REVIEW ARTICLE

The impact of robotic surgery in urology

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Abstract

Introduction: More than a decade ago, robotic surgery was introduced into urology. Since then, the urological community started to look at surgery from a different angle. The present, the future hopes, and the way we looked at our past experience have all changed.

Methods: Between 2000 and 2011, the published literature was reviewed using the National Library of Medicine database and the following key words: robotic surgery, robot-assisted, and radical prostatectomy. Special emphasis was given to the impact of the robotic surgery in urology. We analyzed the most representative series (finished learning curve) in each one of the robotic approaches regarding perioperative morbidity and oncological outcomes.

Results: This article looks into the impact of robotics in urology, starting from its background applications before urology, the way it was introduced into urology, its first steps, current status, and future expectations. By narrating this journey, we tried to highlight important modifications that helped robotic surgery make its way to its position today. We looked as well into the dramatic changes that robotic surgery introduced to the field of surgical training and its consequence on its learning curve.

Conclusion: Basic surgical principles still apply in Robotics: experience counts, and prolonged practice provides knowledge and skills. In this way, the potential advantages delivered by technology will be better exploited, and this will be reflected in better outcomes for patients.

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Introduction

In the field of urology, as in all medical specialties, progress has optimized the diagnosis and treatment of diseases that may arise. The intention of surgical specialties has been that patients who undergo surgery have a pleasant experience without compromising perioperative and postoperative outcomes.

Minimally invasive surgery (laparoscopy) brought important and significant benefits into play such as improved visualization, less pain, decrease blood loss, and it is esthetically superior to open surgery. However, limitations were also identified: a steep learning curve, surgical fatigue (ergonomics), and prolonged surgical time because of the difficulty of the technique; these limitations did not allow the globalization of this technique, and many preferred to continue with open surgery. Robotic surgery has brought solution to these drawbacks.

The past 50 years witnessed a dramatic and exponential development in the field of information technology. These changes influenced different aspects of our lives and surgery is one of the main areas where it played an important role. Initially it was introduced to surgical field when it helped to enhance the surgical feedback in areas where the surgeon naked eye could not evaluate the situation and this came through digitalization of images and magnification in laparoscopy and endourology. Later on, it came to play a role in execution of surgical step through the robotic technology. Actually, robot has exceeded the human abilities in certain aspects like greater degrees of freedom in movement.

History of robotic surgery

Yesterday dreams and the early beginnings

The term "robot" was coined by the Czech play writer Karel Capek in 1921 in his work "Rossum's Universal Robots". The word "robot" is from the Czech word "robota" which means forced labor. Isaac Asimov further popularized this in his short story where he coined the term "robotics" in 1942. Since that time, robots have developed from primitive machines that could perform a variety of menial tasks to today's robots where they can perform very complex tasks.

The modern history of robotic surgery begins with the Puma 560®, a robot used by Kwoh et al. to perform neurosurgical biopsies with greater precision. In 1988, Davies et al. used this system to perform a transurethral prostatectomy. Integrated Surgical Supplies Ltd. (Sacramento, USA) constructed two models with similar features: Probot®, a robot designed specifically for transurethral prostatectomy, and Robodoc®, a robotic system for emptying the femur with more precision in hip replacement operations. The latter system was converted into the first robot approved by the FDA.

As robots developed in the medical field, researchers at the NASA (National Air and Space Administration) Ames Research Center joined the Stanford Research Institute for working on a robotic telemanipulator (SRA) to develop a system for hand surgery. With this the concept "telesurgery" was born which combined virtual reality, robots, and medicine.

Around the same time, Yulun Wang designed a robotic arm to hold a laparoscopic camera. His company, Computer
Motion, commercialized the AESOP®, an automatic endoscopic system for optimal positioning. Then ZEUS® system, another type of modern robot launched in 1998, introduced the concept of telerobotics or telepresence robotic surgery. Jacques Marescaux used this robot in September 2001 to perform the first transatlantic remote laparoscopic cholecystectomy. While sitting in New York he operated on a patient in Strasbourg, France. This was a major landmark for surgery. The main drawback of the ZEUS® system is the large size of robotic arms, which limits the space in the operating room and collisions between the trocars are frequent.

