

# ANESTHETIC CARE OF THE PATIENT FOR ROBOTIC SURGERY

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## **Introduction**

Technological advances in medicine and surgery have undoubtedly changed today's practice. One of the most important recent developments to surgical practice has been the adoption of computer assisted robots. Although robots have been around for the past 75 years, it is only recently that their use in surgery has dramatically increased<sup>1</sup>. With the growing market pressures for minimally invasive procedures, the role of robotic assisted surgery and its advantages of improved surgical precision over standard open and laparoscopic procedures will likely grow. To date since 1998, there have been approximately 80,000 robotic assisted surgical procedures. Currently about 400 medical centers in the United States have surgical robotic systems. As the number of surgeons adopt and learn to master this new tool, which is still in the learning phase, anesthesiologists should have a basic knowledge of these systems in order to formulate an anesthetic plan, recognize potential complications and provide safe patient care.

## **History of Robotic Assisted Surgery**

A robotic device is, technically, a "powered, computer controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a wide range of tasks"<sup>2</sup>. Robotic systems used in surgery today are computer assisted devices and are not true robots, because they lack independent motions or preprogrammed actions. However, they offer significant advantages such as three-dimensional view, visibility of difficult to reach areas, easier instrument manipulation and the possibility

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of remote site surgery. A more accurate descriptor for these devices is a computer-enhanced telemanipulator. The surgeon is “teleported to the operative site”, and is able to manipulate surgical instruments as if he or she were in the surgical field. Thus, surgical robots perform tasks under the surgeon’s control in what is referred to as a “master-slave” relationship. The robot does not replace the surgeon, but instead performs and enhances the precision of the surgeon’s hands. Today robotic surgery has application in urologic, gynecologic, cardiac, orthopedic, and pediatric surgery. It has also been used by the otorhinolaryngologist.

Today’s medical robotic systems can trace their origins to the United States Department of Defense’s (DOD) desire to decrease war casualties. The DOD sought a system that allowed combat surgeons rapid access to treat exsanguinating soldiers on the battlefield from a safe distance: thus the concept of telerobotic surgery was born. These systems were initially designed for open surgeries and were shown to be feasible in an animal model; however, they were never applied to humans. In the early 1990’s, researchers at the National Air and Space Administration (NASA) Ames Research Center joined with those at the Stanford Research Institute to develop a telemanipulator for hand surgery.

While government backed agencies were working on telerobotics and telemanipulation, civilian surgical practice was advancing with the growth of minimally invasive laparoscopic techniques. The first laparoscopic cholecystectomy was performed in 1987 and since then, laparoscopy has gained widespread use and acceptance by surgeons in a variety of procedures<sup>3</sup>. The convergence of the concept of telerobotic surgery with laparoscopic surgery eventually developed into two FDA approved telemanipulative robotic systems: the da Vinci Robotic Surgical System and the Zeus Robotic Surgical System. In April of 1997, the first robotic assisted surgery was performed by Jacques Himpens, MD and Guy Cardiere, MD using the da Vinci surgical system.

## **Robotic Systems**

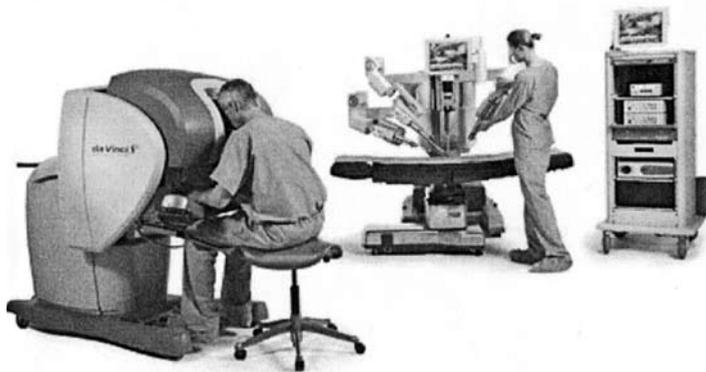
As previously mentioned, there are two surgical robotic systems in commercial use today: the Zeus® surgical system (Computer Motion,

California) and the da Vinci® surgical system (Intuitive Surgical, California). Intuitive Surgical have acquired Computer Motion and will continue to support institutions that have a Zeus system. Thus only the da Vinci system is commercially available now in the United States.

