Notable Grand Rounds
of the
Michael & Marian Ilitch
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School of Medicine

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THE HISTORY, CURRENT APPLICATIONS AND ETHICAL CONSIDERATIONS OF ROBOTIC SURGERY

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About Notable Grand Rounds

These assembled papers are edited transcripts of didactic lectures given by mainly senior residents, but also some distinguished attending and guests, at the Grand Rounds of the Michael and Marian Ilitch Department of Surgery at the Wayne State University School of Medicine.

Every week, approximately 50 faculty attending surgeons and surgical residents meet to conduct postmortems on cases that did not go well. That "Mortality and Morbidity" conference is followed immediately by Grand Rounds.

This collection is not intended as a scholarly journal, but in a significant way it is a peer reviewed publication by virtue of the fact that every presentation is examined in great detail by those 50 or so surgeons.

It serves to honor the presenters for their effort, to potentially serve as first draft for an article for submission to a medical journal, to let residents and potential residents see the high standard achieved by their peers and expected of them, and by no means least, to contribute to better patient care.

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The History, Current Applications and Ethical Considerations of Robotic Surgery

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Slavic root, *robot-*, with meanings associated with labor. The word 'robot' was first used to denote a fictional humanoid in a 1920 Czech-language play *R.U.R.* (*Rossumovi Univerzální Roboti — Rossum's Universal Robots*) by Karel Čapek. (Source: Wikipedia)

1. HISTORY

Telepresence

The concept of telepresence, the use of virtual reality technology to remotely perform actions in a distant location, was conceived by NASA scientist Scott Fisher, PhD.

In the 1980s, Fisher contributed to the development of the first "virtual reality" system, which consisted of a wearable head-mounted visual display that allowed the wearer to interact and control a virtual environment with hand gestures, through the use of a DataGlove. (**Fig 1**.)

Fisher, joined by plastic surgeon Joseph Rosen, MD, recognized a potential advantage of telepresence to the field of surgery. Fisher and Rosen later collaborated with Phil Green, PhD of the Stanford Research Institute (SRI) to begin development of the first telepresence surgery system.

Fig. 1. An early telepresence system

Originally, the concept consisted of a surgeon wearing the head-mounted display, with 3-D visual and audio, and DataGloves, to control operative instruments remotely. Unfortunately, the quality of the graphics display was not adequate to provide safe operative visualization and the DataGloves could not control the remote instruments with appropriate dexterity.

The Green Telepresence Surgery System

In 1987, US Army Colonel Richard Satava, MD joined the SRI team and the development of the first robotic surgery system prototype began.

The prototype was known as The Green Telepresence Surgery System. It consisted of two separate units: the telepresence surgeon's workstation (TSW) and a remote surgical unit (RSU). The TSW had a stereoscopic video monitor and a pair of instrument manipulators which transmitted the surgeon's hand movements to the RSU. At the RSU, the manipulator end-effectors could be exchanged for different instruments which included forceps, needle drivers, bowel graspers, scalpels and cautery.

The system was originally designed to assist with open surgery. The transition to laparoscopic surgery occurred after COL Satava observed the presentation of Jacques Perrisat's videotaped laparoscopic cholecystectomy at the SAGES conference in 1989. COL Satava saw that this surgical system could solve the fulcrum effect problem experienced in laparoscopic surgery, as well as improving visualization, and surgeon ergonomics.

Military Funding

In the military, continual efforts were taking place to improve battlefield mortality from traumatic injuries. One of the rate-limiting steps in the treatment of battlefield injuries was the absence of a surgeon at the causality site available to provide immediate care. COL Satava presented a video of telepresence surgery at Walter Reed Medical Center as a solution to this problem. The idea being to "bring the operating room to the casualty". From then on, the project was funded by the Pentagon's Defense Advanced Research Projects Agency (DARPA).

The idea was to develop a TSW that could remain at the MASH unit, while the RSU was transported by an armored vehicle to the causality site. The surgeon could then perform the operation from a distance while the patient was being transported to the nearest MASH unit.

In June 1993, the first demonstration of the telepresence surgery system occurred during field exercises at Fort Gordon in Augusta, GA on a pig intestine model. The attempt to adapt the telepresence surgery system for military use led to many advancements in the technology including improved visualized with 2-3x magnification in full color and high-definition.

