Robotic prostate surgery

Michael Muntener, Daniel Ursu, Alexandru Patriciu, Doru Petrisor and Dan Stoianovici†

The increasing popularity of robot-assisted radical prostatectomy has put the field of robotics in the spotlight. However, the relationship between medical robotics and the field of urology is older than most urologists know and it will most likely have a bright future beyond any contemporary application. The objective of this review is to provide an insight into the fundamentals of medical robotics and to highlight the history, the present and the future of urological robotic systems with an emphasis on robotic prostate interventions.

Over the past few decades technological advances have revolutionized the way we practice medicine. Today, medicine relies heavily on technical equipment and technology is evolving ever more rapidly. The field of urology has a very rich tradition of embracing the use of advanced and pioneering technology to make existing procedures more tolerable and efficient as well as developing new treatment modalities. The advent of robotics in prostate surgery is a new horizon of this tradition. The robot-assisted laparoscopic radical prostatectomy (LRP) is certainly a robotic success story and the da Vinci® Surgical System (Intuitive Surgical) is the most famous representative of medical robots currently in use. However, the use of robots for prostatic interventions has a longer, less well-known history and it will most likely have a bright future beyond any current application. Apart from a general overview of robotic surgical systems, this review will focus on the past, present and future of robotic prostate interventions.

Fundamentals of surgical robotics

The robot, a term first coined by the Czech playwright Karel Capek in 1921 in his play Rossum's Universal Robots, comes directly from the Czech word ‘robot’ which means industrial worker. It is of no surprise then that the first robots, as we know them today, appeared in the fields of industrial manufacturing where automatization became increasingly important for economic efficiency during and after World War II.

By definition, a robot is a mechanical device that is controlled using a computer system [1]. In particular, a medical robot is a controllable mechanical device that undertakes one of four healthcare-specific roles: a supportive role to patient and staff, laboratory assistance, for rehabilitation or surgery. Urological medical robots are robots that belong to the last category and are defined by three essential components: the manipulator, image acquisition device and a computer.

The surgical manipulator is an electromechanical arm equipped with sensors and actuators responsible for holding and precisely moving instruments under computer control. The most commonly employed kinematic architecture for surgical manipulators is the remote center of motion (RCM) concept [2], developed in 1995 at IBM® [3]. This architecture, specific to surgical robots, aims to reproduce a surgeon’s natural motion during laparoscopic surgery by allowing the manipulator to consistently enable and facilitate the pivoting of instruments about a fixed point in space during the surgical procedure; that is, the point where the laparoscopic instrument enters the body (FIGURE 1) [4].

The image acquisition device allows the robot and surgeon to visualize the surgical environment and define the operating tasks...
of the robot. Different imaging modalities, such as MRI, ultrasound, computed tomography (CT), infrared or video, are used to communicate the visual information. Manipulators that are controlled by the surgeon throughout the whole operating procedure may use video, infrared or ultrasound in combination to give the surgeon visual cues as to the position of the instruments. For example, the da Vinci Surgical System, a master–slave remote manipulator, in which the surgeon (master) remotely directs the robot (slave) through each task, uses stereo endoscopes to give the surgeon a 3D view of the region of surgery. The image acquisition aspect of a surgical robot becomes particularly important if the robot is to perform surgical tasks on its own. In this instance, the image modalities used must be of a very high resolution and accuracy, so that they are correctly interpreted by the image processing algorithms in the computer. For soft tissue surgeries, MRI is the imaging modality of choice, offering high-definition images that can easily be converted into 3D volumes to allow precise motion planning, trajectory following and target location. Alternatively, fluoroscopic markers can be inserted into a soft tissue to give the proper orientation cues, but that is more invasive to the patient, and thus mainly used during testing procedures.

The third main component of the surgical robot, the computer, performs two main roles. Its primary role is as a coordinator, which translates the human operator’s commands into specific actions performed by the robot manipulator. In doing so, the computer employs powerful algorithms that use the imaging data as a reference in order to guide the manipulator to an anatomical target specified by the surgeon. Thus, the computer is the link between the ‘data world’ of medical information (images, sensors and databases) and the physical world of surgical actions [3]. The computer’s secondary role is as a data recorder, recording the data relevant to the surgery, such as manipulator tracking and organ displacements. This data can then be used to update the intraoperative sequences of the surgery, via surgeon-assisted decision making.

