Telesurgery: Windows of Opportunity

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Abstract:

Minimally Invasive Surgery is the most important revolution in surgical technique since the early 1900s. Its development was facilitated by the introduction of miniaturized video cameras with good image reproduction. The marvels of electronic and information technology have strengthened the biochemical and molecular power of diagnosis and the surgical and medical management of gynecology, transforming the very practice of medical science into a reality that could barely be envisaged two decades ago. We now enter the age of Robotics, Telesurgery, and Therapeutic Cloning. This dynamic process of reform continues to deliver practitioners with information, ideas and tools that spell answers to some of the most pressing dilemmas in clinical management. New technology will provide us with better opportunities of vision of the operative field, such as 3-D Endoscopy. Other promising technologies such as incorporation of ultrasonography, magnetic resonance imaging, laser-based technology or assisted optical coherence tomography will not only enhance better visualization of the surgical field, but also discriminate the pathologic tissue from the normal one, enabling the surgeon to excise the pathologic tissue accurately. Pain mapping and photodiagnosis offer a new direction in the diagnosis of microscopic endometriosis. Better detection of the disease results in higher chances of success following treatment.

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Introduction

Minimally Invasive Surgery is the most important revolution in surgical technique since the early 1900s. Its development was facilitated by the introduction of miniaturized video cameras with good image reproduction. Prior to 1980, traditional gynecological surgery had remained unchanged over 60 years. The use of the laparoscope, introduced in the late 1960s, was initially restricted to diagnostic and sterilization procedures. Kurt Semm from Kiel pioneered operative laparoscopy in the 1970s. The CO_2 laparoscopic laser was introduced in the 1980s. In 1988, Harry Reich performed the world's first laparoscopic hysterectomy which subsequently broadened the appeal of this approach. By the early 1990s, the availability of surgical aids such as quality cameras, ports, staples and electrosurgery had facilitated the progression of laparoscopic surgery into mainstream gynecology.

Laparoscopic cholecystectomy was the first procedure to be widely accepted and several others are now well established. The early limits of the technology involved the gynecologists using a purely optical telescope for illumination and visualisation and operating unassisted. With one hand on the telescope, the gynecologist had only one hand to manipulate the viscera, and thus the technical repertoire was limited. The development of miniaturised television cameras that give an adequate image was key in the minimal access revolution. It allowed the assistant to have the same view as the surgeon. The assistant could therefore hold the camera (allowing the surgeon to operate with two hands) and retract the viscera to improve the access. Laparoscopic cholecystectomy was soon shown to be possible, and rapidly became the procedure of choice. The principles that were developed for laparoscopic cholecystectomy have now been applied to many other abdominal and thoracic operations.

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Future Trends

The major areas of gynecological surgery today are:

1. Obstetrics – antenatal, intrapartum and postpartum maternal and fetal surgeries
2. Fertility enhancing surgeries and Assisted Reproduction
3. Oncosurgery
4. Gynecologic Urosurgery
5. Pelvic Floor and Retroperitoneal surgery
6. Uterine surgery – transcervical and transperitoneal

The major developments in future, likely to impact surgical techniques, are:

1. Evolution of anesthetic agents – Minimal post-op recovery time
2. Advanced real time imaging systems
3. Newer generation of minimally invasive operating instruments with higher degree of automation (Robotics)
4. Advanced drug delivery systems for more targeted therapy
5. Stem cell therapy for reconstructive therapy
6. High resolution and high magnification optical imaging
7. Real time histopathology, on table in situ histology
8. Immunomodulative therapy for transplants
9. Newer hemostatic and tissue ablation techniques
10. Telemedicine

Apart from these, lifestyle and environmental factors are likely to play a role in determining the course of gynecological surgery in the coming five decades. These include:

1. Increase in lifespan
2. Changing life styles and social concepts of child bearing
3. Late marriages and delayed conceptions
4. Lower family sizes and evolving human relationships
5. Emergent viral agents
6. Environmental toxins

Technological Advances

Virtual Reality Simulators and Robots

Advances in computer graphics, robotics and virtual reality (VR) technology have opened up new possibilities in medicine. The use of Robots is rapidly developing in surgery, although the word is slightly misused in this connection. None of the systems under development involves a machine acting autonomously. Instead, the machine acts as a remote extension of the surgeon. The correct term for such a system is a 'Master Slave Manipulator', although it seems unlikely that this term will gain general currency. Robots fit readily into the infrastructure of today's hospitals (Fig 1). Users of this technology, the new generation of computer literate physicians and patients, recognize their potentials and benefits.