The license for telepresence surgical systems was acquired by Frederic H. Moll, who created the company Integrated Surgical Systems (now Intuitive Surgery, Inc.). He redesigned the Telepresence surgery system and created the da Vinci Surgical System®, classified as a master-slave surgical system. The da Vinci surgical robotic system is the most comprehensive system developed to date. It uses true 3D visualization and EndoWrist®. FDA approved it in July 2000 for general laparoscopic surgery and in November 2002 for mitral valve repair surgery.

The da Vinci robotic surgical system also has drawbacks: the big robot size requires spacious operating rooms. It also requires a large number of delicate connections that are within the OR and can cause accidents. In addition, in certain operations such as bowel resection, when access to more than one quadrant is necessary, assembly and disassembly of the robotic arms are required, which subsequently results in longer operative time. This means that the history of robotic surgery is still being written; the steps taken in the last three decades have been important, but there is still a long way to go.

Urology in the age of informatics minimal invasion

The field of urology has been characterized by the innovation and accomplishment of different surgical techniques that have optimized the treatment of patients with genitourinary tract pathology.

Laparoscopy was the door to minimal invasion in urology. It started in 1991 by Dr. Clayman with the first laparoscopic radical nephrectomy. The success of this case encouraged several urological groups across the world to develop, learn and implement multiple procedures making use of the advantages of laparoscopy: small incisions, less bleeding, shorter time to recovery, and better access to surgical field, besides an improved visualization of the structures in order to achieve good results intra and post-operatively.

In 2000, when robotic technology was first introduced to urology, its advantages were readily recognized such as three-dimensional vision, the use of instruments that move with greater degrees of freedom compared to conventional laparoscopy. It also eliminates the tremor of the hand movements, so we can achieve a more precise intervention.

In spite of the growth in robotic surgery in almost all the surgical areas, it has been the urology field where it has caused main impact, with vast expansion and excellent results in different types of interventions: simple prostatectomy, radical prostatectomy, partial nephrectomy, live donor nephrectomy and pyeloplasty, among others. The first robotic radical prostatectomy was performed by Binder and Kramer in Germany, while Abbou et al., in France, were the first ones in publishing it in the literature. The group of Guilonneau et al. reported the first nephrectomy® and robotic lymphadenectomy as a treatment for prostate cancer.

It is noteworthy that experience in robotic surgery has shown that until today surgical skills remains the most important determining factor for the final outcomes of the procedure. If the surgeon has performed more cases and becomes more familiar with workspace, and better identifies the landmarks, he makes fewer mistakes which in turn results in better outcomes.

Robot is not future anymore, current application

Technological advances continue to impact the modern practice of urology, none more so in recent years than the development of robotic surgery. Since the first publication of a series of patients undergoing robot-assisted radical prostatectomy in 2001, the field has seen a dramatic increase in the use of robotic surgery for urologic procedures. In the USA, 42% and 63% of all radical prostatectomies in 2006 and 2007, respectively, were performed with robot assistance.

The minimally invasive nature of these procedures allows better precision, decreased blood loss, decreased morbidity, and shorter hospital stay and convalescence while preserving functional and oncologic outcomes. Additionally, the application of robotic surgery has spread beyond radical prostatectomy to include radical cystectomy, nephrectomy, partial nephrectomy, adrenalectomy, and other urological procedures like pyeloplasty, ureteral reimplantation, etc. Robotic surgery has even seen dramatic growth in pediatric urologic applications.

Learning curve in robotic surgery

Robotic surgery has not only changed the way we do surgery, it has revolutionized the way we teach and learn to operate. It has become part of the surgery training programs, and has been used for teaching surgery and to practice with three-dimensional virtual models instead of patients. The exponential growth in robotic technology has resulted in an ever-growing requirement for surgeons trained in robotic urologic surgery.

How to define the learning curve and how long does it take?

The learning curve is originally an aeronautical term to characterize the diminishing amount of time required to perform a repeated task. Today, it describes a self-declared point at which a surgeon reaches a comfort zone when performing a procedure that guarantees effectiveness and safe outcomes. This period or number of cases is variable and difficult to establish. It depends on the surgeon’s preset benchmarks, previous experience in laparoscopy or open procedures, and personal skills. Performing a greater number of cases will decrease surgical times, complication rates or conversion, and improve functional outcomes.
There is no standard way to measure the learning curve in the RARP; it is the surgeon who decides when he has the necessary experience. For this reason the learning curve in robotic urology is still controversial. We think that the learning curve for basic proficiency of RARP is approximately 20–25 cases; this early stage has focused on the acquisition of skills in novice robotic surgeons.\textsuperscript{15,11} Measurement of success of this first step is the ability to perform the case under 4 h with a smooth postoperative hospital course.