Robotic systems involved in urological surgical procedures can be grouped in two main categories according to their mode of operation [3]. The first category is comprised of computer-integrated surgical systems for which the operator defines the task and the system accomplishes the task on its own. Such systems are image driven and are made to excel at reaching a target specified by the surgeon. In the future, such systems are envisioned to have the ability to perform integrative pre-operative planning and be capable of intraoperative decision making, based on the changing intent of the surgeon, all while minimizing the trajectory and target reaching errors.

The second category of urological robotic systems consists of operator-driven manipulators, which exhibit low integration with the medical environment, and where the surgeon continuously controls the position of the robot and decides what task needs to be performed. These systems are designed primarily to scale a surgeon’s movement, eliminate tremor and improve instrument accuracy. Endoscopic manipulators such as the Automatic Endoscopic System for Optimal Positioning (AESOP®) and the ZEUSTM, a surgical robotic system, master–slave remote manipulator, both built by Computer Motion (CA, USA); as well as the da Vinci master–slave manipulator, built by Intuitive Surgical (CA, USA), fall under this category.

History & past achievements
As in other medical robotic fields, robots for prostatic surgery evolved quite naturally from industrial robots. Robotic development in this field was slower than in orthopedics or neurosurgery owing to the challenges imposed by the deformability and high mobility of urological organs [4]. Investigators in this field saw the potential of fine-tuning and adapting different versatile multiple degree of freedom industrial robots to perform specific surgical tasks. Of course, a couple of critical modifications were necessary, considering the working conditions of the industrial robot and the transplanted habitat in which the surgical robot would be performing.

Most importantly, safety issues regarding the movement, working tolerances and positioning of the robot had to be considered. Most industrial robots work in environments that are off-limits to humans and so large motion envelopes and rapid position changes are not dangerous to personnel. Moreover, the working tolerances of industrial robots, while precise, are not as precise as operating on human tissue would require. Thus, once in the operating room, space and human proximity become crucial issues. Important considerations arise, such as streamlining a robot’s silhouette and motion envelope as much as possible, owing to space constraints. Another
equally important factor is the robot's synergy with other medical equipment such as MRI scanners whose performance is affected by the presence of electronics.

The robot's movements had to be limited and slowed down considerably so that they would not pose a threat to the patient and nearby doctors. This was usually achieved by reengineering the mechanical drives with larger gears and more precise actuators for slower movement. Often, the robot's control electronics would also be changed to achieve slower, overdamped movement to ensure a precise motion envelope. The latter would also ensure a better working tolerance.

The positioning of surgical robots also took on new challenges from their industrial predecessors. Most crucially, the positioning of the robot had to be very precise to avoid any complications during surgery. It was very important that once positioned into a task, the robot would remain in that position until the end of the task, even during a power outage. The safest and most efficient method devised was to move the robot into the required position before the operation and then power off the components of the robot that were no longer needed during the surgery.

In addition, designers of surgical robots sought to take advantage of other powerful techniques already in use in the medical field such as MRI scanners. Since these devices are easily affected by, and can disrupt, electronic communication, special design characteristics had to be adopted to assure coexistence in the operating room. Researchers turned to more expensive paramagnetic materials to construct the robot's body with fiber optic sensors and wiring in order to eliminate electronic interference.

The first pioneers to successfully answer the challenge of constructing and using a surgical robot in the operating room were Imperial College (London, UK), based Davies 'Mechtronics in Medicine' group [6]. In 1988, Davies sought to use an industrial Puma 560® (RimLab) six degrees of freedom (DOF) industrial robot to perform a transurethral resection of the prostate (TURP) [5]. The original robotic concept proved inadequate for the conical prostate resection geometry required and two additional frames contributing two DOF were added to the robot, for a total eight DOF system. Since the Puma 560 part of the system was only used to position the robot in place, while the additional frames contributed to the cutting, it was decided that the Puma 560 should be replaced with a manipulator that focused specifically on positioning the prostate-resecting framework. Therefore, by limiting its motion envelope and its DOF, the robot was kept simple, slender and safe, and was tailored to perform a specific task. Indeed, after a special purpose manual framework on performing the prostate resection was designed in 1989, a robotic motorized system 'Surgeon Assistant Robot for Prostatectomy' (SARP) was successfully built and clinically tested in April 1991, making it the first active robot used to remove patient tissue [6].

