ORIGINAL ARTICLE

Robotic surgery: History and teaching impact

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Abstract
Context: The purpose of this article is to review the history of robotic surgery, its impact on teaching as well as a description of historical and current robots used in the medical arena. 
Summary of evidence: Although the history of robots dates back to 2000 years or more, the last two decades have seen an outstanding revolution in medicine, due to all the changes that robotic surgery has made in the way of performing, teaching and practicing surgery. 
Conclusions: Robotic surgery has evolved into a complete and self-contained field, with enormous potential for future development. The results to date have shown that this technology is capable of providing good outcomes and quality care for patients.

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Cirugía robótica: Historia e impacto en la enseñanza

Resumen
Contexto: El objetivo de este artículo es hacer una revisión de la Historia de la cirugía robótica, su impacto en la enseñanza, así como una descripción de los robots antiguos y actuales usados en el campo médico. 
Resumen de evidencia: Aunque la historia de la robótica tiene 2.000 años o más, las últimas dos décadas han mostrado una marcada revolución en Medicina, debido a todos los cambios que la cirugía robótica ha provocado en la manera de hacer, enseñar y practicar cirugía.
Introduction

Robotic surgery has been considered by some authors as the future of surgery due to the dramatic changes and impact that it has shown in the last two decades. It has had a rapid development and has shown numerous advantages of enhancing surgical techniques, which, in turn, is changing the way we practice and teach surgery.

The da Vinci® Robotic Surgical System (Intuitive Surgical Sunnyvale, CA) is the only one of its kind to be approved by the Food and Drugs Administration (FDA). It offers several advantages over conventional laparoscopic surgery, such as 3D vision, dexterity, articulated instruments, increased range of motion, elimination of fulcrum effect, tremor filtration and an ergonomic position for the surgeon. These advantages translate into a more delicate treatment of tissues, precision surgery and improved results for patients.

The purpose of this article is to describe the history of robotic surgery including its evolution and improvements in teaching and practicing surgery.

Robotic history

Karel Capek in 1921 introduced the notion and the term robot in his play Rossum’s Universal Robots.1,3 The word robot comes from the Czech word “robota”, meaning “labor”. Later, in 1942, Isaac Asimov inspired by Capek’s works defined the term “robotics” and wrote the three rules of robotics in his books Runaround and I Robot.1-5 Though robotics is a relatively new term, autonomously operated machines can be dated from 400 BC when Archytas of Arentum developed a steam-driven, self-propelling wooden bird capable of flying 200 m.6

However, the first robot that imitated human movements of the jaw, arms and neck was designed by Leonardo da Vinci in 1495 and was named the Metal-Plated Warrior (Fig. 1). This invention served as an inspiration to Gianello Torriano, who created a robotic mandolin-playing lady in 1540.7

“’The Writer’”, developed by Jaquet-Droz in 1772, was the first robot with a programmable wheel used to write whatever the user desired. Attaching this wheel to a feather pen, “’The Writer’” was able to make complete sentences, spacing between words and lines, and even place periods after sentences, replicating a task previously only performed by humans7 (Fig. 2).

The impact of robotics on medicine has created new aspects of medicine such as telesurgery (surgery performed with the surgeon and the patient in different locations). In 2001, Dr. Marescaux performed the first telerobotic surgery (telerobotic = surgeon console and patient cart are not in the same place) using ZEUS® surgical system: a transatlantic

Conclusiones: La cirugía robótica ha evolucionado hasta ser un campo aparte, con un enorme potencial para su futuro desarrollo. Los resultados muestran hasta ahora que esta tecnología es capaz de ofrecer buenos resultados y un adecuado tratamiento a los pacientes.

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operation performing a cholecystectomy in a 62 year-old patient with cholelithiasis with the surgeons in New York (EEUU) and the patient in Strasbourg (France).⁹

**Current robots**

The modern history of robotics in surgery begins with the Puma 560®, a robot used to perform neurosurgical biopsies by Kwoh et al. in 1985 in a very precise way.⁸⁻¹⁰ Later in 1988, Davies et al. performed a transurethral resection of the prostate using the same system.¹⁰,¹¹

Integrative Surgical Supplies Ltd. of Sacramento, created two models with similar characteristics: PROBOT®, a robot designed specifically for transurethral resection of the prostate and ROBODOC®, a robotic system designed to machine the femur with greater precision in hip replacement surgeries.¹ This last one was the first surgical robot approved by the FDA.¹,³

Today, many robots and robot enhancements are being researched and developed. When we talk about robotics, we must emphasize and focus on the major robotic surgical systems that have contributed in the development of current systems.

**AESOP®**

The Automated Endoscopy System for Optimal Positioning (AESOP®) was the first robot to be approved by the FDA for abdominal surgical procedures,¹²,¹³,¹⁴ designed by Computer Motion, Santa Barbara, CA and approved in 1994. It is basically a robotic arm that holds a laparoscopic camera and can be controlled by voice commands. The latest generations added seven degrees of freedom to mimic the human hand¹⁴,¹⁵ (Fig. 3).