The da Vinci® system is composed of 3 distinct parts (Figure 1): The first part is a control console where the surgeon sits to view and control the robot from a remote location. The console has a place where the surgeon attaches his hands and his hand motions are translated into surgical instrument motion. The surgeon's fingers are connected via the console and robot to the surgical instruments. The console also has a 3 dimensional viewer. With the surgeon sitting at the console, manipulating the robot and simultaneously looking into the viewer, he/she has the simulated experience of being present in the operating field. The computer that runs the entire system is housed in the console. The console also has other capabilities that allow specific adjustments of the video system and robotic arms along with the ability to adjust for comfortable ergonomics. Motion scaling can be adjusted from a 1:1 up to 5:1 ratio. This means that 5 inches of hand motion can be translated to 1 inch of surgical instrument motion. The system can thus filter out hand tremors. Foot pedals on the console allow the surgeon to control electrocautery, ultrasonic instruments, adjust the focal point of the video camera, disengage the robot instruments, and alternate between robotic arms as the need arises.

*Fig. 1*

*Indicates the 3 parts of the da Vinci system*

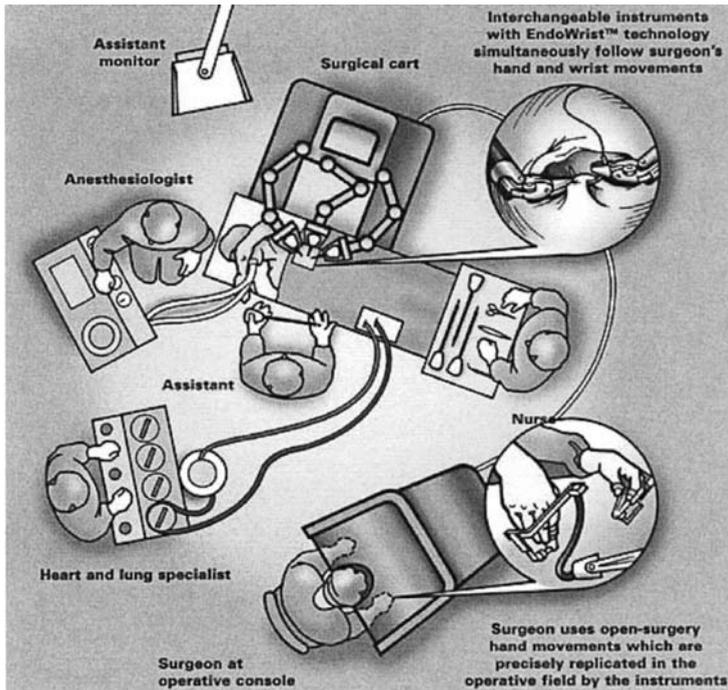


The second component consists of a tower which contains video equipment to record and display images of the surgical site onto two dimensional monitors for the convenience of the rest of the operating room team. Other laparoscopic instruments such as insufflators are on this tower.

Finally, the third component is the robot itself which consists of three or four arms. The original da Vinci® robot had three arms. The central arm holds the video telescope while a right and left arm perform manipulations. A four arm robot was later added. It is identical to the other two arms in functionality. It can be positioned and locked into place, acting as a stationary retractor. The surgeon can then assist him/herself when retraction is needed. Figure 2 indicates how personnel would be positioned for a cardiac surgical procedure.

*Fig. 2*

*The relative positions of the operating room personnel*



Similarly, the Zeus® system also consists of a control console where the surgeon operates the robot remotely and the robot with three arms. The main differences between these two systems is that the Zeus® uses a voice activated camera, the robotic arms are attached to the OR table and the robotic arm only allows for 5 degrees of motion versus the 7 degrees of motion in the da Vinci® system.

### **Initiating a Robotic Surgery Program**

In order to institute and run a successful robotic surgery program, hospital administration must commit to the continual financial support of the robotic system. The initial and recurring costs of running a robotic surgical program are significant. However, the potential growth of surgical volume and increased institutional recognition from the availability of a robotic program may offset these costs by increasing surgical volume and attracting new faculty. In today's information age, patients are more educated about their options and often have a strong desire to seek out the most advanced therapies which makes the existence of a robotic program a marketing tool.

