On the Cutting Edge: Robotic Surgery's Renaissance

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Abstract
The concept of Minimally Invasive Surgery is becoming the common standard of care across many surgical specialties. An exciting advancement in this area of surgery is the da Vinci Surgical System (Intuitive Surgical Inc.®, Sunnyvale, California) which has enhanced the revolutionary technique of laparoscopy with the integration of cutting-edge computer and robotic technology. This form of "telepresence" surgery allows the surgeon to remotely control four robotic arms that are inserted into the patient through small keyhole incisions. The system provides the surgeon with improved precision, dexterity, and visualization while optimally decreasing patient morbidity and recovery following an operation. St. Michael’s and Toronto General Hospitals purchased this system in 2008, thereby increasing their dedication to provide advanced surgical care and training. This article will examine the development of the da Vinci Surgical System, its current applications and acceptance, and its future in Canadian healthcare.

Introduction
The Italian Renaissance was an era of growth, innovation, and prosperity. Leonardo da Vinci (1452-1519) was a notable figure of the movement and provided a vast number of contributions to many different areas of art and science. Many of his ideas were significantly advanced for the time and have continued to inspire intelligent minds over the years. Ingenuity and innovation are synonymous with the da Vinci name and are fitting descriptors of one of the more exciting advancements of modern surgery. The da Vinci Surgical System (Intuitive Surgical Inc.®, Sunnyvale, CA) has enhanced the revolutionary techniques of laparoscopy and minimally invasive surgery (MIS) with the integration of cutting edge computer and robotic technology. Along with the ZEUS Robotic Surgical System (Computer Motion Inc.®, Goleta, CA) the da Vinci represents the newest of the two FDA-approved robotic systems as well as the only system with FDA approval for performing suturing and cutting under the direction of a surgeon. The da Vinci is now the primary technological platform as the ZEUS system is no longer commercially available. Therefore, this article will focus primarily on the da Vinci surgical system.

The da Vinci system was purchased at a price of $4.5 million by St. Michael’s (SMH) and Toronto General Hospitals (TGH) in March and September 2008 respectively. The integration of this system will optimally enhance patient care as well as the repletion of these prestigious centres and the Department of Surgery and Faculty of Medicine at the University of Toronto. Additionally, Sunnybrook and Toronto East General hospitals are currently involved in the fundraising and testing phases required to obtain this system.

Telepresence Surgery
Telepresence technology allows the surgeon to remotely perform the surgical procedure. It was initiated through a collaborative project between Stanford Research Institute, United States Department of Defense, and the National Aeronautics and Space Administration. This project was originally designed to provide emergency operative care to wounded soldiers on the battlefield. Robotic arms were designed to be attached to an armoured vehicle to allow a surgeon to perform surgical care from a remote location.

Intuitive Surgical Inc.® adapted the prototype to be used in hospital operating rooms (ORs). In 1997, the prototype “Mona” was used by a surgical team in Belgium to perform a cholecystectomy, the first telepresence surgery. Subsequently, the da Vinci System was developed and approved by the FDA and Health Canada in 2000 and 2001 respectively.

da Vinci SD Model
The da Vinci system was designed to improve vision, dexterity, and precision in MIS. There are three main components that comprise the system (Figure 1). The surgeon console allows the surgeon to control the system remotely and does not require them to be scrubbed in for the procedure. The system is only active when the surgeon is seated at the console with their head in the viewing area. Visualization of the operative field is accomplished via three-dimensional (3D) high-definition (HD) technology that provides an additional 6-10x magnification. The surgeon inserts their hands into finger controls or “masters” which translate their hand and wrist movements into electric signals. These are then translated in real time into the exact movements of the instruments (Figure 2). Motion scaling can be adjusted for 1:1, 3:1, and 5:1 to allow for improved precision. For example, on 5:1 scaling, 5 units of motion by the surgeon’s hand are translated into one unit of motion by the instrument. Finally, foot pedals are used to control which instruments are active inside the patient.

The patient side cart is situated next to the operating table and has four robotic arms: three EndoWrist® instruments and an endoscope. Each instrument is inserted into the patient through a ‘keyhole’ incision approximately 1-2 cm in diameter. The first two arms represent the surgeons left and right hands and the third arm allows for the use of an additional instrument (Figure 3). The EndoWrist® instruments permit the same movements which are normally present in the surgeon’s hand and wrist dur-
On the Cutting Edge: Robotic Surgery's Renaissance

ing open surgery. There are a large number of attachments available that are similar to conventional surgical instruments (e.g. scalpel, scissors, graspers, cautery, etc.). Each instrument can be used for up to ten cases after which it is inactivated by an internal computer chip. The fourth arm holds a 12-mm endoscope which contains two 5-mm telescopes to facilitate 3D HD vision of the operative field.

