

Evolution and Future Directions of Robotic-Assisted Urology

Jason D. Engel

INTRODUCTION

Urology has always been known as the surgical specialty that embraces new technology most readily resulting in the steady integration of novel approaches to urologic problems. This approach has led to the development of minimally invasive procedures that have replaced their more traditional surgical counterparts. Examples include stone disease management and the development of laser and thermotherapies for benign prostatic hypertrophy.

Robotic surgery represents the next forefront of technology that will likely lead to dramatic changes in how urologic procedures will be performed in the future. Although there still exist unanswered questions as to the efficacy and outcomes regarding robotic surgery such as prostatectomy, the emergence of data to substantiate the benefits of robotic surgery seems inevitable. Urology is now experiencing many of the controversial issues that were discussed earlier in “General Surgery” with the introduction of laparoscopic cholecystectomy. In the field of general surgery, laparoscopy changed the standard of care. Such a course of evolution is likely with robotic surgery in urology.

All new technologies evolve over time. It is expected that future development will lead to alterations of our present approach. This chapter will serve as a brief overview of the processes that have led to the current state of surgical robotics in urology. Some insight into possible future directions of and challenges to robotics will be presented.

EARLY RESEARCH AND DEVELOPMENT

Although cardiothoracic surgery and urology have fully embraced robotic technology and have begun to widely incorporate its usage, the first applications of surgical robotics were in the fields of neurosurgery and orthopedics.^{1,2}

The first efforts to create a prototypical system for robotic surgery led to the development in the late 1980s of

what was described as a “telepresence” surgical system designed to aid in microsurgical applications by providing steadiness and ease in movement. This system was created as a joint collaboration between researchers at the NASA (National Aeronautics and Space Administration) Ames Research Center and engineers at the Stanford Research Institute. Its efficacy was demonstrated in a small study in rats where 10 femoral artery anastomoses were performed with 100% patency.³

Through funding and support from the Department of Defense, this initial step was then expanded into a system designed to perform open surgical stabilization of battlefield trauma patients via telesurgery. With this system, ultimately called the “SRI Green Telepresence Surgery System,” a mobile, armored surgical unit would be taken into battlefield situations. Trained medical practitioners would place the injured soldier into the operating field, and rear area surgeons would perform stabilizing maneuvers from a remote site. This system used instruments similar to those used in standard laparoscopy (four degrees of freedom), but was intended solely for open surgery. Basic feasibility was demonstrated, with the drawback of significantly longer operative times.⁴ This system has not yet been reported as being used in an actual battlefield scenario. Its creation did, however, serve as the initial step in the eventual creation of the da Vinci surgical system.

The applicability of the SRI Green Telepresence Surgery System was soon after demonstrated for open urologic surgery. This system was used to perform a small number of nephrectomies, cystotomy closures, and ureteral anastomoses in pigs. The basic ability to manipulate an endoscope was also demonstrated.⁵ This was purely a prototypical system, with several limitations requiring enhancement. The commercial rights to this system were licensed to Fredrick Moll, MD, in 1995, and stood as the basis for the creation of Intuitive Surgical Systems (Sunnyvale, CA). By 1997, this system was enhanced and achieved approval from Food

and Drug Administration (FDA) for open surgical assistance. This system evolved into the da Vinci system that is used today. It is of note that a similar system was created in the mid to late nineties in Germany named ARTEMIS (Advanced Robotic Telem manipulator for Minimally Invasive Surgery). This system was the first to introduce six degrees of freedom and three-dimensional (3-D) visualization. However, this device never advanced beyond the prototypical stage.⁶

The development of what are termed as “precise path” robotic systems, or units that perform robotic functions autonomously based on predetermined programming, also served as an essential step in the advancement of surgical robotic technology as a whole.⁷ One of the first of these systems created was initially termed the “Surgeon Robot for Prostatectomies,” and was later renamed the “Probot.” In 1991, this became the first robotic system used for resection of human tissue. Ten TURPs (Transurethral Resections of the Prostate) were reported, with encouraging preliminary results.⁸

Further refinements to this system were made in Singapore, leading to the creation of the “Urobot.” This device kindled the hope of eventually performing laser prostatectomies, prostate biopsies, and brachytherapy.⁹ Dornier medical systems advanced this device as a commercial prototype called the “Surgeon Programmable Urological Device,” or SPUD. It has not been further developed or promoted.