Teamwork is essential to the success of a robotics program at any institution. It is necessary to ensure that the hospital administration, surgical anesthesia and nursing departments are committed to the success of the program. The mere existence of a robotic system does not constitute a successful robotics program. Surgeons must be interested and technically capable of performing the operations. The challenges that must be overcome when initiating a robotic program include increased operating time and the surgical learning curve. Surgeons eventually gain the experience to reduce operative times to comparable open or laparoscopic benchmarks.

Nursing personnel must become familiar with setting up and trouble shooting the robotic equipment, the special instruments, and the surgical procedure. Challenges faced by nurses are the robot's size and operating personnel have to move to accommodate to this large mass. Transporting the equipment in and out of the operating room can be difficult. The setup

is complex. Nurses turn on the robot and calibrate the equipment. Draping the robot for sterility is another learned technique. The instrumentation, the docking of the robot and trouble shooting are unique to this technology. With increased experience and volume, improved efficiencies for anesthesia, nursing and ancillary OR staff will occur.

### **Advantages of Robotically-Assisted Surgery**

Recently, there has been an enormous push towards increasing use of minimally invasive surgery. The purported advantages of laparoscopic assisted surgeries include reduced postoperative pain, improved cosmesis (smaller incisions), shorter hospital stays, faster postoperative recovery, potentially lower costs, and improved patient satisfaction<sup>4</sup>. Robotic assisted surgery is an evolutionary step in the advancement of minimally invasive surgical procedures. These technological innovations have improved on disadvantages inherent in commonly performed laparoscopic techniques. One advantage of computer assisted robotic surgery over standard laparoscopy includes improved operative field visibility with three dimensional imaging systems. The 3 dimensional images that the surgeon views occur naturally because each eye is linked to a separate camera. The human brain then processes each image giving the surgeon depth perception. A synchronizer within the system maintains each frame from each camera in phase. A safety feature built into the system is that an infrared sensor crosses the plane of the viewer. The console will not move any of the robotic surgical arms or instruments unless the surgeon is in position to view the surgical field. If he/she moves his/her head out of the plane of the infrared sensor the console will not follow commands. Another advantage of the robotic system, computer assisted scaling, improves control of fine movements and reduces the “fulcrum effect” which amplifies unwanted motions such as hand tremor.

Finally, robotic systems allow for more ergonomic, anatomic control of instruments which closely mimics the movement of the human wrist<sup>5</sup> (i.e.: 7 degrees versus 4 degrees of motion with laparoscopy). In order

to better understand the seven degrees of motion, freedom of robotic instruments, one's extended arm, reached out at shoulder height arms can be used to mimic the following motions: The arm can move up and down in a vertical plane (1), side to side in a horizontal plane (2), extend forward to reach an object and retract back (3), rotate around its central axis as when supinating and pronating the hand (4). With the addition of a "wrist", the wrist can be extended and flexed (5), laterally moved to the ulnar and radial sides (6), and finally the hand (instrument) can open and close as if grasping (7).

### **Pitfalls/limitations of Robotic-Assisted Surgery**

Despite the advantage to robotic surgery, there are some limitations that must be considered. Several pieces of equipment, each being extremely bulky require large amounts of precious operating room space. In smaller or older operating rooms, such space constraints may be the limiting factor to adoption of robotic techniques. Another drawback is the large size of the robot itself, making positioning of the robotic arms extremely important in order to avoid collision with its own arms, assistants and/or the patient. Invasion of the anesthetic work space is almost unavoidable and anesthesiologists must be aware that the overbearing size of the robot may impair their ability to quickly access the patient. The staff must be trained and prepared to quickly detach and remove the robot from the patient in the event of an emergency. Patients also must be correctly positioned for surgery from the start since repositioning a patient is almost impossible once the robot has been stationed for surgery. In addition, current robotic systems lack tactile feedback from the instruments. Surgeons must therefore rely solely on visual cues to modulate the amount of tension and pressure applied to tissues to avoid organ damage.

Cost may also be another limitation to using robotic systems, especially for smaller community hospitals. There is a large initial cost of approximately \$1 million dollars to purchase the robotic equipment and a recurring annual service contract fee of about 10% of the purchase

price. Since each instrument in the da Vinci® system has a finite life of ten surgical procedures, reordering consumable instruments adds significant cost to the use of this system. Other cost considerations include initial increased OR setup time, increased surgical operating times as individuals climb the learning curve and OR staff training time.