A second-generation prostate resection robot, the 'Probot', presented in 1995 by Davies and largely based on the system presented in 1991, has been introduced and used in clinical trials at Guy's Hospital (London, UK) [7]. The Probot is based on the concept of a passive rigid mounting frame being used to position and support the smaller motorized robot, which resects the prostate. An easy to use intuitive program allows the surgeon to measure the prostate and select the resection geometry on the touch screen. Tests with the robot have shown its ability to consistently perform the surgeon-specified resections within acceptable error boundaries [8].

The initial success of the Probot has continued with further developments of the prototype by the Sing Computer-Integrated Medical Intervention (CIMI) Research Group at Nanyang Technological University, Singapore. Sing, one of the founding research members of SARP, has taken the original concept and produced a universal platform named URobot, which is designed to be used with different treatment modalities, such as interstitial laser coagulation, laser resection and TURP, to treat prostate enlargement [9]. This prototype platform, named Surgeon Programmable Urological Device (SPUD) in medical literature, is meant to be both a therapeutic and a learning tool for urological surgeons. In 1998, SPUD entered clinical trials in Changi General Hospital (Singapore).

Noteworthy in the domain of robotic brachytherapy of prostate cancer, is the Chinzei group from the National Institute of Advanced Industrial Science and Technology (AIST), (Tokyo, Japan). In 2000, the group ran preclinical studies at Brigham and Women's Hospital in (MA, USA), for a robot conceived to assist the surgeon with needle insertion into the body. The robot's rigid arms can hold, rotate and insert the needle according to a radiologist's predefined trajectory. Interestingly, the Brigham MRI robot is the first robot intended to be MRI compatible. The system was designed to coexist with powerful MRI systems; this posed new challenges in terms of controller and body design. Electric fields picked up by MRI scanners lead to poorer quality images, and the pulsating magnetic fields emitted by the scanners not only attract metallic objects, but also disrupt and destroy electrical systems. Therefore, a new approach to the robot's sensors and components was devised. The body of the Brigham MRI robot is completely constructed of paramagnetic materials. None of its sensors (such as the ultrasound distance range finders) are magnetic and robot communication in the proximity of the MRI scanner is achieved via fiber optics to avoid noise interference. The preclinical tests performed on this system demonstrated that the robot can coexist with both surgeon and MRI scanner, without disrupting the work of either [10]. Specifically, the Chinzei group work has shown that coexistence of medical robots with restrictive image modalities, such as MRI, is not only possible but truly beneficial.

The achievements of Rovetta and colleagues from the Polytechnic Institute (Milan, Italy), in the field of image-guided robotic prostate surgery are equally important. In 1995, the group was able to demonstrate a long desired goal of medical robotics, namely the use of image processing for achieving automatic guidance of the robot [11]. The robot performed a transperineal prostate biopsy with the use of transrectal
robots that are still in use. For sale, however, support continues to be provided for the ZEUS system. The ZEUS system is no longer offered for hospital use. The da Vinci system is currently the most widespread medical robot allowing the hook-up of another system (Socrates™, Computer Motion). However, the ZEUS system had telementoring capabilities, which were not available in the da Vinci. The da Vinci's instruments had seven DOF, making it advantageous over the ZEUS, which had five in the early versions, and later versions had six DOF with the addition of tips that could articulate in a single plane (MicroWrist®, Computer Motion). However, the ZEUS system had telementoring capabilities, allowing the hook-up of another system (SocratesTM, Computer Motion) which could allow a surgeon in another location to control the endoscope during the surgical procedure. In 2003, the makers of the ZEUS and da Vinci merged and the da Vinci system is currently the most widespread medical robot allowed for hospital use. The ZEUS system is no longer offered for sale, however, support continues to be provided for the robots that are still in use.

Present robotic applications in prostate surgery
In this section we will focus on robotic camera holding systems and the da Vinci Surgical System, which is the only robotic system currently available for assistance in prostate surgery.

