

## ■ INTRODUCTION

On July 11, 2000, the Food and Drug Administration (FDA) approved the first completely robotic surgery device, the da Vinci surgical system from Intuitive Surgical (Mountain View, CA). The system enables surgeons to remove gallbladders and perform other general surgical procedures while seated at a computer console and three-dimensional (3D) video imaging system across the room from the patient. The surgeons operate controls with their hands and fingers to direct a robotically controlled laparoscope (**Fig. 1**).

This system and other robotic devices developed or under development by companies such as Computer Motion (Santa Barbara, CA) and Integrated Surgical Systems (Davis, CA) have the potential to revolutionize surgery and the operating room. They provide surgeons with the precision and dexterity necessary to perform complex, minimally invasive surgery (MIS) procedures, such as beating-heart single- or double-vessel bypass and neurological, orthopedic, and plastic surgery, among many other future applications. Manufacturers believe that their products will broaden the scope and increase the effectiveness of MIS, improve patient outcomes; and create a safer, more efficient and more cost-effective operating room. It is the vision of these companies that robotic systems will one day be applicable to all surgical specialties, although it is too early to tell the full extent to which they will be used.



**Fig. 1:** Robotic surgery port placement for nephrectomy.

The first generation of surgical robots is already being installed in a number of operating rooms around the world. These are not true autonomous robots that can perform surgical tasks on their own, but they are lending a mechanical helping hand to surgeons. These machines still require a human surgeon to operate them and input instructions. Remote control and voice activation are the methods by which these surgical robots are controlled. Robotics are being introduced to minimal access surgery because they allow for unprecedented control and precision of surgical instruments. So far, these machines have been used to position an endoscope, perform gallbladder surgery, and correct gastroesophageal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery.

Recently, transatlantic surgery between USA and Strasbourg is a revolution in transatlantic minimal access surgery. In this surgery, there was slight delay (66 ms) in transfer of data but in future, this delay can easily minimized. In the future, remote handling technology will overcome the manipulative restriction in the current instruments. There is no doubt 10 years from now that some surgeons will be operating exclusively via a computer interface controlling a master-slave manipulation. *If computer-controlled machinery can mimic the awareness, adaptability, and knowledge of a human surgeon, such a takeover in the operating theater is actually realistic.*

In the operating room of the future, physicians will use tiny high-tech tools to travel inside the body with dexterity and precision beyond imaging. The future of any new technology depends upon the training.

Three surgical robots that have been recently developed are:

1. da Vinci surgical system
2. ZEUS robotic surgical system
3. Automated Endoscopic System for Optimal Positioning (AESOP) robotic system.

The “da Vinci” system has seven degree of freedom movement, so it can perform more complex task. The “da Vinci” system has been used to perform a number of general surgical procedures such as cholecystectomy and fundoplication. Robotic fundoplication allows easier passage around and behind the esophagus during its dissection and

easier mobilization of the curvature of the stomach. Suturing the wrap and the crural approximation are also easier with the help of these robots.

The \$1 million da Vinci system consists of two primary components:

1. A viewing and control console
2. A surgical arm unit (**Figs. 2A to C**).

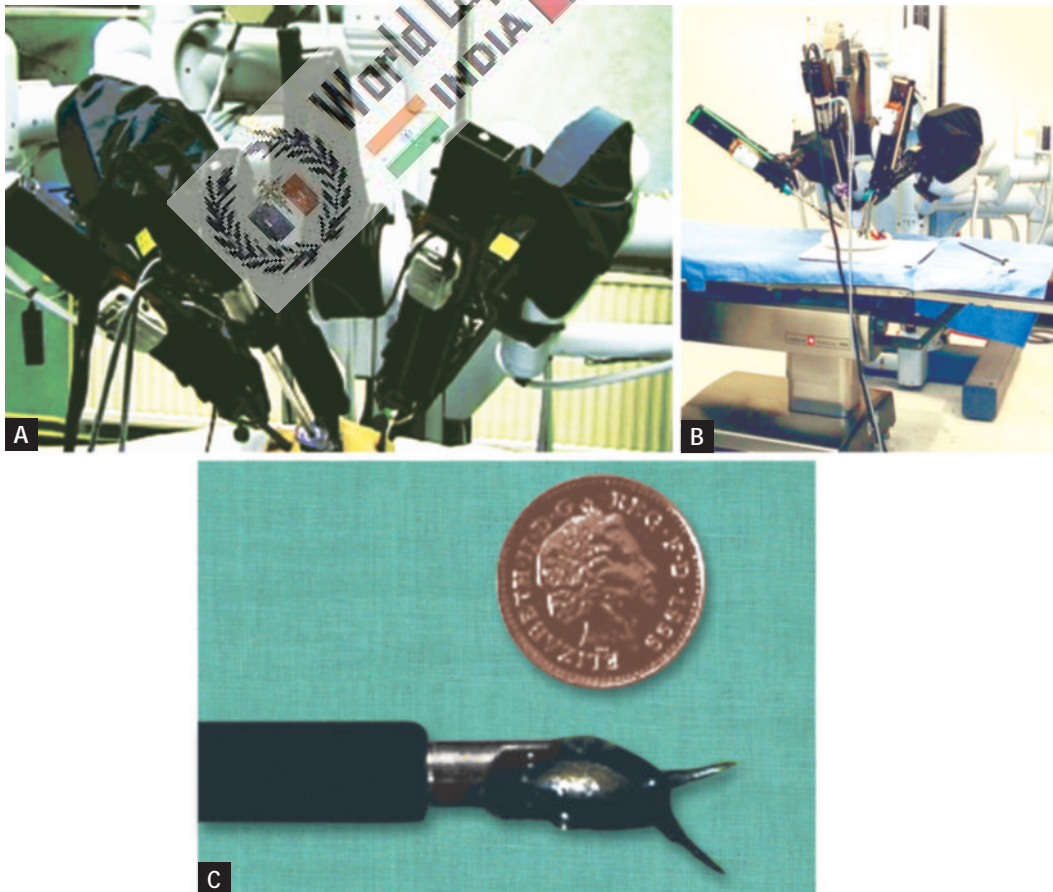
In using da Vinci for gallbladder surgery, three incisions, no larger than the diameter of a pencil, are made in the patient's abdomen, which allows for three stainless-steel rods to be inserted. The rods are held in place by three robotic arms. One of the rods is equipped with a camera, while the other two are fitted with surgical instruments that are able to dissect and suture the tissue of the gallbladder. Unlike in conventional surgery, these instruments are not directly touched by the doctor's hands.