### **Surgical Procedures Performed with Robotics**

Although the da Vinci® robotic systems were initially designed for cardiothoracic surgeries, there are an increasing number of other surgical procedures utilizing robots. Most of the studies concerning robotically assisted surgeries address the safety and feasibility of these systems. Vidovsky et al studied the feasibility of robotic assisted surgery in 51 patients undergoing cholecystectomy<sup>6</sup>. They were able to complete 48/51 procedures robotically as initially planned. There were significant complications related to the robotic approach. Mean operating time was 77 minutes. The set up time decreased from 30 minutes (first 16 cases) to 18 minutes for the last 15 cases, indicating a learning curve of between 16-33 cases. Other studies have shown similar results. Anvari et al reported no mortality, no intraoperative complications, no conversions to open or laparoscopic procedures, and similar blood loss when comparing robotically assisted laparoscopic colorectal surgery to conventional laparoscopic surgery<sup>7</sup>. Unfortunately, for surgeons experienced in performing laparoscopic colon surgery, robotic assistance offers few advantages over the conventional laparoscopic techniques, because the anastomosis in colon surgeries are stapled rather than hand sewn. In addition, colon surgery often requires views of four quadrants in the abdominal cavity. Robotic-assisted surgery limits access to multiple quadrants secondary to its size; therefore, in order to gain access to other quadrants, the time consuming effort of manually readjusting the position of robotic arms is necessary.

In addition to surgeries already mentioned, reported cases of robotically assisted general surgeries include: gastrectomy, gastric bypass, and pancreatoduodenectomy<sup>8</sup>. Robotics have also been used in many

cardio-thoracic, gynecologic, neurosurgical, ophthalmologic, orthopedic and urologic cases. Specific case reports include esophagectomy, thymectomy, lobectomy, pericardial window, coronary artery bypass graft, mitral valve surgery, atrial septal defect repair, Fallopian tube anatomists, retinal surgery, total hip and knee arthroplasties, radical prostatectomy and cystectomy with urinary diversion, pyeloplasty, and nephrectomy<sup>9,10,11,12</sup>. To date, >30,000 patients have undergone robotic radical prostatectomy world wide.

In a review of 358 laparoscopic radical prostatectomy (LRP) and 322 robotic assisted laparoscopic radical prostatectomy (RAP) procedures at City of Hope National Medical Center, there were no intraoperative or postoperative mortality and the complication rates for both of these operations were comparative to published radical prostatectomy data<sup>13</sup>. The operative times were 4.1 hours for the LRP and 3.1 hours for the RAP. The estimated blood loss was 200 ml for the LRP and 250 ml for the RAP. Anastomotic leak occurred in 13.5% of LRP, and 7.5% of RAP. There was an incidence of delayed hospital discharge due to ileus in 5.4% of LRP and 2.8% in RAP. Postoperative blood transfusions were required in 2.3% of LRP, and 1.6% in RAP. The robot malfunctioned in 2 of the 322 robotic assisted cases. One case was converted to a laparoscopic prostatectomy. In the second case the nonworking robot was replaced with a working robot.

With future developments in robotic systems, it is conceivable that all surgeries may eventually be done with robotic assistance.

### **Anesthetic Concerns with Robotically-Assisted Surgery**

In order to provide safe patient care, anesthesiologists must understand the ramifications of robotically-assisted surgery on anesthetic management. Several important issues related to and specific to robotic surgeries include patient positioning, duration of the procedure, development of hypothermia, the hemodynamic and respiratory effects of the pneumoperitoneum and occult blood loss.

### *Patient Positioning*

Robotic surgery with the da Vinci® system does not allow for changes in patient position on the operating room table once the robot has been docked. Therefore, the robot should be docked only after the patient has been optimally positioned for surgery. Patient positioning varies with each surgical procedure and the anesthesiologist should be cognizant of optimal placement prior to docking the robot. Procedures in the pelvis such as prostatectomy are usually done in the lithotomy and steep trendelenburg position, while those in the upper abdomen and the diaphragm are best performed in the supine and reverse Trendelenburg positions. Procedures in the chest are commonly done in the lateral position, with variations of Trendelenburg or reverse Trendelenburg position according to the surgical site. Mediastinal surgeries often require the lateral position with lateral table tilt. Many laparoscopic surgical procedures require extreme patient positioning in order to take advantage of gravitational effect that allows movement of obstructing organs from the surgical field. Since extreme positioning often increases the risk of patients sliding off the OR table, restraints must be used. An effective method is found by taping a foam egg crate mattress to the operating room table. Contrary to the usual placement of egg crates, the convoluted side of the foam faces down to the OR table while the smooth side contacts the patient. An appropriate amount of traction is generated to prevent patient movement.