The most clinically advanced example of a precise path system has been the PAKY (Percutaneous Access to the Kidney) device, developed at the Johns Hopkins University, Baltimore, MD. This device has been applied clinically, and will continue to undergo modification. Equivalence to a manual approach in terms of accuracy has been demonstrated.^{10,11}

CLINICALLY AVAILABLE DEVICES

■ AESOP AND HERMES

The basic research and prototype advancements described above have led to several clinically available devices that have eventually secured FDA approval. Computer Motion, founded in 1989 by Yulun Wang, PhD, led the way in this regard with the introduction of the AESOP (Automated Endoscopic System for Optimal Positioning) device in 1993. The AESOP’s primary purpose was to hold and maneuver an endoscope or a laparoscope. The initial version, the AESOP 1000, was limited by its need for hand controls. The AESOP was next refined to use foot controls, followed by its most recent version, which is controlled by



FIGURE 39-1. The AESOP 3000 robotic arm (Courtesy of Intuitive Surgical, Sunnyvale, CA; with permission).

voice command. The AESOP allowed telemonitoring to become relatively simple, with several successful episodes of international mentoring taking place.^{12–17} A similar device, the “Endo-Assist” (Armstrong Health Care, High Wycombe, United Kingdom) has also been devised but is not marketed in the United States.¹⁸ (Figure 39-1 is a photo of the final version of the AESOP—the AESOP 3000.)

The concept of the surgeon controlling the operative environment during laparoscopy was advanced with Computer Motion’s next offering, the HERMES operating room (OR) control center. Using voice controls transmitted via a headset, the surgeon is able to control nearly every aspect of the laparoscopic operative theater. This includes nearly all functions of the laparoscopic camera, insufflation, light source, video capture, OR lights, OR phone, and the OR table functions. This system is integrated with the voice module of the AESOP, so camera positioning is also controlled. (Figure 39-2 is a photo of the HERMES system.) The AESOP is still available for purchase, with support for preexisting HERMES systems still provided by Intuitive Surgical.

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FIGURE 39-2. The HERMES system (Courtesy of Intuitive Surgical, Sunnyvale, CA; with permission).

■ MASTER-SLAVE SYSTEMS (ZEUS AND da VINCI)

The culmination of Computer Motion's efforts to provide a surgeon with the ability to perform laparoscopic surgery with full control of not only the environment and the camera but also the instruments was the introduction of the ZEUS system in 1999. In addition to the AESOP arm, three additional robotic arms are mounted to the operating table. A potential advantage of ZEUS system over the da Vinci system is that the arms can move with changes in table position. The AESOP is controlled via voice commands from the surgeon's headset. The instrument arms are controlled by the surgeon sitting at a console via form-fitted handles. The operation is visualized on a flat 2-D monitor, although basic 3-D viewing can be achieved using polarizing glasses. This is not the same binocular 3-D reproduction produced by the da Vinci system. The instruments used with this system have six degrees of freedom (MicroWrist) as opposed to seven degrees of freedom with the da Vinci system. (Figure 39-3 depicts the ZEUS system)

Much of the clinical experience with the ZEUS system has been in Europe, with limited introduction and utilization in the United States. The ZEUS system is credited with many clinical firsts in the field of cardiac surgery, and it was this system that was first used to perform a robotic nephrectomy. However, it was not until the approval and clinical introduction of the da Vinci system that robotics in urology became commonplace. The ZEUS system is no



FIGURE 39-3. The ZEUS system (Courtesy of Intuitive Surgical, Sunnyvale, CA; with permission).

longer sold worldwide, with product support only being provided by Intuitive Surgical.

In July 2000, the FDA approved the da Vinci system for laparoscopic surgery. The da Vinci system had gone through several stages of development as had Computer Motion's products, with research and development initiated by the original SRI Green Telepresence Surgery System. The fundamental difference between the da Vinci and ZEUS systems is that the da Vinci system has all of its robotic arms on a self-contained robotic cart, and the console has all of its features integrated into one ergonomic unit. The da Vinci system has true binocular 3-D visualization generated at the camera level, seven degrees of freedom with its instruments (EndoWrist), and hand positioning at the console. These features combine to give a more realistic impression that the robotic instruments inside the patient are actually extensions of the surgeon's hands. The latest version of the da Vinci system has four instrument arms. The fourth arm serves as a substitute for a second human assistant. The da Vinci system does not integrate the ability to control the operative environment, as does HERMES. As of this writing, over 115 hospitals in the United States are currently using the da Vinci system for urologic surgery, with 60 more hospitals in the development and training phase. (Figures 39-4 to 39-6 show the da Vinci system.)