Final SRI System

By 1997, the SRI system now included a RSU with 6 degrees-of-freedom, and interchangeable surgical instruments that could be exchanged at bedside by an assistant. (**Fig 2**.)

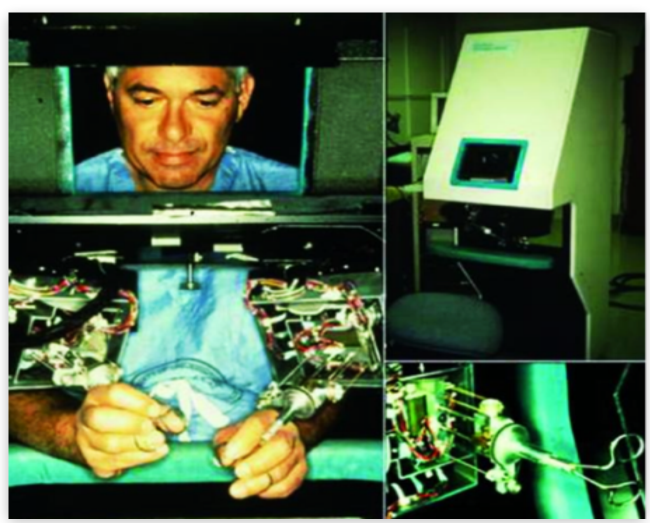

Fig. 2. Green Telepresence surgical system first prototype

Private Industry — Computer Motion

In 1990, Yulun Wang, MD started Computer Motion which developed AESOP, the first surgical robotic system to be FDA approved. They quickly advanced the technology of AESOP into ZEUS, the first complete robotic surgery surgical system.

It is not well-known that Children's Hospital of Michigan, a unit of the Detroit Medical Center, was the site of the world's first pediatric surgeries in the late 1990s. Doctors Michael D Klein, Scott E Langenburg, Mustafa Kabeer, Attila Lorincz, and Colin G Knight completed 25 Nissen fundoplications, 18 cholecystectomies), 2 Heller myotomies, 2 splenectomies, 2 Morgagni hernia repairs, and single cases of complex pyloroplasty in the chest, bowel resection, left Bochdalek congenital diaphragmatic hernia repair, esophageal atresia and tracheoesophageal fistula repair, and choledochal cyst excision. There were no complications.[1,2]

On September 7, 2001, ZEUS performed the first transatlantic surgery ("The Lindbergh" Surgery) with surgeon Jacques Marescaux, MD. He performed a robotic cholecystectomy from New York City on a patient located in Strasbouerg France. The surgery was estimated to cost greater than $1 million. The media coverage at the time was overshadowed by the events of September 11.

Private Industry — Intuitive

Intuitive Surgical was founded in 1995 by Fred Moll, MD and John Freund, MD along with electrical engineer Robert Younge. They were eventually able to acquire the intellectual property for the Green Telepresence System from SRI. Intuitive's first prototype was Lenny (abbreviation of Leonardo). Eventually Lenny was upgraded to Mona (Mona Lisa), which was the first robotic surgical system to move onto human trails.

The first robotic procedure performed on a human being was done using Mona in 1997 by Jacques Himpens, MD, a bariatric surgeon in Belgium. He performed two cholecystectomies and a lysis of adhesions on the same day. Publications regarding these first human trials are lacking, as submissions were refused by NEJM and The Lancet due to the "seemingly incredible nature of robots assisting with surgery". Eventually a piece was published by Dr. Cadiere in 1998 in Obesity Surgery which stated that telesurgery