Effect or tips of the da Vinci surgical system incorporate miniature wrists that allow them to mimic any movement made by the surgeon at the control console. Sitting at the control console, a few feet from the operating table, the surgeon looks into a viewfinder to examine the 3D images being sent by the camera inside the patient. The images show the surgical site and the two surgical instruments mounted on the tips of two of the rods. Joystick-like controls, located just underneath the screen, are used by the surgeon to manipulate the surgical instruments. Each time one of the

joysticks is moved, a computer sends an electronic signal to one of the instruments, which moves in synchronization with the movements of the surgeon's hands.

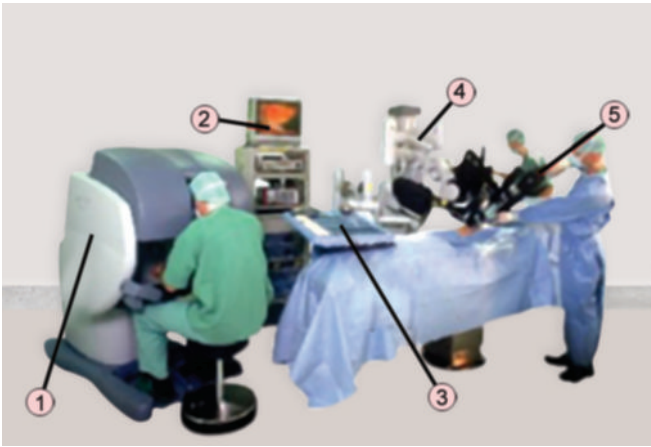
Another robotic system is the ZEUS system, made by Computer Motion, which is already available in Europe. However, both the da Vinci and ZEUS systems must receive governmental approval for each procedure that a surgeon plans to use it for. The \$750,000 ZEUS has a similar setup to that of the da Vinci. It has a computer workstation, a video display, and hand controls that are used to move the table-mounted surgical instruments. While the ZEUS system has not yet been cleared for American use beyond clinical trials, German doctors have already used the system to perform coronary bypass surgery.

The ZEUS system employs the assistance of the AESOP robotic system. Released by Computer Motion in 1994, AESOP was the first robot to be cleared by the FDA for assisting surgery in the operating room. AESOP is much simpler than the da Vinci and ZEUS systems. It is basically just one mechanical arm, used by the physician to position the laparoscope. Foot pedals or voice-activated software allows the surgeon to position the camera, leaving his or her hands free to continue operating on the patient (**Fig. 3**). The use of a computer console to perform operations from a distance opens up the idea of telesurgery, which would involve a doctor performing delicate surgery thousands of



**Figs. 2A to C:** (A and B) Robotic arms of da Vinci surgical system; (C) Effector tips of the da Vinci surgical system.





**Fig. 3:** Robotic surgery. (1) Surgeon console; (2) Image processing equipment; (3) EndoWrist instruments; (4) Surgical arm cart; and (5) High-resolution three-dimensional (3D) endoscope.

miles away from the patient. If it were possible to use the computer console to move the robotic arms in real time, then it would be possible for a doctor in New Delhi to operate on a patient in New York. A major obstacle in telesurgery has been the time delay between the doctor moving his or her hands to the robotic arms responding to those movements. Currently, the doctor must be in the room with the patient for robotic systems to react instantly to the doctor's hand movements.

Having fewer personnel in the operating room and allowing doctors the ability to operate on a patient, long distance could lower the cost of health care. In addition to cost-efficiency, robotic surgery has several other advantages over conventional surgery, including enhanced precision and reduced trauma to the patient. For instance, heart bypass surgery now requires that the patient's chest 30.48 cm long incision. However, with the da Vinci or ZEUS systems, it is possible to operate on the heart by making three small incisions in the chest, each only 10 mm in diameter. The patient would experience less pain and less bleeding, which means a faster recovery.

Robotics also decreases the fatigue that doctors experience during surgeries that can last several hours. Surgeons can become exhausted during those long surgeries and can experience hand tremors as a result. Even the steadiest of human hands cannot match those of a surgical robot. The da Vinci system has been programmed to compensate for tremors, so if the doctor's hand shakes, the computer ignores it and keeps the mechanical arm steady. While surgical robots offer some advantages over the human hand, we are still a long way from the day when autonomous robots will operate on people without human interaction. But, with advances in computer power and artificial intelligence, it could be that in this century a robot will be designed that can locate abnormalities in the human body, analyze them, and operate to correct those abnormalities without any human guidance.



**Fig. 4:** Robotic surgery via master-slave manipulator.

The fallopian tube reconnection procedure, referred to as tubal reanastomosis, was performed by Dr Tommaso Falcone, who is Head of the Reproductive Endocrinology and Infertility Section at the Cleveland Clinic. Dr Falcone used Computer Motion's ZEUS robotic surgical system as part of a clinical trial, approved by the United States FDA.

The patient, a 33-year-old woman, and her healthy 10-day-old son are both in excellent condition and have returned to their Cleveland-area home. The mother had originally undergone a tubal ligation sterilization operation in her 20s. She and her partner later wished to have a child together and began preparing for a reversal operation. The patient saw an advertisement for the ZEUS study and consulted with trial leader Dr Falcone. The lady was informed in detail of the investigational protocol and agreed to have the robotically-assisted procedure.

In addition to the ZEUS System, Computer Motion markets the AESOP 3000, a voice-controlled endoscope positioning system, and the HERMES Control Center, a centralized system, which enables the surgeon to voice control a network of "smart" medical devices. Currently, the ZEUS system is under an FDA-approved investigational device exemption and is also CE marked for commercial sale in Europe.

Robotics 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.

Minimal 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 surgeons capabilities. The goal is to restore the tactile cues and intuitive dexterity of the surgeon, which are diminished by MIS. A slave manipulator, controlled through a spatially consistent and intuitive master with a force feedback system, could replace the tactile sensibilities and restore dexterity (**Fig. 4**).