The ZEUS and da Vinci systems have been compared head to head. In 2001, Sung and Gill performed various



FIGURE 39-4. The 4-arm da Vinci system (Courtesy of Intuitive Surgical, Sunnyvale, CA; with permission).

maneuvers in pigs with the two systems. They reported on operative time, anastomotic time, blood loss, and adequacy of surgical dissection. These authors concluded that in their small series the learning curve, operative time, and ease of technical movements were superior and more intuitive with the da Vinci system.¹⁹



FIGURE 39-5. Operating at the da Vinci console.



FIGURE 39-6. da Vinci console control arms.

FUTURE DIRECTION

The da Vinci system has clearly demonstrated its clinical utility and is sure to expand in terms of availability and applicability. Whereas the vision of Computer Motion for expanding the usage of the ZEUS system was via telesurgical mentoring and the potential ability for future remote surgery, Intuitive hopes to expand the availability of the da Vinci system by simply having more and more hospitals equipped with the device. Computer Motion actually formalized its efforts at employing telesurgical capability with its SOCRATES system. This unit was used in several surgical settings for telemonitoring and, in some cases, actual telesurgery. Unfortunately, the legal implications of not having the surgeon in the immediate vicinity of the patient during surgery are unlikely to be resolved in the medicolegal climate of United States. Furthermore, the da Vinci system was designed to be more user friendly and intuitive, so that even the laparoscopically inexperienced surgeon can eventually be successful.²⁰⁻²² On the basis of this reasoning, it seems as if Intuitive Surgical is not formally developing telesurgical capability for the da Vinci system. Rather, work is being aimed toward forming a network system to streamline and simplify the ability for surgeons to observe robotic surgeries as part of a mentoring program in conjunction with hands-on training on their own da Vinci system.

From a technical standpoint, this author can imagine several enhancements that would improve the functionality of the da Vinci system: (a) Although its absence is not as much of a disadvantage as has been proposed by open surgeons, the development of tactile feedback is a worthwhile

goal. (b) The ergonomics at the hood could also be improved, with the possible integration of a supportive chair into the console unit. (c) As the advantage to the surgeon of being able to control the entire operative environment has been shown to shorten operative time (as well as surgeon frustration) considerably,²³ it would seem that an integration of HERMES technology would be in order, with the development of dedicated da Vinci ORs with all elements of the operation integrated into the operative console. (d) The visual screen function in the console could be enhanced with radiological imaging so that anatomical correlations to radiological findings could be made during surgery. Although information as to the actual ongoing work and future research and development is proprietary, Intuitive Surgical does express a commitment to ongoing research aimed at moving closer to the goal of device improvement and expanded availability of robotic surgery.

Hopefully, future technological advancements will enable the da Vinci system to be used for operations other than radical prostatectomy, pyeloplasty, and ureteral surgery. The da Vinci system, in this author's opinion, has not demonstrated a technical or economic advantage for typical extirpative renal surgery over standard laparoscopy. However, its common usage will likely be expanded to radical cystectomy in the future. With the current state and success of neobladder reconstruction in both men and women, precise dissection of the prostatic apex is crucial. Salvage of a long urethral length, as well as the sparing of the neurovascular bundles in men, are also steps that are perhaps best performed with the da Vinci system. Feasibility and success with cystectomy and both neobladder and ileal conduit reconstruction have already been demonstrated.^{24,25}

The single largest impediment to the widespread use of robotics in urology is cost. As a function of market economy, the key to addressing this problem, and the limits it puts on hospital profitability, will be competition. For now, there are no other commercially available robotic surgical devices that are FDA approved for laparoscopic surgery. Therefore, urologists and their hospitals have only one choice, with little room for economic positioning or bargaining. However, significant work is being done internationally, aimed at the creation of an independent technology that holds with it the promise of more economical, more compact, and lighter devices. The ongoing research and development, both in United States and abroad, suggest that technological advancement and economic refinement seem assured in the future.

■ RESIDENT TRAINING

The best way to disseminate robotic technology and make its usage more commonplace is to train the next generation of urologists. This training, however, has several unique limitations. In the perfect setting, each academic institution currently performing this surgery would be able to have an extra da Vinci system that could be used solely for training purposes. A virtual reality trainer would also be an option, as is seen in flight training and other technical areas.