Then between 26 and 75 cases, improving perioperative outcomes (OR time, EBL, length of stay) will take place and proper patient selection is important during this window to achieve these goals. The surgeon will feel that he is able to optimize dissection of bladder neck, the dissection of seminal vesicles, preservation of nerves and the anastomosis.

At the end of this stage the surgeon is capable of performing challenging cases like post TURP patients, large prostates, big median lobes, and patients with prior pelvic surgery. The measurement of success of this stage is to have smooth progress of the procedure despite these challenging circumstances. Between 76 and 200 cases, the surgeon is able to discern different anatomical variations and improves his nerve sparing approach. Finally, between 300 and 700 cases, the surgeon continues to improve on the technique and his perioperative outcomes; OR times are usually less than 2 h at this period. Bleeding and length of stay may be stabilized.\textsuperscript{12}

Virtual and guided robotic surgery training

A robotic surgeon in training learns surgery through the classic way of “supervised trial and error”. The da Vinci SI Surgical System offers a dual console used for both training and collaboration. During a dual console operation, each surgeon sits at his or her individual console and can see the same high definition images of the anatomy from the 3D endoscope. When the dual console is used for training, control over instruments can be easily and quickly exchanged during surgery – meaning the teaching/mentoring surgeon can hand over control of the instruments to the resident/fellow at any time. This enables a see-and-repeat model of instruction designed to accelerate the learning curve (Fig. 1).

Another tool that enhances learning is the Mimic dV-Trainer\textsuperscript{TM}, using a compact hardware platform that closely reproduces the experience of the da Vinci surgeon console. Mimic’s simulation exercises were developed in close collaboration with Intuitive Surgical\textsuperscript{TM} to achieve unparalleled realism. Mimic accelerates the learning curve; the dV-Trainer provides independent on-demand training that emphasizes system awareness, instrument manipulation, and basic surgical skills such as needle handling and energy management.

Studies conducted with residents and medical students show that suturing, and intracorporeal knotting are 65% faster with the robot compared to laparoscopy. The three-dimensional view allows us to increase the speed by 30%. The ideal situation would be if the surgeon had a mixture of robotic and laparoscopic training.\textsuperscript{13–16}

Robotic prostatectomy: a vivid model of robotic success

One of the techniques that have largely evolved after introduction of robot in urological practice is radical prostatectomy. This occurred for two main reasons: Firstly, early diagnosis and surgery may cure the disease in one hand, and prostate cancer has been more frequently diagnosed in its early stages on the other hand. The second reason is the high technical demands of the procedure; the work area is best approached by the robotically which gives better exposure and greater ranges of motion.\textsuperscript{17}

In less than a decade, the robot-assisted radical prostatectomy (RARP) became the most frequently used surgical technique for treating prostate cancer. Today more than 85% of the radical prostatectomies in USA are performed robotically due to the enthusiasm of the surgeons, the interest of the patients, and effective trade promotion campaigns.\textsuperscript{16,19}

Initially, the proponents of open radical prostatectomy emphasized that results of robotic surgery need to be shown scientifically and that this technique is safe and effective beyond speculations, promises and marketing before accepting it. For a new surgical technique to survive it is essential to be subjected to scrutiny of critical analysis and has its outcomes precisely evaluated like oncological, perioperative, and short and long term functional outcomes. These results are important and must be taken into account whenever a new therapeutic approach is used, in spite of the fact that no surgeon regardless of the technique used can guarantee favorable outcomes all the time.\textsuperscript{18}

As far as the main objective of the procedure is concerned which is cancer control, robotic prostatectomy provided answers to people who looked at robotic prostatectomy with skepticism and showed that biochemical recurrence free survival is comparable to open prostatectomy at two and five years.\textsuperscript{20}