The imaging system is contained within a portable video cart or integrated into an audiovisual system in the OR. The HD screens allow the assistants, nurses, and students to view the procedure.

Applications

The original surgical application for the da Vinci system was for cardiac surgery. However, the scope of its use has spread over many of the surgical specialties since its inception. The da Vinci system has been successfully used in Otolaryngology, General Surgery, Gynaecology, Cardiac/Thoracic Surgery, Vascular Surgery, and Paediatrics. At both Toronto hospitals, the system will be used primarily for urological and gynaecological surgeries. In addition, the system will be used by general surgery and oncology at SMH and TGH respectively.

Benefits

The da Vinci system continues the surgical trend of MIS which yields many benefits for the patient and surgeon. Smaller incisions translate into decreased blood loss, reduced post-operative pain leading to less narcotics, shorter stays in hospital, and quicker recovery. The system builds upon conventional laparoscopic techniques and has eliminated many of its drawbacks. There are no counterintuitive hand movements, which would make laparoscopic training especially challenging for residents and surgeons (e.g. when the surgeon moves their hand to the right, the instrument moves to the left inside the patient). A fine motor filter removes natural hand tremors leading to increased precision. In addition, the EndoWrist® technology has improved the limited instrument movement and manipulation in the operative field. A robotic arm controls the positioning of the endoscope that provides a 3D HD view of the operative field. This provides the surgeon with adequate depth perception and camera stability which was previously difficult to determine using the 2D view with conventional laparoscopy. The use of four robotic arms decreases the number of assistants that are required during the procedure. Finally, an improved ergonomic design allows the surgeon to be seated comfortably at the console, thereby eliminating long periods of standing and holding laparoscopic instruments in awkward positions.

Learning Curve

A potential drawback of any new surgical technique has to do with the concept of its learning curve (LC), defined as “the number of cases that a surgeon must complete to obtain enough sufficiency and mastery in a surgical technique with the minimum of complications.” Thus, successful training in robotic surgery is not a matter of simply being able to complete a procedure without making a mistake, but rather how quickly and easily a surgeon can adapt to the new technique.

For a relevant comparison, it is pertinent to contrast the LC for the da Vinci system with laparoscopic surgery. For laparoscopic prostatectomy, studies have shown the LC to be between 10 to 60 cases for surgeons with no previous laparoscopic experience. Interestingly, the LC for the da Vinci system from a number of independent studies ranges from only 20 to 50 cases.

There are a number of reasons for this discrepancy in LCs between laparoscopic and robotic surgery, such as the increased degrees of freedom, the lack of counterintuitive movement, and added spatial perception. Probably the most important factor for robotic surgery’s ease of use is its ability to facilitate advanced techniques, such as suturing, which the laparoscopic approach struggles to recreate efficiently.

The LC for any procedure and surgeon will vary depending on a number of identified factors, such as manual dexterity, previous laparoscopic experience, receptiveness to technology, and change in general surgical experience. Cardiac surgeons, for instance, who infrequently use laparoscopy tend to have a more difficult time, while younger surgeons with extensive training in video assisted surgery will be more amenable to robotics.
It should also be noted that the surgeon’s LC only takes into account the actual time spent operating whereas the elaborate docking setup of the machine has its own learning curve for hospital staff. Setup requires the appropriate sterile installation of ports in the patient followed by the four arms of the system being hooked up to functional probes that go in each port. This process can take up to an hour for an inexperienced team.26

To facilitate the learning experience, surgeons are given training sessions at four locations across North America which offer two and three day programs. This enables future robotic surgeons to obtain valuable experience from experts using animal models before they ever get into a real OR.25

Acceptance

Whether robotic surgery in its current incarnation becomes commonplace in Canada depends on a number of factors. Robotic surgery in the private healthcare climate of the United States can justify its high price tag through the added business a hospital can attract using a prestigious device such as the da Vinci. However, the Ontario Health Insurance Plan pays the same amount to the hospital for a robotic surgery as it does for the same laparoscopic procedure.26 This means the difference in cost for each operation must be covered by the hospital, leaving only the largest centres in Canada with the potential for operating a system like the da Vinci. Exacerbating this expense beyond the initial sale price is the actual operating cost of the da Vinci. The $4.5 million investment covers the system, training, support, and five years worth of “disposables,” the one-time use items which are discarded after every operation. After five years, however, the hospital must cover the disposable costs on its own, which at approximately $2800, are $2000 more expensive than laparoscopic surgery per operation.26