Fig (1). Robot

In developed countries, more elderly people require hospital care and fewer working-aged people are able to provide it. One solution is automation in health care. Advances in telecommunications now routinely allow surgeons to view operations taking place in distant hospitals using video conference techniques. Adding a robot assistant to this set-up allows a distant surgeon to participate directly in the procedure, controlling the robot in exactly the same way as if they were in the same room.

Virtual Reality Training Systems

Virtual reality based surgical simulation systems will become even more realistic in the future. They will be integrated into multimedia teaching and training environments and all surgical disciplines will be covered. [1-9]

To provide the virtual environment, a realistic 3-D representation of the anatomic sites is derived from 2-D medical image data using imaging algorithms and visualization techniques (Fig 2). Thus the surgeon is able to perform endoscopic procedures on the virtual situs (Fig 3). By means of realistic user interface, the gynecologist is able to grasp, cut, coagulate, introduce new instruments, suture, apply clips, initiate bleeding, achieve hemostasis and retract the intestines, all in a realistic simulation scenario. A capability score can also be drawn up for each trainee. [10]

Fig (2). Virtual Surgery

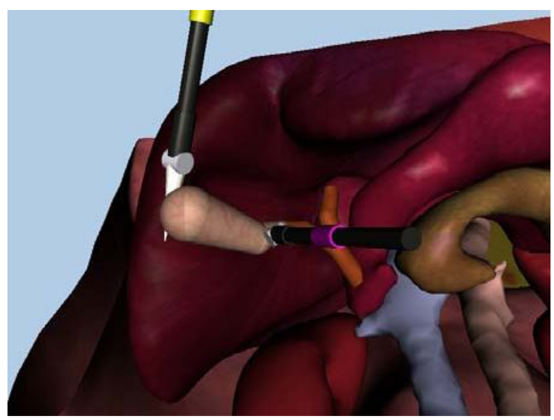

Fig (3). Virtual laparoscopic surgery from a haptic bench

Robotic Assisted Laparoscopic Surgery

Minimally invasive surgery is itself a form of telemanipulation because the surgeon is physically separated from the workspace. Telerobotics is an obvious tool to extend the surgeon's capabilities. The goal is to restore the tactile cues and intuitive dexterity of the surgeon, which are diminished by minimally invasive surgery. A slave manipulator, controlled through a spatially consistent and intuitive master with a force feedback (haptic) system, could replace the tactile sensibilities and restore dexterity.

Several passive mechanical devices, primarily used to hold the telescope, have been developed as assistants for general laparoscopic surgery. They successfully reduce the stress on the surgeon by eliminating the inadvertent movements of a human assistant, which can be distracting and disorienting. [11]

There are many different types of robotic camera holding systems. AESOP (Automated Endoscopic System for Optimal Positioning), available with hand, foot or voice control, received the robot of the year award 2000 in medical application.[12] The surgeon can direct the articulated metal arm by voice control. The laparoscope can be moved in any direction – left, right, up, down, forward or backward. The da Vinci is another surgical system, whereby it is possible to perform complex surgical procedures through 1 cm ports in a sitting position with a so called Surgical Immersion technology, with the look and feel of an open surgery (Fig 4 and 5). It has two primary components: the surgeon's viewing and control console, and the surgical arm unit, which holds and manipulates the detachable surgical instruments. The effector arms of the da Vinci surgical system have attached instruments that are controlled by the surgeon, who sits at the adjacent console. These pencil sized instruments with tiny electromechanically controlled 'wrists' duplicate the movement of the surgeon's hand and wrist at the operative site. The effector tips of the system incorporate miniature wrists that allow them to mimic any movement made by the surgeon at the control console. The eyes and hands of the surgeon are completely immersed in the patient.[13-15] With the da Vinci Surgical System, the future of surgery is at your fingertips. 'Motion scaling' software is used to translate large natural movements to extremely precise micromovements. Surgeons can immediately observe the instruments and the patient's body respond to the movements of their hands on the handles, as if they were performing the operation directly. This avoids the need for the reversed counterintuitive motions used in minimally invasive surgery. An interesting repertoire is its use in open procedures that require extreme precision – for example, microvascular anastomosis and nerve repair. In such settings, the robot can enhance the surgeon's skill by eliminating physiological tremor. However, the system is very expensive and not yet in widespread use.

