and the anatomical target. Lenfant *et al.* in 2020 identified 10 cm as the minimum distance between the entry point of the instruments and the anatomical target. In case it is not possible they also proposing, as an alternative solution, to obtain a sufficient distance between the instruments and the anatomical target, using the Gelpoint System to allow you to expand the work space in order to start the triangulation of the instruments outside the abdominal cavity. They called it floating docking technique and involves the positioning of the GelSeal cap and the robotic trocar 8 cm above the skin, then using the wound retractor (Alexis®) as a tunnel to allow for an adequate pneumoperitoneum (30).

However, the structural changes introduced at the robotic system and instrumentation level have entailed some limitations regarding the field of view and the maneuverability of the instruments in terms of rotation, force and range of action, partly bypassed by the introduction of a virtual visual overlay called "Navigator" able to show the surgeon the position of the robotic instruments even if they are outside the visual field (26).

In studies in the literature, the single-port robotic system has proved feasible and safe, although in small cases series. Re-evaluating the development of robotic surgery, with each innovation, it aroused great enthusiasm, leading to a great diffusion of the method before having randomized clinical trials that confirmed the effective improvement of the technique compared to the gold standard. The urological community should not miss the second chance to be able to evaluate an emerging technique based on comparative clinical studies.

## Cost analysis of robotic surgery

In evaluating the development of a method, a fundamental part is linked to the cost analysis of the same. In relation to robotic surgery, a lot has been said about it. This analysis consists of many aspects, not only related to hospitalization and the costs of the operating room, but also to the patient's reintegration into society and the possible emergence of postoperative complications. For this reason, Bijlani *et al.* in 2017 analyzed the cost impact of robotic surgery and concluded that despite the higher initial costs, this method allows the health system to save by affecting early discharge, fewer complications and a faster return to work (31).

## Conclusions

Single-port robotic surgery represents an important technological innovation. It has been shown to be feasible and safe even in major surgery. However, it requires randomized controlled comparative clinical trials to evaluate perioperative and long-term outcomes.

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## References

1. Dasgupta P, Jones A, Gill IS, et al. Robotic urological surgery: a perspective. BJU Int 2005;95:20-3.
2. Leal Ghezzi T, Campos Corleta O. 30 Years of Robotic Surgery. World J Surg 2016;40:2550-7.
3. Fisher SS, McGreevy M, Humphries J, et al. Virtual environment display system. Paper presented at: Proceedings of the 1986 workshop on Interactive 3D Graphics. New York, NY, USA: Association for Computing Machinery, 1987:77-87.
4. Green P, Satava R, Hill J, et al. Telepresence: Advanced teleoperator technology for enhanced minimally invasive surgery (abstract). Surg Endosc 1992;6:90.
5. Parekattil SJ, Moran ME. Robotic instrumentation: Evolution and microsurgical applications. Indian J Urol 2010;26:395-403.
6. Himpens J, Leman G, Cadiere GB, et al. Telesurgical laparoscopic cholecystectomy. Surg Endosc 1998;12:1091.
7. Hagen ME, Stein H, Curet MJ. Introduction to the robotic system. In: Kim KC. editor. Robotics in general surgery. 1st edition. Springer, 2014:9-15.
8. Binder J, Kramer W. Robotically-assisted laparoscopic radical prostatectomy. BJU Int 2001;87:408-10.
9. Schuessler WW, Schulam PG, Clayman RV, et al. Laparoscopic radical prostatectomy: initial short-term experience. Urology 1997;50:854-7.
10. Rassweiler JJ, Teber D. Advances in laparoscopic surgery in urology. Nat Rev Urol 2016;13:387-99.
11. Rassweiler JJ, Autorino R, Klein J, et al. Future of robotic surgery in urology. BJU Int 2017;120:822-41.
12. Ficarra V, Novara G, Artibani W, et al. Retropubic, laparoscopic, and robot-assisted radical prostatectomy: a systematic review and cumulative analysis of comparative