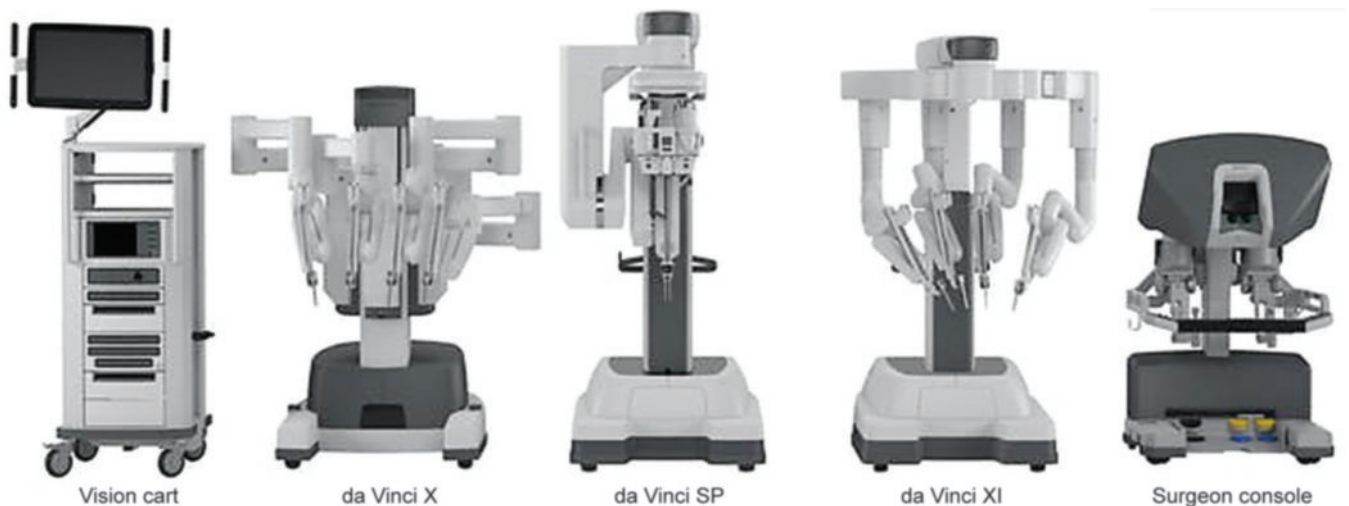


Fig. 5: Master-slave manipulator.



Fig. 6: Robotic console.



Fig. 7: Robotic arm.

Although the potential of robotic surgery is just beginning but progress may come quickly. Laparoscopic gallbladder surgery was first done in 1987, but it became standard within 5 years. Just think about a surgeon! He picks up this black box and waves it over your body and you are fixed. How is that going to happen? One day, a surgeon may use robotic devices to enter the body through its own orifices. They could carry medical instruments inside the body, where they would be manipulated by simple computer commands (Figs. 5 to 7).

The robotic arm after addition of wrists permits the surgeon to mimic his own movements, rather than experience limitations of the rigid long cylindrical laparoscopic instrument and has obvious advantages in terms of dexterity and complexity of instrument (Fig. 8).

## ■ INSTRUMENTS OF ROBOTIC SURGERY

### da Vinci Surgical System (Figs. 9 to 20)

Using the most advanced technology available today, the da Vinci surgical system enables surgeons to perform delicate and complex operations through a few tiny incisions with increased vision, precision, dexterity, and control. The da

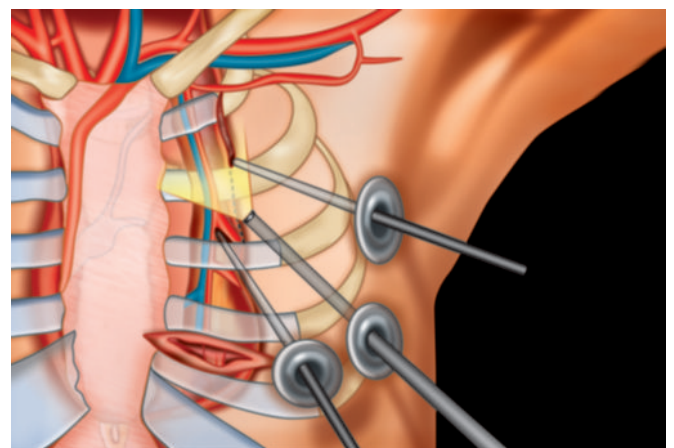


Fig. 8: Ports in cardiac minimal access surgery.

Vinci surgical system consists of several key components, including: an ergonomically designed console where the surgeon sits while operating, a patient-side cart where the patient lays during surgery, four interactive robotic arms, a high-definition 3D vision system, and proprietary EndoWrist instruments.





Fig. 9: da Vinci high-definition surgical robot.



Fig. 10: da Vinci surgeon console.

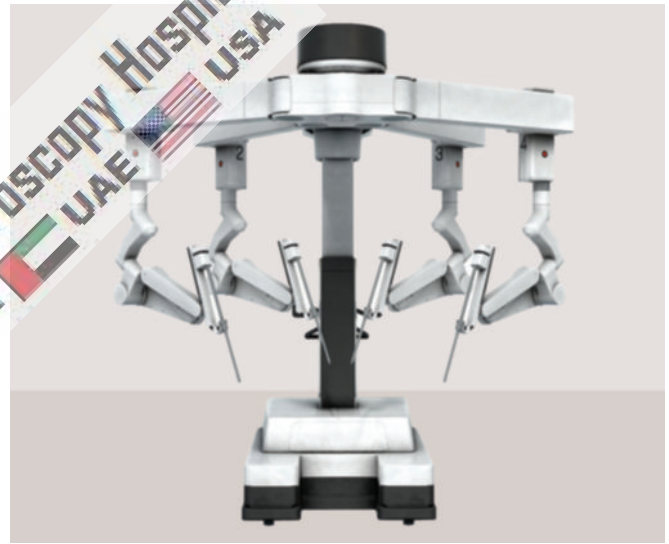


Fig. 11: Patient cart.



Fig. 12: Seven-degree movement is possible.



Fig. 13: da Vinci vision cart.