The advantage of having dedicated laboratory environments where laparoscopic familiarity and skill is gained on inanimate objects, animals, and cadavers is well known.²⁶ Such facilities serve as the initial exposure to complex laparoscopic procedures at several centers across United States, including ours, and shortens the learning curve considerably through the ability to practice outside the OR. However, given the current price of the machine, such a facility using a da Vinci system is not economically practical. Therefore, the ability for a resident to gain familiarity and experience as the primary surgeon in the OR is severely limited given the need to keep OR times down in order to maintain hospital profitability.

At our institution, two attending surgeons have been involved in every robotic case performed thus far. Residents serve as primary assistants, and become facile at management of the robotic cart, port placement, and the challenges and nuances involved with assisting during these cases. After demonstration of proficiency at these steps, which is highly variable between residents, limited involvement as the primary surgeon is allowed. Hopefully, these problems in resident training will be addressed by industry in the future. Until that time, growth of robotics in urology will likely be steady but limited.

CONCLUSIONS

During the past 15 years the technological advances in surgical robotics have been phenomenal (see [Table 39-1](#) and [Figure 39-7](#)). In essence, this area of research has been translational in nature in that basic research has led to prototypes that are now being used for mainstream clinical benefit. There are refinements to be made in the future, both technologically and economically. However, it seems certain that surgical robotics is here to stay, and that robotics will likely act as a springboard for future technological advancements in urologic surgery around the world.

AQ3: Is the sentence "Therefore, the ability for ... profitability" okay as edited?