Another factor important to widespread acceptance is whether doctors consider robotic surgery as the next step in surgery’s evolution, or just another gimmick. A 2006 poll of urology residents across Canada and the U.S. found that over half of the respondents believed that robotic surgery “looked promising but was not currently the gold standard,” with only 30% responding that “they would be performing robotic surgery after residency.”25 Still, with the increased number of systems, exposure of doctors to robotic surgery, and access to specialized training, it is becoming more common with over 1000 da Vinci systems in 36 countries worldwide.27 For example, the number of urological procedures performed worldwide with the da Vinci system has continued to increase from 1500 to 20 000 to 36 000 in the year 2000, 2005, and 2006 respectively.28 In 2003, London Health Sciences Centre was the first hospital in Canada to use the system.29 Other cities in Canada that have the system include: London, Montreal, Toronto, Edmonton, and Vancouver.

Future

Across the surgical fields there is agreement that robotic surgery represents a huge potential, but there is little consensus as to whether we are in the midst of a dramatic paradigm shift, or whether its inherent financial burdens will limit it to novelty status. While the arrival of robotic surgery may make it appear as though the future of surgery is here now, there are still further improvements and applications on the immediate horizon.

The lack of tactile feedback is one obvious element that the makers of the da Vinci can improve to closer approximate the lifelike feeling of a surgical procedure.11-13,17 The technology for such a feedback system certainly exists and is currently used in a variety of simulator technologies. The problem lies in that incorporating such a feedback mechanism into the current da Vinci system would render it so prohibitively expensive that only a handful of the largest hospitals would ever be able to afford it. Once either the cost of the machine or the tactile feedback technology is reduced, we may see the emergence of robotic systems that will allow surgeons to make use of the benefits of a robotic operation without having to sacrifice their haptic “feel” of operating.

Because the da Vinci console does not need to be in close proximity to its operating arms, the potential for long-distance telepresence surgery seems to be a natural extension of the existing technology. In fact, the world’s first transatlantic surgery was performed in 2001 by a Canadian-born general surgeon Michel Gagner operating from Mount Sinai Hospital in New York on a patient in Strasbourg, France.30 For a country such as Canada, with a large number of remote communities relative to the small number of major medical centres, the prospect of being able to operate on patients thousands of kilometres away is especially significant. At the time, Dr. Gagner noted that “when the technology becomes cheaper and fibre optics are easily connected in different parts of Canada, between hospitals and remote nursing stations, we would be able to treat an Inuit patient who has a particular injury or disease…[or in] remote areas, Third World countries, on ships and on isolated islands.”30 However, as with tactile response, there remain a number of hurdles to the successful implementation of a teleSURGERY program in Canada. Firstly, as anyone watching video on the Internet can attest to, a significant time delay in transmission of information exists, resulting in a delay from the time the surgeon moves his hand to the time the robot moves on the screen. The transatlantic surgery, for instance, required a special engineerto optimize the transmission, as well as the presence of a backup network in case the transmission became unstable.31 Thus, for remote areas to benefit from robotic surgery, they would need a sufficient level
of infrastructure and tech support. Additionally, the equipment will need to be vastly reduced in size in order to increase its portability. Furthermore, the transmission must be specially encrypted in order to avoid the catastrophic possibility of having the telesurgery “hacked”. Thus, for now at least, it is far more realistic to still bring the patient to the surgeon, as robotic surgery is still only in its infancy. As costs decline and technology improves, there is certainly the means to drastically improve the accessibility of our health care system by offering outstanding surgical care to outlying populations.

Conclusion
There is no question that robotic surgery as it exists in Canadian hospitals represents a powerful new tool in the modern surgeon’s armament, improving on many of the shortcomings of laparoscopy, with the addition of special features that can enhance a surgeon’s own natural abilities. Whether these improvements can ever be realized on a larger scale depends on whether they are perceived as significant enough to warrant the sizable outlay of investment from the finite resources of our healthcare system. The technology of tomorrow is already here, but until it can be reconciled with today’s economic realities it will remain more a novelty than an effective means of improving the health of Canadians on a significant scale. Leonardo da Vinci’s designs ranged from the revolutionary, in the modern tank, to the ultimately unrealized in the ornithopter, an ill-fated flying machine. Where on this spectrum the da Vinci surgical system falls, only time will tell.

Conflicts of Interest
None to disclose.

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