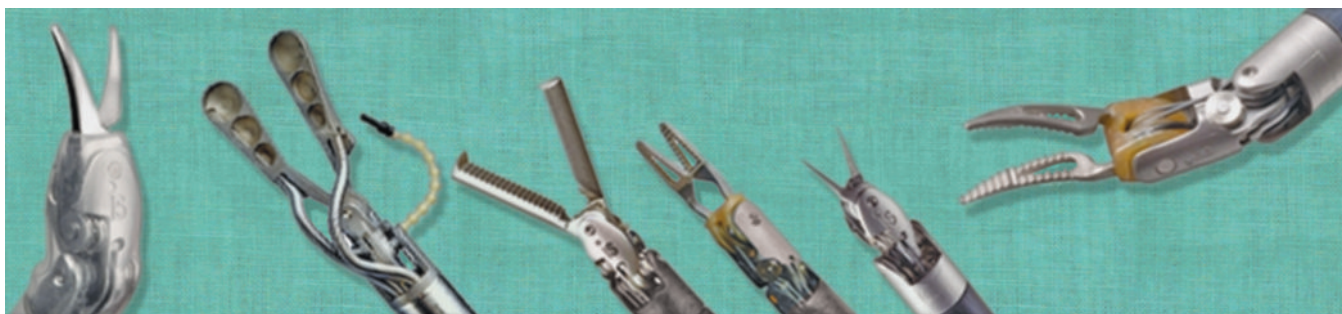
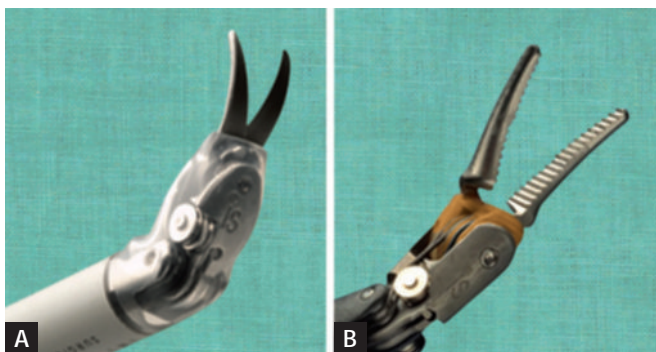
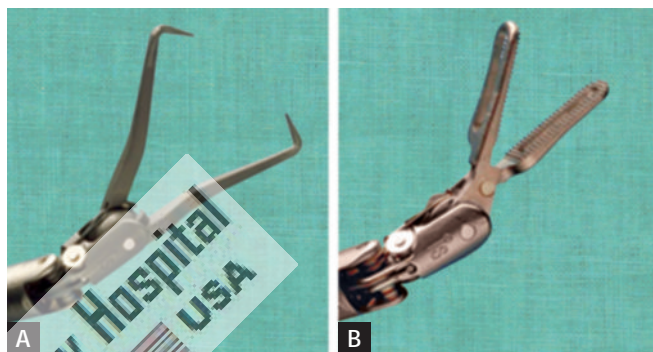


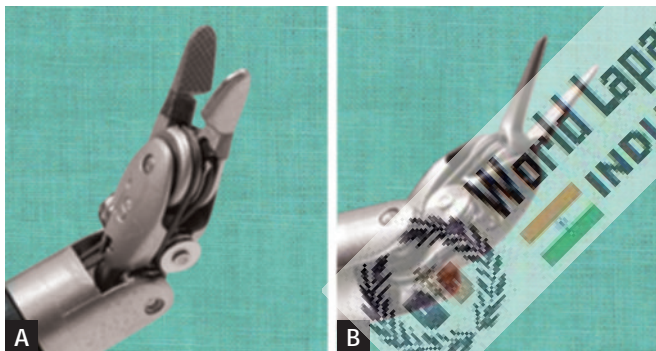
Fig. 14: Robotic EndoWrist instruments.



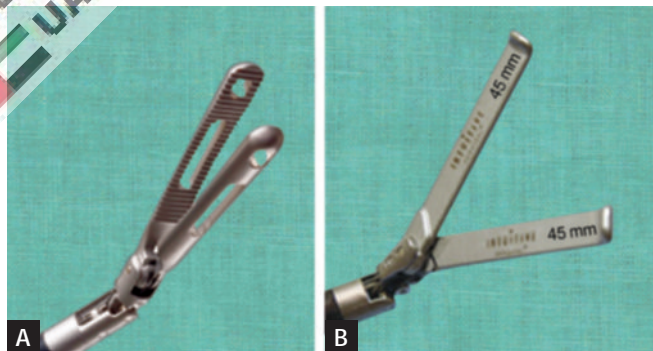
Figs. 15A and B: Robotic scissors and bipolar dissector.



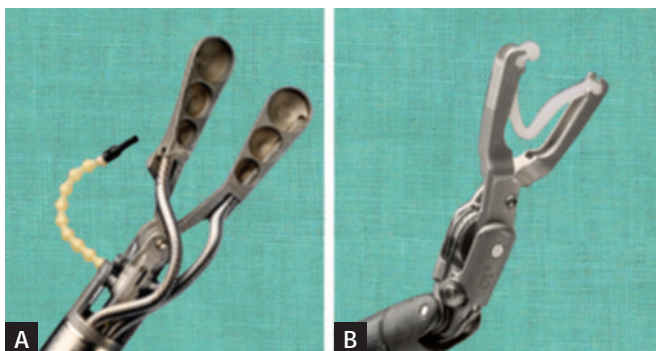
Figs. 16A and B: Robotic tenaculum and grasper.



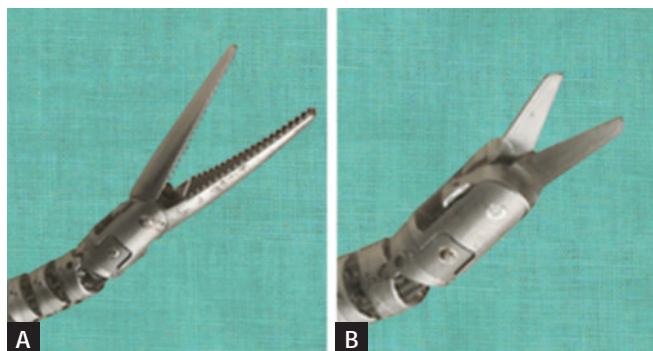
Figs. 17A and B: Robotic needle holder.



Figs. 18A and B: Robotic atraumatic grasper.



Figs. 19A and B: Robotic clip applicator.



Figs. 20A and B: Robotic scissor and Maryland.

da Vinci is powered by state-of-the-art robotic technology that allows the surgeon's hand movements to be scaled, filtered, and translated into precise movements of the EndoWrist instruments working inside the patient's body.

### Core Technology

- System components
- Three-dimensional high-definition (HD) vision.

## Instrumentation

Using the da Vinci surgical system, the surgeon operates seated comfortably at a console while viewing an HD, 3D image inside the patient's body.