Some procedures require the patient's airway to be at a distance from the anesthesiologist and the anesthesia machine/monitor. Upper abdominal and thoracic surgeries are done with the OR table rotated 180 degrees away from the anesthesiologist and with the robot positioned cephalad above the patient. Mediastinal procedures require the OR table to be rotated 90 degrees away from the anesthesiologist. During these cases, access to the patient's airway is nearly impossible, thus field avoidance precautions must be exercised. These cases are particularly challenging if one lung ventilation is requested since frequent use of the fiberoptic bronchoscope may be necessary.

It is imperative to ensure the patient is properly positioned with pressure

points adequately padded prior to draping and docking the robot. The size and bulk of the robot over the patient and the significant draping on both the robot and patient, make it difficult to access the patient intraoperatively. Robotically assisted surgeries are often lengthy procedures, especially for inexperienced surgeons, thus adequate pressure point padding is essential to avoid tissue and nerve impingement. Careful attention should also be given to the robotic arms to prevent them from contacting the patient. Pressure or crush injuries may occur if constant vigilance is not exercised. As a reminder, cameras and light sources should be carefully monitored and never left directly on drapes to avoid operating room fires and thermal injury to the patient.

### *Physiologic Perturbations*

Once proper patient positioning has been achieved, there are intraoperative considerations must be addressed. The physiologic perturbations during robotic surgery are similar for both laparoscopic and thoracoscopic procedures. Laparoscopic procedures are associated with phasic changes in hemodynamic parameters secondary to CO<sub>2</sub> insufflation. Increases in systemic vascular resistance, mean arterial pressure, filling pressures and a 50% reduction in cardiac index may occur after initial carbon dioxide insufflation<sup>14</sup>. The cardiac index gradually increases and systemic vascular resistance decreases 10 minutes after CO<sub>2</sub> insufflation<sup>15,16</sup>. Central venous pressure and pulmonary capillary wedge pressures may rise during pneumoperitoneum. Hemodynamic changes correlate with increases in intraabdominal pressure and its effect on the diaphragm<sup>17</sup>. Hemodynamic changes are also affected by the patient's position. Most studies have shown a 10-30% reduction in cardiac output in Trendelenburg<sup>18,19</sup> and reverse Trendelenburg positions<sup>14,20</sup>.

The presence of a pneumoperitoneum affects many organs. It increases cerebral blood flow<sup>14</sup>, and increases intracranial pressure<sup>15</sup>. In the liver it decreases portal vein flow, hepatic vein flow, total hepatic blood flow, and flow through the hepatic microcirculation<sup>16,17</sup>; however, there are no changes in hepatic artery flow<sup>16</sup>. In the gastrointestinal system it decreases

gastric pH<sup>17</sup>, mesenteric blood flow, and gastrointestinal microcirculation blood flow<sup>16,18</sup>. The pneumoperitoneum produces a decrease in renal artery blood flow, renal vein blood flow, and a decrease in medullary and cortical flow<sup>19,20,21</sup>.

The respiratory system is greatly impacted by CO<sub>2</sub> insufflation. Pneumoperitoneum may decrease pulmonary compliance by 30-50% in both healthy and obese patients<sup>19,20</sup>. It reduces the functional residual capacity due to diaphragmatic elevation. Peak airway pressure, plateau pressure, and intrathoracic pressure are increased<sup>22</sup>; however, there are usually no significant changes in ventilation or perfusion in healthy patients<sup>21</sup>. The maintenance of normocarbica and acid base status may be challenging in patients with poor preoperative respiratory statuses. The main factors contributing to an increase in PaCO<sub>2</sub> and respiratory acidosis are the peritoneal absorption of carbon dioxide, increased dead space in patients with coexisting lung disease, increased metabolism, inadequate ventilation, subcutaneous emphysema, and/or carbon dioxide embolism.