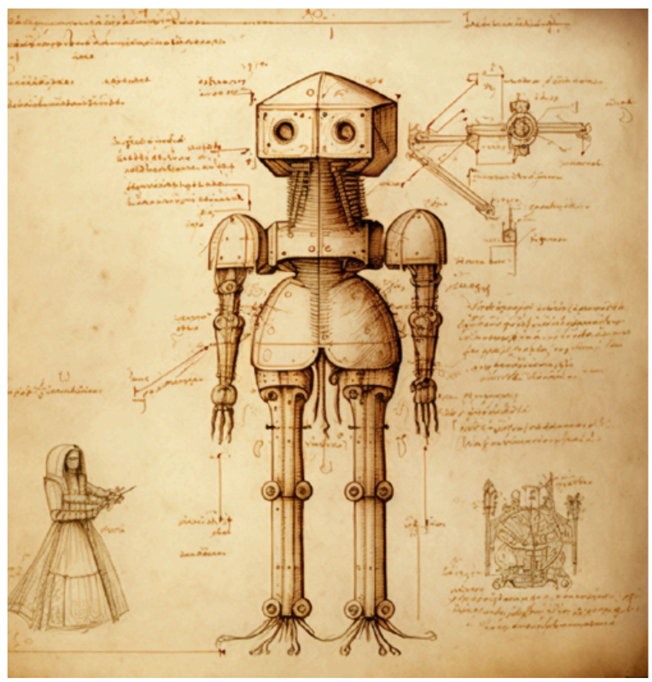

Fig. 3. "Leonardo's robot"—a sketch for a humanoid automaton designed and possibly built by Leonardo da Vinci around the year 1495 (Wikipedia).

[1] Klein, Michael D et al. "Pediatric robotic surgery: lessons from a clinical experience." *Journal of laparoendoscopic & advanced surgical techniques. Part A* vol. 17,2 (2007): 265-71. doi:10.1089/lap.2006.0034

[2] Information on the CHM Zeus procedures was not known at the time of the Grand Rounds talk on which this paper is based, but is included here for completeness.

was safe, feasible and ergonomically advantageous to the surgeon.

The third development by Intuitive was da Vinci.

Da Vinci was cleared by the FDA in 1997, but only for retraction and visualization. It was not fully cleared for general surgery until 2000. By 2001, the Brussels team and groups in Mexico City and Paris had logged a variety of cases in 146 patients by using the Mona and da Vinci systems. In 2003, Computer Motion and Intuitive merged and since then the da Vinci surgical system has continued to improve and be used all around the world for robotic-assisted surgery.

Present Day

Currently, there are approximately 6000 da Vinci surgical systems in operation that have performed 8.5 million robotic procedures worldwide.

In 2023, the da Vinci robotic surgical system is being used in a variety of surgical specialities including general surgery, bariatrics, colorectal, urology, gynecology, thoracic surgery, head and neck surgery and even cardiac surgery.

Comparison to Laparoscopy

14 million laparoscopic surgeries are performed globally every year. The limitations of the procedure include 2D visualization, instrumentation with fixed tips, fulcrum effect (laparoscopic instrument tips moving in opposite directions to the surgeon's hand) and inability to work easily in confined spaces.

The Da Vinci addresses these problems by utilizing 3D operating fields and binocular endoscopic vision with 10-15x magnification. Da Vinci also uses Endowrist systems which imitate wrist and elbow movement to provide greater ROM.

Robotic systems completely eliminate the fulcrum effect. They are able to reach smaller and more confined spaces, such as the pelvis. It also allows for improved surgeon ergonomics—"seated surgeon". It eliminates the problem of physiologic tremor.

A timeline of the development of robotic surgery is attached at an Appendix hereto.

2. CURRENT APPLICATIONS

The use of robotic surgery is increasing rapidly. A cohort study done by Sheetz et al used data from a Michigan clinical registry from January 2012 through June 2018.

Trends were characterized in the use of robotic surgery for procedures for which laparoscopic surgery was already considered safe and effective. An analysis was performed to determine how procedural approaches changed once a hospital launches a robotic surgery program.

The cohort included 169,404 patients from 73 hospitals. The use of robotic surgery increased from 1.8% in 2012 to 15.1% in 2018. (8.4-fold increase). For inguinal hernia repair, the use of robotic surgery increased from 0.7% to 28.8% (41-fold change). The use of robotic surgery increased 8.8% in the first 4 years after the hospitals began the use of robotic surgery. This trend was associated with a decrease in laparoscopic surgery from 53.2% to 51.3%.

Prior to implementing robotic surgery, hospitals use of laparoscopic surgery increased approximately 1.3% per year. After adoption of a robotic surgery program, use of laparoscopic surgery declined 0.3%.

Urology

One of the largest uses of robotic surgery is in the field of urology, specifically in prostatectomy.