- The surgeon's fingers grasp the master controls below the display with hands and wrists naturally positioned relative to his or her eyes
- The system seamlessly translates the surgeon's hand, wrist, and finger movements into precise, real-time movements of surgical instruments
- The patient-side cart is where the patient is positioned during surgery. It includes either three or four robotic arms that carry out the surgeon's commands
- The robotic arms move around fixed pivot points, which reduce trauma to the patient, improve the cosmetic outcome, and increase overall precision
- The system requires that every surgical maneuver be under the direct control of the surgeon. Repeated safety checks prevent any independent movement of the instruments or robotic arms
- A full range of EndoWrist instruments is available to the surgeon while operating
- The instruments are designed with seven degrees of motion—a range of motion even greater than the human wrist
- Each instrument has a specific surgical mission such as clamping, suturing, and tissue manipulation
- Quick-release levers speed instrument changes during surgery
- The vision system is equipped with an HD, 3D endoscope (flexible tube with a camera and light at the tip) and image processing equipment that provides true-to-life images of the patient's anatomy
- A view of the operating field is available to the entire operative room (OR) team on a large viewing monitor (vision cart). This widescreen view provides the surgical assistant at the patient's side with a broader perspective and visualization of the procedure.

## ■ INSTRUMENTS AND ACCESSORIES

Intuitive surgical's exclusive EndoWrist instruments are designed to provide surgeons with natural dexterity and full range of motion for precise operation through tiny incisions. Modeled after the human wrist, EndoWrist instruments can offer an even greater range of motion than the human hand. They truly allow the da Vinci® system to take surgical precision and technique beyond the limits of the human hand. Similar to human tendons, an EndoWrist instrument's internal cables provide maximum responsiveness, allowing rapid and precise suturing, dissection, and tissue manipulation. EndoWrist instruments provide enhanced dexterity, precision, and control:

- 7° of freedom
- 90° of articulation

- Intuitive motion and finger-tip control
- Motion scaling and tremor reduction.

The wrist-like movement, responsiveness, and robotic control afforded by the da Vinci system and its exclusive EndoWrist instruments provide surgeons fluid ambidexterity and unparalleled precision. The EndoWrist instruments are available in a wide selection of specialized tip designs to enable a broad range of da Vinci procedures. As da Vinci surgery is adopted in new specialties, our engineers work side-by-side with surgeons to develop new EndoWrist instruments to address new clinical needs. The following is a list of instrument categories for which intuitive offers specialized tip designs.

Energy instruments are used by the da Vinci surgeon to provide coagulation, cutting, and dissection of tissues. These include monopolar and bipolar cautery instruments (electrical energy), the *Harmonic™* ACE (mechanical energy), the *PK™* dissecting forceps (advanced bipolar), and laser.

Grasping instruments allow for manipulation of a wide range of tissues, from fine, thin tissues such as peritoneum to dense, fibrous tissues such as uterus. Needle drivers provide the ability to suture with the finest of needles used in cardiovascular surgery as well as the thickest needles used in repair of uterine defects. *Suture Cut™* needle drivers include an integral cutting blade for efficient cutting of suture after knot tying and increased surgeon autonomy and efficiency.

Retracting instruments allow the surgeon to dynamically provide exposure of the surgical field. This minimizes dependency on the patient-side assistant, providing the da Vinci surgeon with full control of the operative field.

Clip applicators, probe graspers, and cardiac stabilizers are available to allow the da Vinci surgeon to perform specialized procedures such as vessel clipping, cryoablation, and beating-heart surgery.

A selection of 5 mm EndoWrist instruments provides the surgeon with the ability to use smaller access ports. Some surgeons prefer smaller access ports when performing pediatric, thoracic, bariatric, gynecologic, and general surgery.

## ■ OPERATING ROOM CONFIGURATION, PORT PLACEMENT, AND DOCKING

Before any procedure, the robot has to be prepared for surgery. It includes the connection of all necessary parts such as sterile drapes and connectors needed for surgery and the calibration process. These steps are conducted by a core team of scrub nurses specifically trained in handling the robot while the patient is in preparation for surgery. Currently, the only available system for laparoscopic surgery is the da Vinci surgical system, developed by Intuitive Surgical (Sunnyvale, CA, USA).

Any robotic procedure is performed by a team of surgeons and nurses. It includes the console surgeon, patient-side



assistant surgeon, and the scrub nurse. Although console surgeon is the leader of the team, a trained assistant surgeon is of paramount importance as he/she is the person responsible for robot docking, instrument change, manipulation of laparoscopic instruments, application of hemostatic instruments/clips, lavage and aspiration, specimen extraction, drainage, and closure of abdominal wall. A trained scrub nurse is also important in draping the robotic arms, attaching the optics, instrument changes, and undocking of the robot.

## Operating Room Configuration

This topic includes the optimum positioning of the following components in the operating room (OR) so as to allow for maximum functionality:

- Surgeon console positioning
- Patient cart positioning
- Vision cart positioning.

### Surgeon Console Positioning

The surgeon console is placed outside of the sterile field. It should be oriented in such a position so that the surgeon has a clear view of the operative field, vision cart, and able to communicate directly with the assistant surgeon and the scrub nurse.

For moving or positioning the surgeon console, only the handle (**Fig. 21**) on the back of the console is used. It should never be pushed or pulled by the console body or armrest to maneuver the console into place. Wheel locks located on the rear wheels of the surgeon console should be locked after positioning of console for the surgery.

### Patient Cart Positioning

The patient cart is placed in the sterile field. It should be draped in a separate area in the room prior to moving it into place for surgery. This should be an area of the room where

it will not easily come into contact with nonsterile objects or impede traffic. Once the patient cart is draped and the patient is positioned, prepared, and draped, ports are placed. Then, use the patient cart motor drive to help move the cart into the sterile field.

The patient cart brakes are designed to automatically engage when the motor drive is not in use.

**Motor drive operation:** The motor drive interface consists of the following components (**Fig. 22**):

- Throttle
- Throttle enable switch
- Shift switches.

To operate the motor drive:

- Ensure that the patient cart is powered on
  - Ensure the shift switches are in the drive position (**Figs. 23A and B**)
  - Throttle enable switch is to be held and throttle rotated away from the operator or toward him/her depending on the intended direction of movement
    - The cart power light-emitting diode (LED) will flash green whenever the throttle enable switch is activated
- The drive speed of the cart can be controlled by rotating the throttle to different extent in each direction.

The motor drive will not engage whenever cannulas or instruments are installed on the system. A yellow LED on motor drive interface labeled “cannula installed: cart drive disabled” will indicate when cannulas or instruments are installed and motor drive is nonoperational. This has been done for safety purpose.

**Shift switches:** The patient cart can be moved without the use of the motor drive (for example, during a power loss) by rotating the shift switches (**Fig. 23B**) to the neutral (N) position. The cart can then be moved manually. When the cart has been moved, shift switches should be placed in the drive (D) position to set the patient cart brakes.