 

studies. Eur Urol 2009;55:1037-63.
13. Galfano A, Ascione A, Grimaldi S, et al. A new anatomic approach for robot-assisted laparoscopic prostatectomy: a feasibility study for completely intrafascial surgery. Eur Urol 2010;58:457-61.
14. Cacciamani GE, Medina LG, Gill T, et al. Impact of Surgical Factors on Robotic Partial Nephrectomy Outcomes: Comprehensive Systematic Review and Meta-Analysis. J Urol 2018;200:258-74.
15. Pathirana S, Kam P. Anaesthetic issues in robotic-assisted minimally invasive surgery. Anaesth Intensive Care 2018;46:25-35.
16. Kaouk JH, Goel RK, Haber GP, et al. Robotic single-port transumbilical surgery in humans: initial report. BJU Int 2009;103:366-9.
17. Joseph RA, Goh AC, Cuevas SP, et al. "Chopstick" surgery: a novel technique improves surgeon performance and eliminates arm collision in robotic single-incision laparoscopic surgery. Surg Endosc 2010;24:1331-5.
18. Stein RJ, White WM, Goel RK, et al. Robotic laparoendoscopic single-site surgery using GelPort as the access platform. Eur Urol 2010;57:132-6.
19. Nelson RJ, Chavali JSS, Yerram N, et al. Current status of robotic single-port surgery. Urol Ann 2017;9:217-22.
20. Janetschek G. Robotics: Will they give a new kick to single-site surgery? Eur Urol 2014;66:1044-5.
21. Gaboardi F, Pini G, Suardi N, et al. Robotic laparoendoscopic single-site radical prostatectomy (R-LESS-RP) with daVinci Single-Site® platform. Concept and evolution of the technique following an IDEAL phase 1. J Robot Surg 2019;13:215-26.
22. Bertolo R, Garisto J, Gettman M, et al. Novel System for Robotic Single-port Surgery: Feasibility and State of the Art in Urology. Eur Urol Focus 2018;4:669-73.
23. Agarwal DK, Sharma V, Viers B, Frank I, Tollefson M, Gettman M. Initial experience with da Vinci single port (SP) robot-assisted radical prostatectomies. European Urology Supplements 2019;18:e2280.
24. Kaouk J, Garisto J, Bertolo R, et al. Robotic Urologic Surgical Interventions Performed with the Single Port Dedicated Platform: First Clinical Investigation. Eur Urol 2019;75:684-91.
25. Bertolo R, Garisto J, Eltemamy M, et al. Pure single-site trans-perineal robotic radical prostatectomy: first clinical report using the SP® surgical system. European Urology Supplements 2019;18:e2282.
26. Dobbs RW, Halgrimson WR, Talamini S, et al. Single-port robotic surgery: the next generation of minimally invasive urology. World J Urol 2020;38:897-905.
27. Kaouk J, Garisto J, Eltemamy M, et al. Single-port Robotic Intracorporeal Ileal Conduit Urinary Diversion During Radical Cystectomy Using the SP Surgical System: Step-by-step Technique. Urology 2019;130:196-200.
28. Kaouk J, Garisto J, Eltemamy M, et al. Pure Single-Site Robot-Assisted Partial Nephrectomy Using the SP Surgical System: Initial Clinical Experience. Urology 2019;124:282-5.
29. Kaouk JH, Garisto J, Eltemamy M, et al. Robot-assisted surgery for benign distal ureteral strictures: step-by-step technique using the SP® surgical system. BJU Int 2019;123:733-9.
30. Lenfant L, Kim S, Aminsharifi A, et al. Floating docking technique: a simple modification to improve the working space of the instruments during single-port robotic surgery. World J Urol 2021;39:1299-305.
31. Bijlani A, Hebert AE, Davitian M, et al. A Multidimensional Analysis of Prostate Surgery Costs in the United States: Robotic-Assisted versus Retropubic Radical Prostatectomy. Value Health 2016;19:391-403.

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