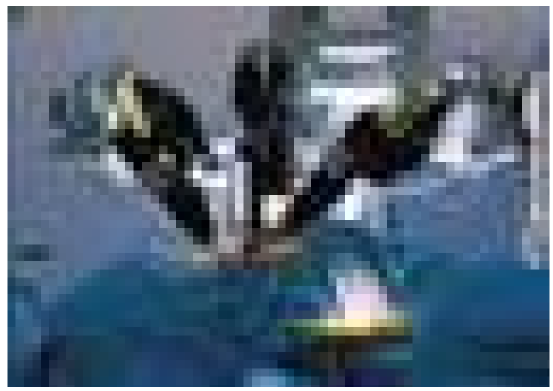

Fig (4) da Vinci

Fig (5). da Vinci in use

Intelligent Operating Rooms

In the Hermes Intelligent Operating Room, as a road map to networked voice-controlled devices, data management and surgeon control is unified in one system (Fig 6). The camera is controlled by an AESOP.[16]

Fig (6). Hermes

Another example of an intelligent operating room is the OR1 from Karl Storz, which realizes the integration and central steering of different operation room components. This allows central control of all operating room components, processing, capturing and mailing of all patient data for data exchange between clinics, doctors and health care staff. Radiological and histological data can also be recalled. [17]

The benefits of both these rooms are at hand: improved ergonomics, better data management, more efficient personnel utilization and optimized surgeon control.

Newer Optics

A new imaging technology that uses directed laser or optical illumination, which is scanned at the distal end of the endoscope has been introduced, especially for flexible endoscopes, which have limited image quality.[18] In this technique, an alternative approach is used, pixel-array acquisition and to scan a spot of light and detect each pixel sequentially by laser scanning or confocal microscopy. Thus, higher image quality may be obtained with this visualization technique when compared to similar diameter normal telescopes. Optical scanning technology may provide narrower telescopes with high quality images, and more space for operative instruments. Thus, thanks to such developments in the visual system, flexible telescopes may more widely be used in gynecological practice involving minimally invasive medical surgery.[19]

Development of three-dimensional (3D) endoscopic instruments has made clear view and perception of depth available.[20] A specialized 3D telescope with a small, light-weight pair of glasses is required for visualization (Fig 7). The images obtained from objects are processed by a control unit (digital image processing module, 3D scan converter, 3D video demultiplexer) and then they are displayed on the 3D monitor. The 3D vision with a perception of depth makes it easier to position instruments and structures in the area of the operation. Thus, diagnostic and operative endoscopy can be performed more easily (localization of the lesions, measurement of the size, suturing, etc). The high-resolution camera gives clearer image reproduction in 3D as well as 2D mode. Single axis image processing eliminates binocular contrasts and eye strain. Polarized glasses allow more than one person to see three-dimensionality. The learning curve in 3D endoscopy is shorter than its 2D counterpart, because 3D modules can provide more actual and realistic views.[21] The development of 3D technology in endoscopic applications will lead to widespread use of minimally invasive endoscopic surgeries in infertility evaluation. Increasing number of surgeons will be able to easily perform basic procedures without difficulty of orientation by means of 3D endoscopy.[22]

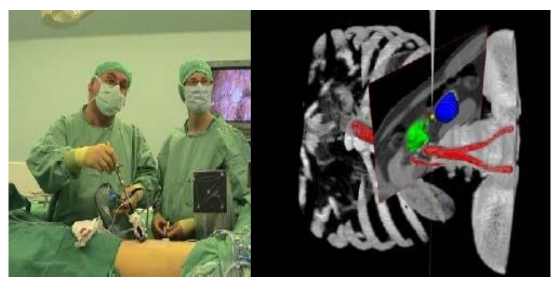

Fig (7). 3D Laparoscopic Surgery in progress

Ultrasound has already been integrated into endoscopy instruments, and attempts are under way to integrate Magnetic Resonance Imagining (MRI) technology into telescopes.[23] It is obvious that optics and laser-based techniques will be integrated as well.[24] Computer-assisted diagnostics for object identification in images will be applied to telescopes for the intelligent, automated segmentation and recognition of pathology at the organ, tissue and cellular levels.[25] Optical technique capable of identifying tissue components and pathology, as well as obtaining microstructural images is known as optical biopsy.[26] Optical biopsy may eliminate several current problems encountered with endoscopy.