Robotic camera holding systems
In 1993, AESOP became the first surgical robotic system to be approved by the US FDA and it remains a widely used system. The AESOP is a table-mounted robotic arm with six DOF, two of which are passive and is a particular implementation of the RCM concept. AESOP is composed of a planar two DOF manipulator attached to a vertical translation stage. The translation stage is attached to the operating table and the robot end-effector accommodates the laparoscope through a passive two DOF joint. A final rotation allows for orientation. When the endoscope is passed through the entry port, its motion is restricted to three rotations about the entry point and one translation about the endoscope axis [4]. As a result, the AESOP can not only precisely manipulate a standard laparoscope or other instrument but it is also designed to eliminate the camera-holding assistant. It is controlled by the primary surgeon either by hand, foot or via a voice control interface and it provides a stable view of the operating field. In an early clinical study, AESOP was found to decrease unwanted camera movements and to provide a better image without increasing operative time [14]. The use of one or more AESOP systems has been shown to allow a surgeon to perform solo laparoscopic operations without a camera holder or surgical assistant [15]. Various laparoscopic operations have been successfully performed with the assistance of the AESOP, including radical prostatectomy [16].

EndoAssist™ (Armstrong Healthcare) is another robotic camera holding system that has recently been introduced into clinical practice. This device is a freestanding laparoscopic camera manipulator controlled by infrared signals from a head-set worn by the operator. The head movements to control EndoAssist can be rapidly learned by the surgeon, and the setup and dismantling times are less than 10 min [17]. Overall, this system has proven to be practical and safe, and reduces operating times compared with a skilled human camera-holding assistant [18]. In another study, the EndoAssist robot was significantly quicker compared with the AESOP device; this was attributed to the increased accuracy of movement in the EndoAssist compared with the voice recognition errors occurring while operating with the AESOP [19].

da Vinci Surgical System
The da Vinci Surgical System represents an improved and renamed version of the MONATM prototype surgical assistance equipment [20], that served as the first prototype surgical system developed at the Stanford Research Institute, (CA, USA) [21]. Its master–slave concept involves a master unit that the surgeon controls. The surgeon's commands (movements) are processed by a computer and sent to the 'slave' components that carry out the task at hand in real time. Master–slave types of systems were first introduced in the 1990s [22,23]. Using master–slave robots, a surgeon seated at a console manipulates levers that control mechanical instruments inside a patient's body. These systems represent a paradigm shift in surgery because the physician is no longer manipulating surgical instruments directly. Hence, these systems have great potential for remote telesurgery.
Apart from the master unit, the da Vinci system consists of a three- or four-arm surgical manipulator. The surgeon sits at the control unit and is presented with a high-resolution, 6–10 times magnified 3D view of the surgical field, which is achieved via two separate lenses positioned on the robotic tower for binocular view. The console is ergonomically designed and the surgeon's hand–eye axis is positioned to create the illusion of operating directly on the patient. The arms of the surgical manipulator are used to control the laparoscope and for manipulating surgical instruments. Each motion of the operator's hands is translated to a movement of the surgical instruments implementing the RCM principle.
Information processing eliminates the fulcrum effect inherent to conventional laparoscopic surgery and thereby makes intracorporeal manipulation more intuitive. Additionally, the information processing allows the robotic system to filter out physiological tremors and to increase movement precision by motion scaling. Motion scaling is the concept that a movement by the operator at the master unit can be amplified or dampened at the end-effector slave unit. Depending on the end-effector in use, the instrumentation provides seven DOF; including rotations aimed at reproducing the human wrist. The 3D view of the surgical field helps the surgeon to accomplish tasks such as intracorporeal suturing, which are very challenging to master in conventional laparoscopy.

The da Vinci system was first used in Europe for cardiac surgery and received FDA approval in July 2000. Since then, the system has been used in a variety of urological applications but it has gained most attention in robot-assisted laparoscopic radical prostatectomy (LRP) [24–27]. Schuessler and colleagues reported the initial case of conventional LRP in 1997 [28]. Guillonneau and Vallancien [29], and Abbou and colleagues [30] refined and popularized this minimally invasive approach. Conventional LRP, however, has proven to be a challenging operation requiring advanced laparoscopic skills. The lack of a 3D visual field and the limited dexterity of conventional laparoscopy limit the surgeon’s working space and complicate tasks such as suturing and intracorporeal knot tying. To facilitate this procedure, several groups have developed robot-assisted LRP programs [31–34].