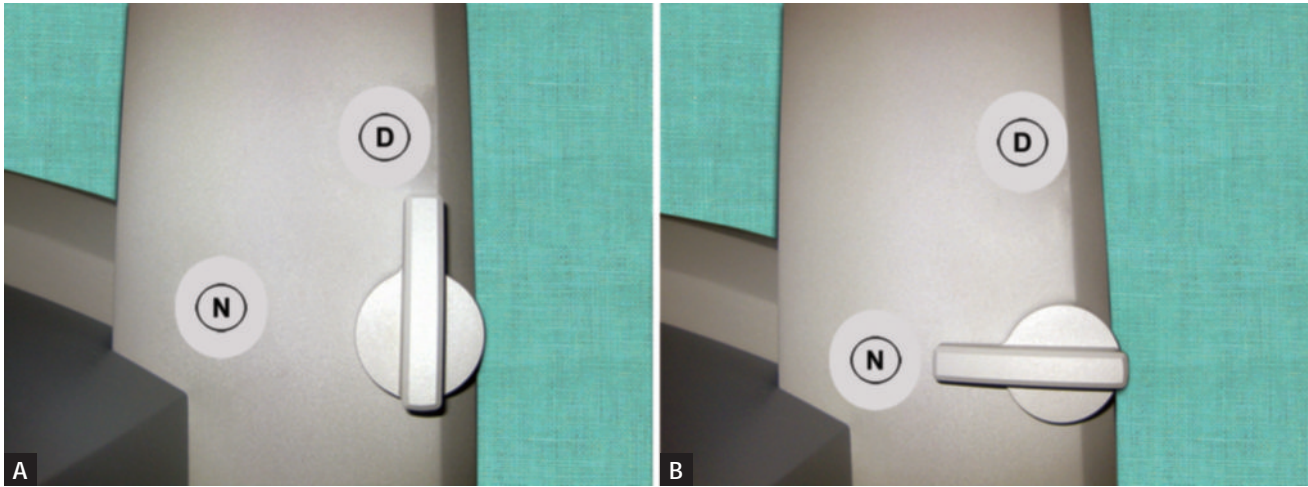


Fig. 21: Surgeon console handle.



Fig. 22: Location of throttle, throttle enable switch, and shift switches.





**Figs. 23A and B:** (A) Drive motor engaged; (B) Drive motor disengaged.  
(D: drive; N: neutral)



**Fig. 24:** Position of vision cart.

For patient safety, the shift switches must be kept in the drive (D) position so that the motor drive remains engaged during surgery (**Fig. 23A**).

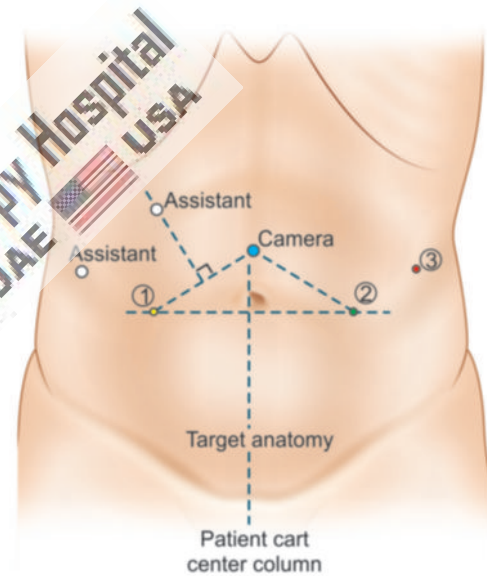
### Vision Cart Positioning

The vision cart is placed adjacent to the patient cart, just outside of the sterile field, to allow the patient cart operator to see the component displays (**Fig. 24**).

- The vision cart should be close enough to the patient cart to allow unrestricted camera cable movement during surgery
- Wheel locks are located on the rear wheels of the vision cart. These should be locked after the cart is positioned for surgery.

### Steps of docking:

- Position patient and OR table, including table tilt
- Position patient cart over patient
- Set patient cart brakes
- Docking the camera arm
- Docking the instrument arms
- Check system setup.



**Fig. 25:** Camera port positioning.

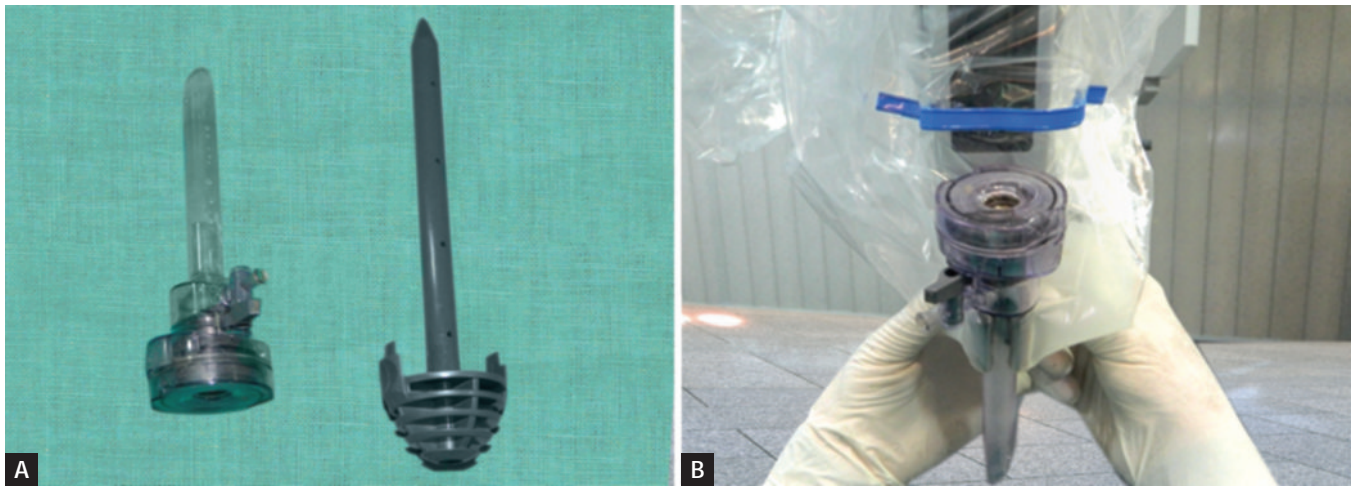
The patient table should be positioned according to surgeon preference (depending on the contemplated procedure) before docking the robotic arms. Once the arms are docked to the ports and instruments are placed, patient position should not be changed. The pneumoperitoneum is created and the ports are inserted by either the lead surgeon or the patient-side assistant surgeon.