Table 39-1. Timeline of Important Computer Motion Events

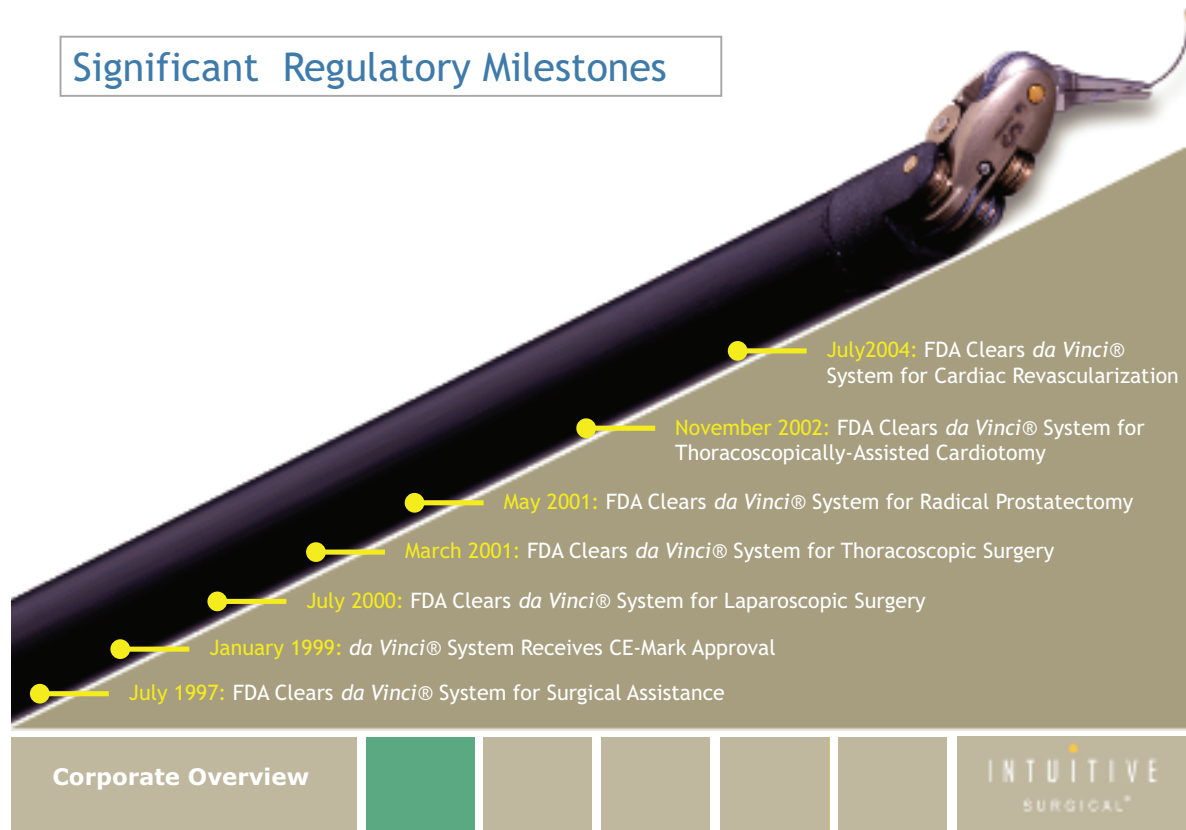
1989	Yulun Wang, PhD, founded Computer Motion.
September 1993	FDA approved AESOP 1000 as the world's first surgical robot.
February 1996	World's first transcontinental diagnostic surgery performed using AESOP endoscope positioner between Belgium and the Netherlands.
June 1996	FDA approved AESOP 2000 as the world's first voice-controlled surgical robot.
March 1997	Computer Motion and Medtronic aligned to market ZEUS for minimally invasive heart surgery.
December 1997	FDA cleared the AESOP 3000 with added functionality for endoscope positioning during extended surgical procedures such as those for cardiac, thoracic, and obesity-related conditions.
January 1998	World's first surgical procedures with a voice-controlled operating system, the HERMES Control Center. Performed by Carlos Gracia, MD, at San Ramon Regional Medical Center in San Ramon, CA. Procedures included right inguinal hernia repair, appendectomy, anterior spinal fusion, and splenectomy.
March 1998	<ul style="list-style-type: none"> • ISO 9001/EN 46001 Certification received for Computer Motion's quality system for the design, manufacture, and service of its medical products. • Computer Motion established its European headquarters at the European Institute of Telesurgery in Strasbourg, France.
April 1998	FDA cleared HERMES Control Center, another world's first.
April 1998	World's first robotic minimally invasive mitral heart valve procedures with ZEUS Robotic Surgical System. Performed by Hermann Reichenspurner, MD, PhD, at the University Hospital Grosshadern in Munich, Germany.
June 1998	<ul style="list-style-type: none"> • AESOP and HERMES received CE-Mark approval. • Computer Motion and Berchtold developed and marketed HERMES-Ready OR lights and surgical cameras. • Partnership formed with Karl Storz Endoscopy to develop and market ZEUS surgical instruments.
July 1998	ZEUS surgical instruments jointly developed and marketed with Scanlan International.
October 1998	Launched world's first network of voice-controlled surgical devices as HERMES-Ready.
December 1998	<ul style="list-style-type: none"> • Computer Motion and STERIS developed and sold HERMES-Ready OR tables, lights, and surgical cameras. • US Surgical partnered with Computer Motion in the development and marketing of ZEUS surgical instruments.
February 1999	ZEUS received CE-Mark approval.
March 1999	New "HEARS" voice control interface launched.
April 1999	<ul style="list-style-type: none"> • W.L. Gore, in conjunction with Computer Motion, developed new suture for minimally invasive robotic heart surgery.
May 1999	<ul style="list-style-type: none"> • HERMES-Ready OR lights jointly developed and sold by Computer Motion and SKYTRON. • Computer Motion and ConMed jointly developed and sold HERMES-Ready electrosurgical units.
July 1999	<ul style="list-style-type: none"> • Launched HERMES-Phone, which makes access to the Internet possible during surgery.

(continued)

AQ4: In Table 39-1, there are two rows for "April 1998." Is it correct as given or should one be "May 1998?"

Table 39-1. Timeline of Important Computer Motion Events (*continued*)

	<ul style="list-style-type: none"> • FDA cleared voice-controlled surgical robot, OR lights and powered surgical instruments, expanding the company's offering of HERMES-Ready medical devices. • Alliance with ValleyLab formed in developing and selling HERMES-Ready electro-surgical units.
May 2000	Distribution partnership for the sale of AESOP, HERMES, and ZEUS in Japan formed with Kino Corporation.
September 2000	World's first minimally invasive kidney removal using ZEUS Robotic Surgical System. Performed by Bertrand Guillonnet, MD, at L'Institut Mutualiste Montsouris in Paris, France.
September 2000	Computer Motion pursues ZEUS clinical studies across five major surgical disciplines for FDA approval: <ul style="list-style-type: none"> • coronary artery bypass surgery, • thorascopic surgery, • cardiovascular surgery, • general laparoscopic surgery, • gynecologic surgery.
June 2003	Computer Motion and Intuitive Surgical merge.

**FIGURE 39-7.** Timeline of important *da Vinci* events (Courtesy of Intuitive Surgical, Sunnyvale, CA; with permission).

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