Meanwhile, significant experience with robot-assisted LRP has accumulated [35], and excellent functional and early oncological results have been reported [36] that compare favorably with the results of conventional LRP and open radical prostatectomy [37]. The learning curve for this very complex laparoscopic procedure has been shown to be shorter using the robot-assisted approach compared with the conventional laparoscopic technique [38–40]. Furthermore, Ahlering and colleagues have shown that a laparoscopically naive yet experienced open surgeon can successfully transfer their open surgical skills to a laparoscopic environment with the help of the da Vinci robot [31]. Although suturing for the inexperienced is easier with the robot, laparoscopic knowledge is still required, and the use of the robot also requires a significant learning curve [41]. Correct trocar placement is necessary to prevent mechanical interference between the robotic arms; however, owing to the lack of tactile feedback, the surgeon must develop an intuition about the suture tension in order to avoid suture breakage and tissue strangulation. The aspects of surgery that require gross, rather than precise, movements, such as the reflection of the bowel or counter traction during dissection, are more difficult with the robotic arms and so laparoscopic surgeons experienced with intracorporeal suturing may not find the robot helpful [42]. In addition, problems associated with cost, maintenance, functional storage and use must be taken into consideration with this complex and expensive technology. For example, in 2006 a three-arm da Vinci system cost US$1.12 million and a four-arm da Vinci cost US$1.3 million. Annual contract fees range between US$120,000–140,000. Moreover, the da Vinci system’s instruments are limited to a life cycle of ten uses and the replacement costs per instrument are between US$1200–4600. Finally, the system at the current configuration is bulky and requires large operating rooms. For this reason, presurgery set-up times add considerably to the total duration of the procedure.

Future robotic applications in prostate interventions

Robotic surgical technology may still be in its infancy, but over a short period its history is remarkable for large advances in the technological aspects of the field of urology. To get an idea of the potential growth of this field, it is enough to compare the number of robot-assisted radical prostatectomy (RP) procedures in the last 5 years; 247 procedures were performed in 2001, followed by 766, 2648, 8642 and 16,000 in 2002, 2003, 2004 and 2005, respectively. By 2006, it is estimated that a full 25,000 or a quarter of the 100,000 RP procedures performed in the USA will be robot assisted [43].

It is highly likely that medical technology will continue to evolve very rapidly and that robotics will play an important role in that progress inside and outside the field of urology. For prostate interventions the near future will mostly bring improvements on the currently existing robotic systems first and foremost the da Vinci system. Future robots are desired to be less expensive, smaller and capable of even smoother and more precise motion. Another development that is eagerly awaited is the addition of tactile and force feedback to master–slave systems. The absence of this so-called haptic feedback is one of the most often quoted drawbacks of the da Vinci system. Haptics is an active area of research within the engineering community [44,45] and much research has already been carried out to investigate new kinds of tactile sensors [46–48].

Telesurgery is an additional application for current robotic systems that may become generally available with improved technical equipment. Telesurgery refers to active control of the surgical instruments by a surgeon located at a remote distance from the operating theater with data transmitted over a telecommunications line [13]. Although telesurgery is already feasible today and a small number of isolated, yet spectacular, transatlantic telerobotic surgeries have been performed [49,50], technical obstacles, among other reasons, have been a primary limitation to its widespread adoption. Telesurgical interventions present many practical challenges and for this reason the FDA mandates the operating surgeon’s presence in the same operating room as the patient. Signal latency resulting from long-distance transmission can cause a delay between the time the surgeon moves an instrument and the time that movement is seen on the video image of the surgical field. Ideally, this signal delay should be less than 10 ms to prevent overshooting of movements. Surgeons can compensate for delays of up to 300 ms but longer delays will significantly hinder remote task performance. For transport of the high
number of audio, video and medical images required during telesurgery, dedicated asynchronous transfer mode lines are considered to be the most reliable and safe. Communication delays are dependent on the distance between the sites, but previous experience (delays of up to 155 ms) and speed calculations have shown that these delays are acceptable when performing earth-to-earth connections [51–53]. New high-speed, broadband technologies, such as cable modems and digital subscriber lines are widely available and data transmission bandwidth with wireless technology has reached levels that can be used in telemedical applications. However, the availability of these technologies is not yet universal. Moreover, redundancy needs to be built into the system as a back-up against primary signal disruption [17]. The connections used for the transfer of patient data should be secure, preventing interruption, redirection or tampering with sensitive information. Advanced encryption protocols are beginning to be applied with success. Telesurgery holds the promise to provide specialized care in remote and underserved areas, including situations such as military operations and space travel. Telesurgery may also serve as an avenue to propagate novel surgical techniques with expert surgeons guiding less experienced ones stepwise through infrequently performed or technically demanding operations. Finally, telemedicine interactions can increase patient access to physicians. Surgeons with particular areas of expertise may operate at any hospital around the world, obviating time-consuming and logistical travel concerns for both patient and physician [17].