The positive surgical margin rates, which are indicators of oncological safety, were found to be similar or even slightly lower in robotic surgery compared to open surgery. This was demonstrated by Dr. Smith who showed in his comparative study that RARP resulted in significantly lower PSM rates compared to open approach (15% vs. 35%).\textsuperscript{21} Perioperative outcomes are other important aspects to assess where robot resulted in better results compared to open surgery. There

\begin{figure}[h]
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\includegraphics[width=0.5\textwidth]{Figure1.png}
\caption{Dual console, da Vinci Surgical System IS.}
\end{figure}
was significant decrease in estimated blood loss, complication rates (robotic 6.6% vs. open 10.3%) and length of stay.\textsuperscript{21,23}

Using prospective, validated quality of life instruments, the patients undergoing RARP were found to have higher scores and faster return to their base line functions when compared with patients undergoing open prostatectomy.\textsuperscript{14}

The so far obtained results for potency and continence have been similar when both groups were compared.\textsuperscript{21,23}

Other urological procedures

Regarding procedures on upper tract, robotic pyeloplasty demonstrated operative times comparable to laparoscopic pyeloplasty but with lower complication rates, faster recovery, and shorter hospital stay.\textsuperscript{25,26} It is emphasized that robotic partial nephrectomy appears to have shorter operative time (193 vs. 152 min), shorter ischemia time (18.0 vs. 14.0 min) and less blood loss (245 vs. 122 ml) compared with laparoscopic partial nephrectomy,\textsuperscript{27} but when compared to open surgery, it showed decreased ischemia time, blood loss and length of stay only,\textsuperscript{28} whereas total operative time was longer.

Nowadays, surgical technologies are under continuous critical evaluation, but in spite of this, robotics has prevailed. The critiques are increasingly positive and with this, several skeptical urological groups have changed their direction to adopt this surgical technology.

The future

Robotic surgery has allowed deeper insight into several intraoperative steps during RARP. With improved 3D visualization and fine execution of surgical tasks with wristed instruments we were able to move a step forward toward optimization of nerve sparing, the goal had always been to preserve the nervous tissue without compromising surgical margins. We have introduced a modification to nerve sparing that took these two facts in consideration. It is necessary to be very meticulous and delicate in the dissection of the nerves to achieve preservation.\textsuperscript{29}

To achieve these aims we tested the prostatic vessel as a fixed and reliable anatomical landmark for intraoperative identification and dissection of the NVB. In that study we found that the distribution of the peri-prostatic arteries is much more consistent on the posterolateral aspect of the prostate compared to veins, that was previously described by other groups.\textsuperscript{30} Moreover, we found that the relation between nerves and vessels is consistent in a way that if nerve sparing is done medial to the vessels a complete or almost complete nerve spare will result. This provided us with a road map for a graded nerve spare tailored according to patient’s underlying needs and pathological characteristics.

This new breakthrough was added to the previously described principles of nerve sparing (athermal dissection, early retrograde release of the NVB,atraumatic) and resulted in the currently utilized technique.

Although multiple treatment options are currently available for these patients, radical prostatectomy remains the standard of care for long-term cancer control. In PSA era, prostate cancer is frequently diagnosed in younger and healthier men who desire to go through a definitive treatment while maintaining their quality of life. RARP came to meet their expectation and helped to achieve this aim. However, we feel that it is no longer a viable tool to measure the outcome of RARP in the same way we used to do before in open prostatectomy.\textsuperscript{11}

Trifecta had been an excellent tool to evaluate radical prostatectomy but it does not address patient satisfaction and we feel that for a counseling tool to be valid in the contemporary robotic approach, we need to include the factors that may compromise our patients’ satisfaction. We identified positive surgical margin and major complications as two factors that need to be added to trifecta factors (BCR, continence, potency) to address this issue.\textsuperscript{30,31}

We believe that the “Pentafecta” is more comprehensive and fulfills the demands of the patients after RARP.

Conclusion

Basic surgical principles still apply in Robotics: experience counts, and prolonged practice provides knowledge and skills. In this way, the potential advantages delivered by technology will be better exploited, and this will be reflected in better outcomes for patients. The main room of improvement is to find better techniques to enhance functional outcomes and to raise the standards of evaluation.

It is difficult to know where we stand now along the path of surgical treatment of localized prostate cancer. However, efforts should continue to explore any potential hope for improvement for the sake of our patients.

Conflict of interest

The authors declare that they have no conflict of interest.

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