### Port Placement

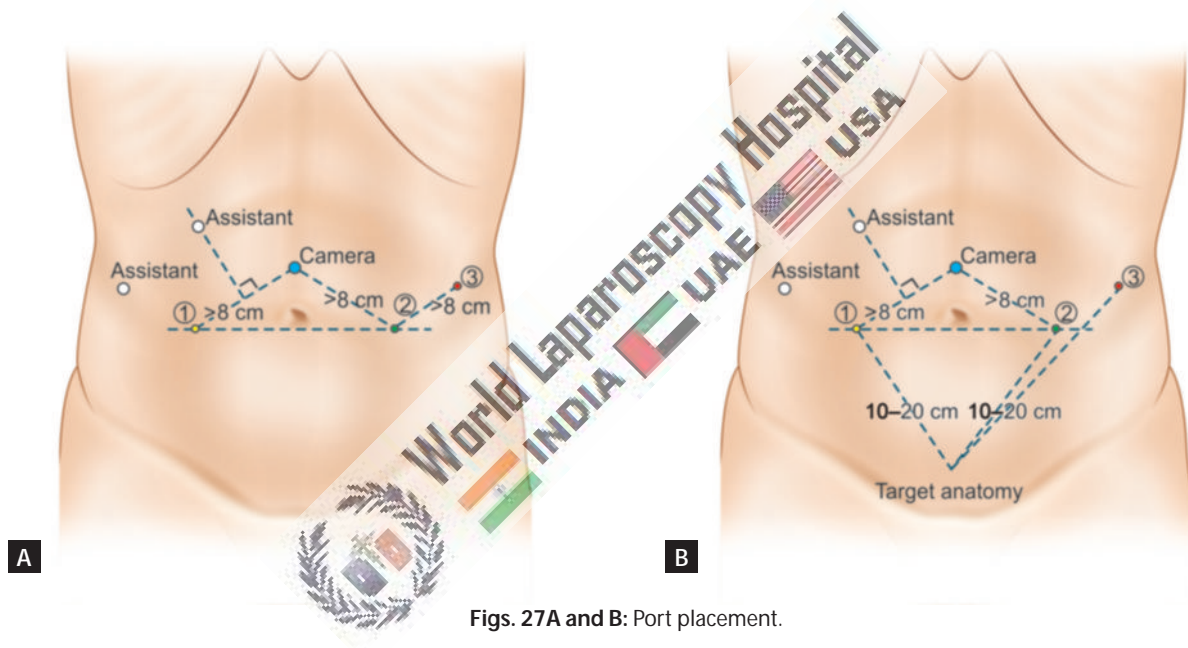
The port positions vary from patient-to-patient, procedure-to-procedure, and surgeon-to-surgeon. It is very difficult to form guidelines-specific position of ports, but broad guidelines are framed to maximize endoscopic view, instrument reach, and to minimize external arm clashing.

Camera port is inserted keeping following principles in mind (**Fig. 25**):

- Should be in line with the target anatomy (TA)
- Should be 10-20 cm distance from the TA



Figs. 26A and B: (A) Disposable 12 mm trocar cannula assembly for camera port; (B) Camera port being mounted on the camera arm.



Figs. 27A and B: Port placement.

- Should be in line with the center column of the patient cart. A diagnostic laparoscopy is done after insertion of the camera port to look for safe entry, any adhesions, and surgical feasibility.

A disposable 12 mm trocar cannula assembly is used as the camera port (Figs. 26A and B). There are specialized camera arm cannula mounts (on the patient cart camera arm) corresponding to each validated third-party cannula.

### Working Ports

An 8 mm da Vinci ports are inserted for robotic arms that are inserted keeping in mind the following principles:

- >8 cm distance between the da Vinci ports (Fig. 27A)
- 10–20 cm distance should be maintained between the da Vinci ports and TA (Fig. 27B).

A 10 cm distance from TA is good but 20 cm distance is better. Ports placed closed to the TA impede the view of the

surgical site and make the operation technically challenging. Conversely, ports placed >20 cm from TA make it difficult to see or reach with robotic instruments.

Assistant port, if needed, is inserted 5–10 cm away from the da Vinci ports in the desirable position. 5 or 10 mm ports can be used according to the intended function of the port.

The da Vinci provides 8 mm reusable cannulas with disposable seals for the robotic arms. They come with bladeless obturator for insertion.

These come in two lengths (Fig. 28):

- Short (11 cm cannula)
- Long (16 cm cannula) for high body mass index (BMI) patients.

### Remote Center Technology

Remote center is the fixed point in the space around which surgical arm and cannula move. It helps in maneuvering



instruments/endoscopes in surgical site while exerting minimal force on the abdominal or thoracic wall (**Figs. 29A and B**).

It is marked on the da Vinci cannulas at a point to minimize stress to the patient. Remote center can be adjusted on patient side at the patient cart using the clutch button.

### Positioning the Patient Cart

Once the patient is positioned and the ports are inserted, it is time to attach patient cart instrument arms to the patient in a process called docking. Before moving patient cart into position over the patient, it is important to align the OR table and the patient. Then, push the patient cart over the patient using the motor drive on the cart.

Motor drive can be used in integrated mode when patient cart is connected to the rest of the system or in standalone mode as well. The *shift switches* on the base of the patient cart need to be set in drive (D) position (**Fig. 30**). Then, the

cart can be moved by pressing the *throttle enable switch* and throttling either forward or backward (**Fig. 31**). It can be moved manually if the shift switch is set in neutral (N) position.

Two people should be used to move the cart, one pushes or pulls the cart and the second person verbally directs regarding the direction of movement. When the cart is in position, shift switch should be set to drive position for locking the cart. Installing the camera or instrument arm locks the patient cart automatically for patient safety.

Care should be taken to align the camera port, TA, and the center column (**Fig. 32**).

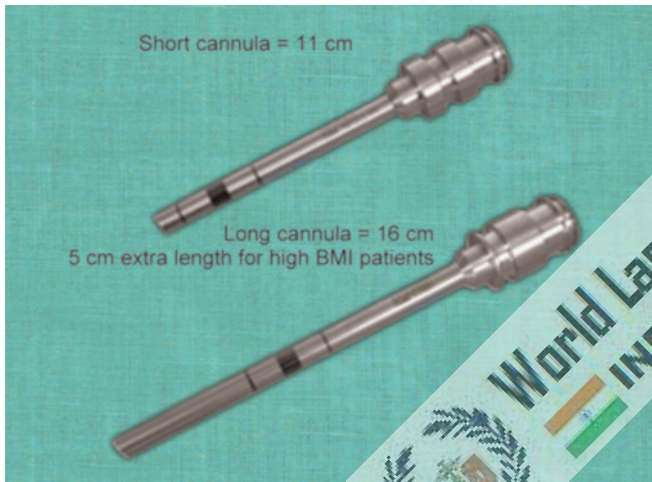
### Docking the Camera Arm

Camera arm should be docked first after positioning the patient cart. Align the camera port, TA, and the center column of the patient cart. Use clutch button to change the angle of camera arm to match the angle of cannula so that it points to TA (**Fig. 33**).