**ZEUS®**

The Zeus® system (Computer Motion, Santa Barbara, CA, USA) is another type of current robot that became commercial in 1998 and introduced the idea of telerobotics or telepresence to robotic surgery.¹ It is composed of a surgeon control console with a 3D imaging system which is at a distance from the robot and 3 table-mounted robotic arms with 4 degrees of freedom. The right and left robotic arms replicate the arms of the surgeon, and the third arm is an AESOP® voice-controlled robotic endoscope for visualization.¹⁶

The main disadvantage of the ZEUS® system was the large size of the robotic arms, which limited space in operating rooms; it also caused collision of the arms when trocars were misplaced. Moreover, the need to wear special glasses made it cumbersome to perform surgery without them.

**da Vinci Surgical System®**

This is the most complete and evolved major robotic surgical system. It consists of 3 components: a vision cart that holds a dual light source and dual 3-chip cameras, a master console where the operating surgeon sits, and a moveable cart where 3 instrument arms and the camera arm are mounted. The console is composed of two "masters" that control the robotic arms with seven degrees of freedom, a computer and a 3D imaging system. An infrared sensor detects when the surgeon’s head is placed into the console and subsequently triggers activation of the two masters and, thus, the robotic arms (Fig. 4).

The da Vinci® Robotic Surgical System also has limitations, the main one is still size; it limits the space in the operating room; moreover, it has a lot of delicate connections that are inside the operating room that may cause accidents or can be damaged if not used adequately. Furthermore, some procedures such as bowel resections that require access to one or more abdominal quadrants mean that the robotic arms need to be undocked and redocked, thus, increasing operative and anesthesia times.¹⁷

![Figure 3 Mimic’s dV-Trainer™](image1)

![Figure 4 Laparoscopic single site surgery da Vinci® platform](image2)
Teaching impact

Robotic surgery has not just changed the way to perform surgery. It has reformed the way to teach and learn surgery. It has also been included in surgery programs around the globe, used to teach surgery and practice on 3D virtual models instead of practicing on patients.

Robotic surgery and surgical education

Despite numerous technological advances, surgical training has stayed more or less unchanged for more than a century. Surgeons in training have always had to gain operative experience through "supervised trial and error" on real patients. This approach makes surgical training completely dependent on the actual case load, prolongs surgical training, and compromises patients' safety. Robotic surgery will create a new medium for acquiring surgical skills through simulation of all operations that can be done via the robot. Surgeons can use surgical robots to practice operations on 3-dimensional, virtual-reality simulators and soft-tissue models that recreate the texture of human tissue through force feedback (haptics refers to the sense of touch, tactile sensation). Image-guided simulations will allow surgeons to practice procedures on 3-dimensional reconstructions of a targeted anatomy scheduled for surgery the next day.

Telepresence surgery (surgery using virtual telepresence in another physical location by means of telecommunication technology) has been successfully used in teaching basic surgical skills to third-year medical students guiding them through telementoring classes.

These systems are expected to significantly enhance the learning curve, allowing trainees to acquire surgical skills in a short period of time while improving patients' safety by reducing surgical errors. Ultimately, these applications will be integral to the training and licensing of surgeons and will provide objective means for assessment of surgical skills.

Robotic technology is expected to play an increasingly important role in the future of surgery. However, most residency programs in the United States have not placed adequate emphasis on training in robotic surgery. A survey in 2002 showed that only 23% of surgical program directors had plans to incorporate robotics into their programs. In 2003, another survey by the same group showed that although 57% of surgical residents demonstrated high interest in robotic surgery, the majority (80%) did not have a robotic training program at their institutions. Few academic centers have developed formal didactics to train teams in robotic surgery.

Ensuring competency to perform robotic procedures is left to individual hospitals. It is expected that as formal training in robotic surgery develops, more standardized credentials will be required to obtain robotic surgical privileges.

Impact on urology and other specialties

Although robotic surgery was developed initially for cardiovascular surgery, the most dramatic impact has been in urology with enormous progression, showing excellent results in several procedures such as radical prostatectomy, partial nephrectomy, live donor nephrectomy, and pyeloplasty among many others.

In less than a decade, robotic-assisted laparoscopic radical prostatectomy has rapidly become the most commonly performed surgical technique for prostate cancer. By 2009, the number of robotic prostatectomies performed was estimated to exceed 60,000, driven by physician enthusiasm, patient interest, and aggressive, effective marketing.

Nowadays, more than 85% of all radical prostatectomies performed in the US are done with robotic assistance, but there are still some skeptics of the technique that have emphasized that the robotic approach needs to show that it is a safe and effective procedure supported by evidenced-based outcomes which go beyond mere speculation, promise, or marketing.

However, a rapidly growing body of evidence is showing that the robotic approach measures up to the past and present standards for radical prostatectomy and, with certain benefits of decreased blood loss and lower morbidity. Robotic surgery may soon represent a new surgical standard of care for the treatment of localized prostate cancer.

Urology is just one surgical specialty that has been highly impacted by robotics, but in fact, it has reached many other fields such as general surgery, cardiac surgery, thoracic surgery, neurosurgery, gynecology, ENT, orthopedic and ophthalmologic surgery.