A new optical imaging technology called 'Optical Coherence Tomography' (OCT) may prove useful in providing more information on tissue morphology during endoscopic and laparoscopic procedures (Fig 8). OCT is a laser-based optical imaging technology that is somewhat analogous to ultrasound B-mode imaging.[27] It uses a technique called 'flow coherence interferometry'. The visualization of image subsurface morphology is the main potential benefit of OCT.[(28)] However, a limitation of OCT is a penetration depth of only 2-3 mm. In contrast to ultrasound, tissue contact or an index-matching gel is not needed in order for images to be acquired, and scanning can be performed over large areas of tissues. For example, endometriotic foci will be more easily recognized by OCT combined with laparoscopy.

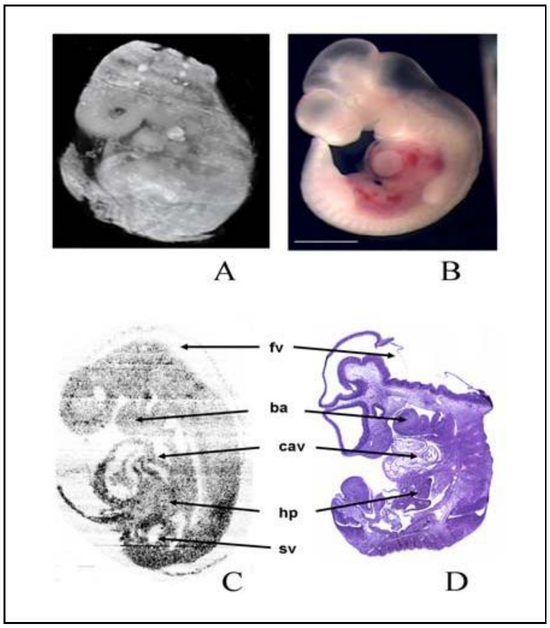

Fig (8). OCT of the murine embryo

Pain Mapping for Endometriosis

Smaller microlaparoscopes and microinstrumentation coupled with video-laparoscopy enable the patient to be an integral part of the operation and interact with the surgeon during the laparoscopy. Thus dawns the age of Patient Assisted Laparoscopy (PAL) or laparoscopy under conscious sedation. Since the patient is the only person in the operating room who knows where the pain starts and where it ends, it always seemed illogical to anesthetize the patient, leaving the surgeon to tell her where her pain was, based upon what he saw. Initial work on mapping of pain associated with the endometriotic lesions resulted in some thought provoking findings.[(29, 30)] The classic black lesions were found to be painful in only 11 % of the patients when the lesion was touched. Similarly, white lesions were painful in 20% of the patients, red in 37% and clear lesions in 32%. These results added further reason as to why initial therapy gave such poor results. Surgeons would only 'see' the black lesions and remove them, but these were the least painful lesions. What became apparent next was the fact that the pain extended 28 mm beyond the visible border of the lesion onto what looked like 'normal' peritoneum. Therefore, if the surgeon only removed the lesion at its border, the microscopic disease in the previously identified normal looking peritoneum would remain and the symptoms would persist or recur. With pain mapping, the patient can determine by her pain where the microscopic endometriosis is, so the surgeon can remove it along with the visible lesion.

Conclusion

Robotic surgical instruments give the surgeon new telesurgery opportunities, such as image - guided positioning, image - augmented dexterity, sensor-guided positioning and dexterity and increased manual dexterity. As a hysteroscopic procedure, the robot-controlled endometrial resection in accordance with the exact measurement of the endometrium is certainly more optimal than manual uncontrolled resection. We are learning from the urologists who have been performing prostate resections by robots. Telescopes, rigid or flexible, are the main components of minimally invasive surgery. Technological advances in the last decade have produced thinner telescopes with good quality of vision so that many procedures such as office hysteroscopy and laparoscopy, and hydrolaparoscopy may be available to the patient in the absence of general anesthesia. However, new technology will provide us with better opportunities of vision of the operative field, such as 3-D Endoscopy. Other promising technologies such as incorporation of ultrasonography, magnetic resonance imaging, laser-based technology or assisted optical coherence tomography will not only enhance better visualization of the surgical field, but also discriminate the pathologic tissue from the normal one, enabling the surgeon to excise the pathologic tissue accurately. Pain mapping and photodiagnosis offer a new direction in the diagnosis of microscopic endometriosis. Better detection of the disease results in higher chances of success following treatment.

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