With very rapidly developing technology, however, the future will not just hold improvements on currently existing robotic systems or new applications for them. There is great potential for the use of robots in medicine in general, as well as in prostate interventions in particular. To reach their full potential robots need to become more integrated systems linked to available imaging modalities [54]. Like most modern medical imagers (e.g., CT and MRI), robots are digital devices. As such, they can easily be programmed to navigate in the 3D coordinated system of the respective imager. Moreover, robots are capable of working more accurately than humans. Therefore, robots are ideal devices to improve image-guided interventions (IGIs), because the success of IGI typically depends on the quality of the image used for the visualization of the target, as well as on the ability to deploy the procedure needle/probe accurately to the desired target. Owing to its easy transperineal and transrectal accessibility, the prostate is a good target for IGI-like biopsy or brachytherapy.

MRI provides the best visualization of the prostate and its surrounding anatomy [55], which should make it the image modality of choice for prostate IGI. The principal limitation to its routine use in IGI in general is the complex and challenging environment [56] inherent to MRI technology and the constrained ergonomics of closed-bore scanners. So far, only a limited number of centers have reported their experience with MRI-guided prostatic interventions [57–60]. Ideally, MRI-guidance would be combined with the precision of robotic manipulation. However, limited accessibility of the patient within the MRI scanner and incompatibility of most components commonly used in robotics, particularly electromagnetic motors, make the development of a MRI-guided robot a very difficult engineering task [61]. Previous research in this field has commonly relied on piezoelectric motors [62–64]. These are magnetic free but employ high-frequency currents creating image distortion if operated closer than 0.5 m from the MRI isocenter [63].

Recently in the authors’ laboratory, the first fully MRI-compatible robot was developed [65]. The device is designed to perform automated MRI-guided prostate brachytherapy and it is currently undergoing preclinical testing (FIGURE 2). The robot is a six position control DOF system, allowing precise needle and seed placement in the prostate. It is built using ceramic, plastic and nonferrous parts, all of which have been tested to ensure full MRI compatibility. Furthermore, it is small enough to elegantly fit standard MRI bores with a patient inside (FIGURE 3). Communication with the computer is achieved via fiber-optic wires and custom-built light encoders, which transmit information to the robot's actuators. These actuators are novel air-powered stepper motors capable of producing precise movement with step increments of 0.083 mm. As such, the robot has no metallic or electronic components present in the MRI room. The robot's control console allows remote connectivity from other users, thereby making the robot telesurgery compatible. To the best of the author's knowledge, this robot is the first fully MRI-compatible surgical robot designed to date.

So far, preclinical tests with the system have shown that it is capable of automated and highly accurate MRI-guided brachytherapy seed placement within a closed-bore scanner and that it
does not deteriorate the quality of MRI [66]. By utilizing online MRI guidance, it is conceivable that a device like our robotic system would improve the accuracy of seed placement in prostate brachytherapy and permit a more customized and targeted distribution of the radioactive sources. Improvements in the placement of the radioactive sources are likely to translate into better cancer control, as well as reduced irradiation of healthy tissue [67,68].

Advances in MRI technology, such as MR spectroscopic imaging, dynamic contrast-enhanced MRI, and the availability of higher field strength scanners, make MRI an increasingly attractive imaging modality for targeting prostate cancer [69–71]. MRI-compatible devices, like the presented robotic system, can be designed to take biopsies, inject liquid agents and insert cryotherapy or radiofrequency probes. In this way, a robot could potentially improve the performance of MRI-guided procedures and IGI in general and also play an important role in the validation and application of newly targeted procedures emerging for diagnosis and therapy of prostatic disease.

As technical development and miniaturization continue, in the more distant future micro- and nanorobots can be foreseen to enter the field of medicine. These robots will use biological components such as proteins, ATP motors and DNA for structural, actuation and information storage components, respectively. They may enter the body via oral ingestion or injection, and be biocompatible so that when their procedure is finished, the body may simply digest or expel them naturally. With this vision in mind it is conceivable that future generations of physicians will be able to treat diseases and maybe even improve on nature on a molecular basis [72]. From fully integrated operation rooms capable of linking multiple compatible devices together, to surgeons practicing their art on patients thousands of miles away, to biomolecular and nanorobots, the future holds great promise for the advancement of medicine.