Virtual training in robotic surgery

Another aspect to consider is that robotics is being used for virtual training. There are a few simulators and software that allow surgeons to practice surgical procedures as many times as they need before actually performing it on a real patient.

Mimic Technologies, Inc. is one of the companies that is working on robotic virtual training and has developed systems such as: Mimic’s dV-Trainer®, a ‘‘flight simulator’’ for robotic surgery designed to allow efficient on-demand training for surgeons learning to use the da Vinci® Surgical System (Fig. 3). Mimic’s Mantis Duo™ is a truly unique two-handed haptic system that can be used for a wide range of simulation applications, including open surgery and robotics with high quality force feedback and little computational overhead to your host PC.

RoSS™ is another robotic surgical simulator from Simulated Surgical Systems LLC, which uses virtual reality to introduce the user to the operation and feel of a robotic surgical console, providing close-to-life experience of working on the master console of da Vinci® Surgical System.

There are also publications about using laparoscopic simulation programs adapting virtual reality trainers improving their capability to develop surgical skills. Feifer et al., 2010, present a randomized controlled trial using LapSim® [LSM], and the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills® (MISTELS) utilizing a hybrid augmented reality trainer, ProMoS® [PM]. Additionally, the use of MISTELS tasks can be adapted for the da Vinci® platform.
Robotics for laparoendoscopic single-site surgery (LESS)

Laparoendoscopic single-site surgery (LESS) is a new vision of surgery that provides the ability to perform major surgery with minimal incisions and nearly scar-free results, it can be regarded as the latest progression in laparoscopic surgery and has garnered much enthusiasm with >400 cases reported. The use of a single incision within the umbilicus conceals much, if not all, of the wound while allowing for access to the abdomen during transabdominal procedures.

The two greatest challenges include clashing of the laparoscope with instruments and the loss of triangulation with limitation of instrument maneuverability. The primary advantage of the da Vinci Surgical System for LESS includes easier articulation using EndoWrist instruments. Other benefits include three-dimensional visualization, motion scaling, and tremor filtration (Fig. 4).

LESS is evolving, and robotic assistance and other technical developments may well lead to its further enhancement. LESS Urology has been used to carry out nephrectomy, partial nephrectomy, donor nephrectomy, adrenalectomy, renal cryoablation, pyeloplasty, ileal interposition, ureteroneocystostomy, varicocelectomy, radical prostatectomy, simple prostatectomy, and radical cystoprostatectomy.

What is next? Future directions

Although future means uncertain things in many aspects of life, in robotic surgery it does not seem to be that way. Every day, there appear new aspects and robot models that actually improve current robotic systems.

Future robots

Robotic surgery has developed over the past 10 years into a proven and growing method of treatment. Titan Medical Inc. is a Canadian company, (TSX VENTURE:TMD) focused on robotic surgical technologies, that is currently developing Amadeus, a 4-armed robotic surgical system, with some particular characteristics such as: multi-articulating arms, communications, enhanced vision systems, and force feedback.

Force feedback is an outstanding and unique characteristic of this robotic surgical system. It enables the elimination and correction of one of the biggest challenges that still remains in current robotic systems: the absence of haptics, which means that the surgeon is unable to know and feel the amount of force needed to pull or grasp tissue without breaking or damaging it. Linda van den Bedem, TU/e researcher in Science Daily report, developed a much more compact surgical robot called Sophie, which uses ‘force feedback’ to allow the surgeon to feel what he or she is doing. Another issue that has been studied is the possibility to have robotic surgical systems controlled by artificial intelligence. In 2010, Duke University bioengineers demonstrated that a robot – without human assistance – can locate a man-made or phantom lesion in simulated human organs, guide a device to the lesion, and take multiple samples during a single session (Duke Robot Biopsy Guided by 3-D Ultrasound).

The researchers believe that as technology is developed, autonomous robots could someday perform many more simple surgical tasks.

However, this is not the end of this futuristic race; there are new challenges to come and the next step to reach could be the use of nanorobots. These are cell sized and can be introduced into the bloodstream being able to destroy cancer cells, repair tissues, or pick up toxic radicals, all guided by remote control.

Conclusions

The history of robotics has shown a rapid evolution in the last decade. This technology has been responsible for establishing new concepts such as telesurgery, imaging symbiosis, and virtual training.

Robotic surgery has developed and enhanced several surgical techniques in specialties such as urology, general surgery, and gynecology, to mention a few. Moreover, robotics has shown results that are changing the way of performing and teaching surgery, establishing new standards of treatment and demonstrating that it is here to stay and evolve.

It has also been able to facilitate and increase the uses of minimally invasive surgery allowing surgeons to use technology like LESS in many procedures.

There is still much in the horizon to study and develop in robotic surgery but the results obtained are encouraging and it seems to be just a matter of time until robotic surgery becomes the new standard of treatment in a significant amount of surgical procedures.

Conflict of interest

The authors declare that they have no conflicts of interest.

References