The Vattijuti Institute of Detroit, led by Dr. Mani Menon, was the first to document the robotic prostatectomy, originally known as the Vattijuti Institute Prosatectomy. Open radical prostatectomy provides a chance for cure from prostate cancer; however, it is associated with high morbidity rates including urinary incontinence and sexual dysfunction.

The introduction of laparoscopic radial prostatectomy showed lower rates of blood loss and transfusion rates, as well as a decrease in mean hospital length of stay. Laparoscopic RP is a technically difficult surgery due to the confined space of the pelvis, and was under utilized due to its steep learning curve.

With the advancement of robotics, the robotic-assisted radical prostatectomy has become the most common surgical approach for RP (80% of all RP procedures in the US) and the evidence shows it is associated with lower blood loss and transfuse rates, as well as lower rates of incontinence and sexual dysfunction. The learning curve is also significantly shorter than for lap RP, around 12 patients.

Colorectal

In colorectal surgery, laparoscopy has been proven to be safe and effective when compared to open surgery. It has been associated with a lower blood loss and shorter LOS. It has also been shown that oncologic outcomes are equivalent to open surgery in the treatment of colorectal cancer.

In recent years, robotic colorectal surgery has become popular. A study by Delany et al. compared robotic surgery to laparoscopic surgery found that robotic colectomy was safe and effective but associated with greater costs and longer operating times.

A study by deSouza et al comparing robotic versus laparoscopic right hemicolectomy also showed higher cost and operating times with robotic surgery, and found that overall morbidity, lymph node dissection, blood loss, conversion rate to open and length of hospital stay were no different in either group, essentially stating there was no benefit to performing the procedure robotically.

The newest area of interest in robotic colorectal surgery is in rectal cancer. For example, laparoscopic total mesorectal excision has been found to be technically challenging due to the limitations of laparoscopy in a narrow pelvis and is associated with a high rate of conversion to open, high positive surgical margin rate and increased rates of incontinence and erectile dysfunction.

For robotic TME, one recent study showed only an improvement in LOS (6.9 versus 8.7 days) in comparison with laparscopic TME, with similar operating times, conversion rates and specimen quality. Another study showed robotic TME had a shorter recovery time for erectile dysfunction when compared to laparoscopy, possible due to the ability to more precisely visualize anatomical planes and nerves.

Although it is agreed that robotic colorectal surgery is safe and feasible, there is limited data to suggest it is better than traditional laparoscopy.

Bariatric Surgery

Bariatric surgery has a unique set of challenges due to the size of the patients, who generally have thick abdominal walls and more visceral fat. These things make exposure and dissection innately more difficult.

Several studies done on robotic bariatric surgery has noted less anastomotic complications with robotic roux-en-y when compared to laparoscopic, and a lower rate of conversion to open surgery.

Head and Neck Surgery

The first case series using the robot in the field of head and neck surgery was in 2006. The approach is generally transoral and provides surgeon's the ability to reach difficult to access anatomical locations resulting in decreased morbidity and improved functional results. Oncologic results appear to be equivalent.

Transoral robotic surgery provides access to the oropharynx, hypopharynx, larynx, oral cavity, parapharyngeal space and skull base. Advantages include absence of a neck incision, decreased duration of need for tracheostomy, decreased duration of tube feeding and decreased LOS.

Cardiothoracic Surgery

Use in the field of cardiothoracic surgery was one of the original applications of the robotic surgical system, AESOP. The first robotic cardiac surgery was performed in the US in 1999. Applications include mitral valve replacement or repair, CABG, closure of atrial septal defects and cardiac tumor resection.

One study performed on more than 700 patients with mitral valve disease showed that the median cardiopulmonary bypass time was 42 minutes longer with the robotic approach than for a complete sternotomy and robotic surgery was also associated with a longer median myocardial ischemia time. Robotic surgery was associated with lower rates of post operative atrial fibrillation and pleural effusion, as well as decreased hospital stay. Pulmonary, renal and neurological outcomes were equivalent.

The use of robotic approach in thoracic surgery is currently widely used for the purposes of oncologic resections for lung cancer, resection of mediastinal tumors, and for esophageal surgery. Studies show that robotic surgery reduces morbidity and mortality when compared to open thoracotomy.