Expert commentary & five-year view
Urology has always been, and will continue to be, at the forefront of integrating innovative new technologies with standard surgical procedures. Current evidence of this is the successful symbiosis between doctor and robot in the operating room. With the assistance of the da Vinci surgical robot, LRP’s are successfully performed in more and more operating rooms across the USA and Europe. Moreover, operating rooms across the world are becoming communication hardwired to allow surgeons to mentor and participate in remote surgical procedures.

In the next 5 years, we expect robot-assisted surgical procedures to become evermore numerous. Given that the use of the da Vinci surgical platform is easier for surgeons to learn than conventional laparoscopy, we expect robot-assisted radical prostatectomy to supersede the conventional laparoscopic procedure. We also expect other improvements to be brought to the robot, and other commercial systems to become available to make the surgical platform even easier to use. These include haptic feedback to give the surgeon a sense of what forces and obstacles are being experienced by the robotic arms, as well as better image acquisition that can even trace desired trajectories for the surgeon to follow and highlight regions of interest to the surgery in general. Providing force-feedback in a local system is not an engineering challenge, but perhaps competition needs to motivate future developments. Telesurgery and telementoring capabilities may also be expected in the next generation of robotic systems.

Furthermore, we expect medical robotic technology to advance more in the next 5 years, specifically with respect to image-guided interventions. We expect to see many promising experimental findings that will show algorithms and robots increasingly able to perform complicated procedures with a high degree of autonomy and precision. These machines will be aided by software capable of distinguishing one organ from another, and of optimizing trajectory following of, for example, needle placement or prostate tissue removal, with little input from the surgeon. The robots will be made to work seamlessly with the imaging modalities they will be using, be they MRI, CT or ultrasound. The integration of robotics and imaging gives robots capabilities that are unattainable to humans, because unlike humans they are digital devices.

Given the worldwide level of regulatory procedures required for the commercialization of medical devices, the novel technologies developed today will not immediately have a broad proliferation into clinical use. However, these are expected to make a direct difference in patient care because better technology equates to better medicine. Whichever way one looks at it, whether from the point of view of the researcher, physician, or that of the patient, we can say with confidence: the best is yet to come.
Key issues

- Urology has always been at the forefront of integrating novel technologies into surgical procedures.
- Robots allow the surgeon to manipulate tools with increased accuracy, thereby potentially improving the outcome of a surgical procedure.
- The da Vinci® robotic system has become successfully integrated in the surgical treatment of localized prostate cancer.
- Currently used robots do not exploit the full potential of medical robotic systems. Progress is expected through integrating medical imaging to surgery and in robotic image-guided interventions.
- The presence of different types of imaging modalities in the operating room, together with the robot, requires that the robot is fully compatible with the other existing equipment. This is an especially important issue where magnetic resonance imaging scanners are used.

References

Papers of special note have been highlighted as:

** of interest
** of considerable interest

Robotic prostate surgery


- Largest experience with robotic radical prostatectomy.

43. Ahlering TE, Skarecky WD. Robot-assisted radical prostatectomy: has the initial promise been fulfilled? Laparoscopy Today 5(1), 6–10 (2006).

- Landmark report.


- Excellent review.


Affiliations

- Michael Muntener, MD
  The Johns Hopkins Medicine, URobotics Laboratory, Department of Urology, Baltimore, MD, USA
- Daniel Ursu, MS
  The Johns Hopkins Medicine, URobotics Laboratory, Department of Urology, Baltimore, MD, USA
- Alexandru Patriciu, PhD
  The Johns Hopkins Medicine, URobotics Laboratory, Department of Urology, Baltimore, MD, USA
- Doru Petrisor, PhD
  The Johns Hopkins Medicine, URobotics Laboratory, Department of Urology, Baltimore, MD, USA
- Dan Stoianovici, PhD
  The Johns Hopkins Medicine, URobotics Laboratory, Department of Urology, Mason F Lord West Tower, Room W115, 5200 Eastern Avenue, Baltimore, MD 21224, USA
  Tel.: +1 410 550 1980
  Fax: +1 410 550 0773
dss@jhu.edu
  http://urology.jhu.edu/urobotics