The same principles that apply for thoracoscopic surgery apply for robotic assisted thoracic surgery. A combination of patient position, one lung anesthesia, and surgical manipulation alter ventilation and perfusion. Pulmonary shunting is the most important factor determining oxygenation during surgery. This shunt may be limited in the non-ventilated lung by disease or hypoxic pulmonary vasoconstriction. The lateral position reduces shunting by following the principle of gravity and decreasing blood flow to the nondependent lung. Normocarbica is usually easily maintained during one lung anesthesia due to the high solubility of CO<sub>2</sub>. Frequently robotic assisted surgeries require insufflation of CO<sub>2</sub> in the chest (CO<sub>2</sub> pneumothorax) which increases the airway pressures during one lung anesthesia. The continuous insufflation of CO<sub>2</sub> into the chest improves the surgical field by collapsing the lung further and by shifting mediastinal structures away from the surgical site. Insufflations of the chest are usually achieved when the intrathoracic pressure is 10 mmHg. As intrathoracic pressure rises during chest insufflation, there can be both a decrease in venous return and compliance of the heart which may result in hypotension and hemodynamic instability. At the same time the dependent lung

develops higher airway pressures and ventilation can become difficult. As CO<sub>2</sub> is insufflated and absorbed, the rate of elimination must also increase, a difficult feat to achieve during one lung anesthesia as minute ventilation may already be maximized. Another important consideration during robotic thoracic procedures is that there may be violation of the contra lateral pleura which can result in occult blood loss and a tension pneumothorax on the dependent chest. It may present as hemodynamic instability and near impossible ventilation of the dependent lung. Immediate discontinuation of CO<sub>2</sub> insufflation is mandatory to alleviate the tension pneumothorax. During surgery the inspired oxygen (FIO<sub>2</sub>) should be kept at 1.0 and the airway pressure kept below 30 cm H<sub>2</sub>O if possible. The ventilation should be adjusted to maintain PaCO<sub>2</sub> around 40 mmHg, serial blood gases should be considered, and the application of positive end expiratory pressure (PEEP) to the dependent lung or continuous positive airway pressure (CPAP) to the nondependent lung may assist in oxygenation.

Some concerns have been raised about the applicability of robotic and laparoscopic surgery in the obese patient<sup>23</sup>. Arterial oxygenation and A(a) DO<sub>2</sub> are significantly impaired in overweight patients under general anesthesia in Trendelenberg position. Pneumoperitoneum may transiently reduce impairment in arterial oxygenation and decrease A(a) DO<sub>2</sub>. Hemodynamic parameters are not affected by body weight.

Other practice has centered on fluid replacement in steep Trendelenberg position. Crystalloids have a short lived existence within the vascular space. By gravitational effect, edema may quickly form around the face, eyes and upper airway. Post extubation respiratory distress has been described, requiring emergent reintubation<sup>24</sup>. Recommendations are to restrict fluid replacement to 1-2 liters over the course of surgery, to use colloids and to ensure that the patient can breathe around an endotracheal tube with a deflated cuff.

### **Robotic-Assisted Surgery: Future Directions**

The future of robotically-assisted surgery seems promising; however, there are still many unanswered questions as the technique is still in

its infancy. Regarding the effectiveness of these surgeries few clinical outcome studies have been performed as of yet, therefore, further research addressing these issues must follow. Furthermore, with the current focus on health care cost containment, cost effective studies will be included. Other limitations to current robotic systems that will be addressed include start up costs. As is the case with most manufactured goods, increasing volumes of robots should decrease the unit cost of production. Advances in the robots are continually being made as physicians and industries collaborate. A second generation da Vinci® robot was announced in January of 2006. It has the same core technology as the current system but with a faster set up, rapid instrument exchange, multi-quadrant access and multi-image display capabilities. Finally, the possibility of providing expert surgical care to traditionally rural and underserved communities may one day be realized with telerobotic surgery. There has been a successful remote robotic assisted laparoscopic cholecystectomy performed on a patient in Germany while the surgeons were located 14,000 km away in New York<sup>25</sup>.

Robotically-assisted surgery is established and will likely play an increasingly large role in the future of surgical practice. The technology of robotic assistance has overcome the limitations of conventional laparoscopy, thus securing its utility in microsurgical procedures. These advantages include improved surgical precision, better visualization, and more intuitive/ergonomic instrument control thus leading to faster surgical learning curves for surgeons. Anesthesiologists must be aware of these changes and adjust their practice in order to provide safe patient care.

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