3. ETHICAL CONSIDERATIONS

The three laws of robotics

Author Isaac Asimov wrote the famous novel titled *I, Robot*, in which he described "Three Laws of Robotics":

> *1. "A robot may not injure a human being or, through inaction, allow a human being to come to harm."*
>
> *2. "A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law"*
>
> *3. "A robot must protect its own existence"*

These laws can be extrapolated to the robots used in surgery and allow us to consider the ethical implications of their use.

Although robotic surgery is widely used and has proven that it is safe and effective in many different areas of surgery, there is limited data on its actual advantages. We are aware of its potential advantages including increased visualization, 3-D field of view, increased wrist motion and dexterity, but not all of these advantages have translated into tangible data in studies. There is also a learning curve to overcome.

While robotic courses can help introduce surgeon's into the field of robotics, these courses may not be enough to prove proficiency in certain types of cases. Robotic credentials are not granted for each operation, therefore surgeons proctored on relatively simple procedures can be credentialed for all robotic operations in their fields regardless of complexity.

There is also the consideration of the effect on surgeon training. Increasing robotic use may decrease a trainee's exposure to more traditional approaches, making them wary of these approaches in an emergency.

Robotic systems are complex pieces of technology with numerous opportunities for failure. Failure of the robotic system during operation could potentially bring harm to the patient.

We must remember that the field of robotic surgery is a multi-billion dollar business and although we use these tools to attempt to better our patients lives, profit will always be a consideration in its use. Each DaVinci surgical system costs around $2 million, with annual maintenance feeds totaling about 10% of the initial purchase (200,000) + costs for disposable equipment. "An analysis of new technology and health care costs of 20 different robot-assisted surgeries published in the *New England Journal of Medicine* in 2010 showed that the use of the robot added 13% (US$3200) to the total average cost of a procedure in 2007."

Hospitals invest large amounts of money into installation of these surgical systems. There may be external pressure on surgeon's to utilize the robot in order to maximize the hospital system's investment. Hospital systems may also try to advertise the use of minimally invasive procedures in order to bring in elective business. Surgeon's may be asked to participate in marketing aiming to bring in patients requesting these approaches. Hospital systems also often only have a limited number of robotic surgical systems, and therefore have allocated block time for surgeon use. Surgeon's may feel external pressure to book robotic surgeries in order to preserve this hard to come by block time.

CONCUSION

Robotic surgery has rapidly gained popularity with surgeons of all specialities and its applications will only continue to accelerate in the coming years. While it has proven to be safe and feasible, data on its superiority to more traditional approaches remains limited.

Surgeons' responsibility is to the patient. They should use the approach that is safest and most aligned with their skill set, while resisting external pressure to sway their operative approach.

* * *

Appendix: Timeline of Robotic Surgery

1951

Engineer Raymond Goertz designs the first teleoperated articulated arm for the US atomic energy commission, meant to help handle radioactive material safely.

1954

Engineer George Devol patents a programmable robotic system designed for transferring objects and developed the world's first industrial robot, Unimate

1961

Unimate was installed by General Motors to assist with automobile production

1969

Victor Scheinman develops the "Stanford arm", an all-electric, computer-controlled robotic arm with six-axis articulation.

1977

The "Stanford arm" is sold to Unimation, and in collaboration with General Motors, the Programmable Universal Manipulation Arm, or PUMA, is developed.

1985

PUMA is the first robot used for a surgical procedure, performing a stereotactic brain biopsy at Memorial Medical Center in Long

1992

ROBODOC, a computer guided mill, is used to assist in coring of the femoral head in order to fit a replacement hip prosthesis

1993

Computer Motion, funded by NASA and the Pentagon, released the Automated Endoscopic System for Option Positioning (AESOP).

1995

Intuitive Surgical founded by Drs. Fred Moll and John Freund with help of engineer Robert Younge

1996

Computer Motion builds upon their original product AESOP, to create ZEUS, a surgical system consisting of three robotic arms attached to an operating table.

1997

Intuitive develops the first prototype of what will eventually become da Vinci, Lenny.

Later the same year, Lenny receives upgrades and becomes known as Mona.

2003

Intuitive and Computer Motion merge and eventually become the sole proprietors to the robotic surgical system known today as da Vinci.