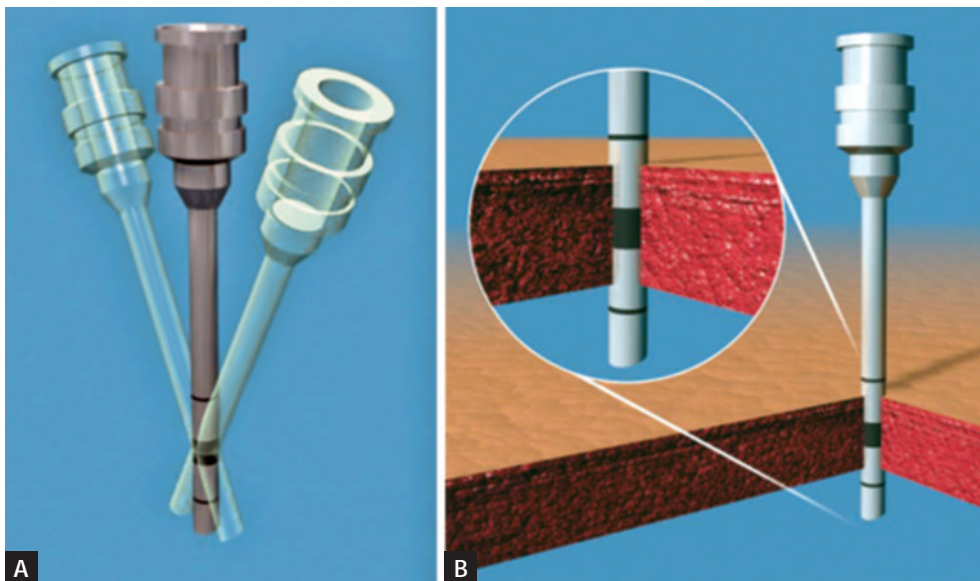
Stabilize the cannula at the port site with one hand pointing it toward the TA. Bring cannula into the cannula mount on the camera arm and clip both wings shut to hold the cannula in place (**Fig. 34**).

Camera arm setup joint #2 is placed opposite the instrument arm 3 (**Fig. 35**). Setup joints are numbered starting from the joint closest to the center column. Setting the system in this position allows maximum range of motion for all instrument arms.

There is a thick blue line and a blue arrow on setup joint #2 on the camera arm indicating the *sweet spot* (**Fig. 36**). Sweet spot should be aligned by lining up the blue arrow within the boundaries of blue line. Setting sweet spot gives patient cart arms maximum range of motion ensuring instrument and endoscope reach of all parts of TA.



**Fig. 28:** The da Vinci cannula (BMI: body mass index).



**Figs. 29A and B:** Remote center technology.

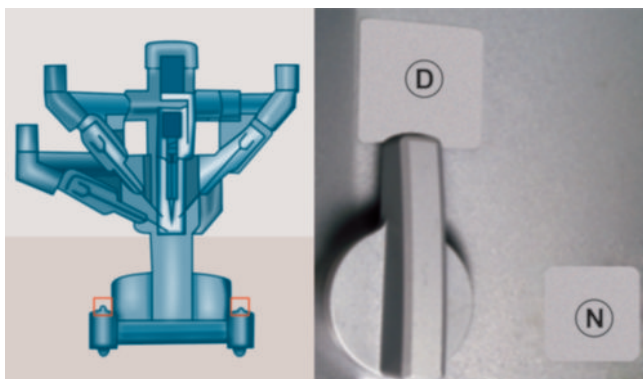


Fig. 30: Shift switch.



Fig. 31: Throttle with throttle enable switch.

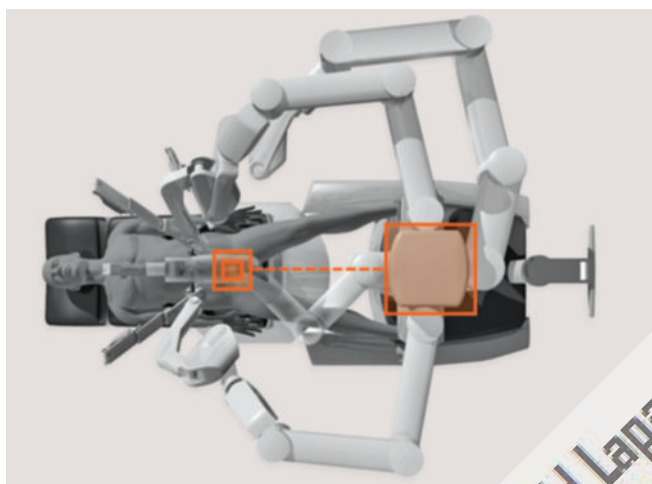


Fig. 32: Alignment of camera arm, target anatomy and center column of patient cart.

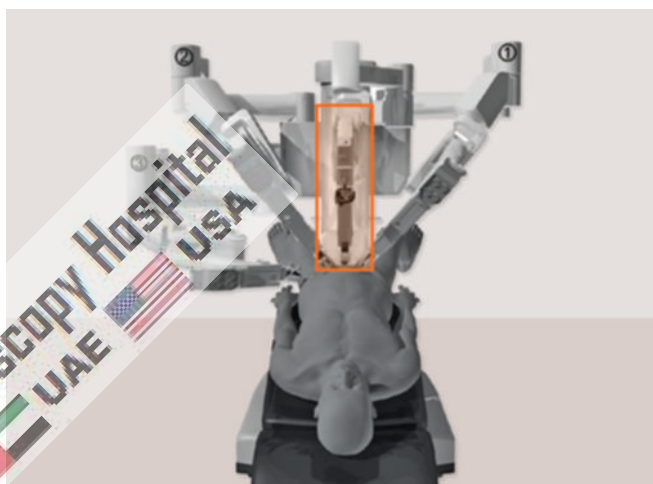


Fig. 33: Docking the camera arm.



Fig. 34: Mounting cannula to camera arm.



Fig. 35: Camera arm setup joint #2 facing opposite instrument arm 3 (arrow).

Remember that overextending or not extending the camera arm enough will limit the instrument range of motion.

Align the camera arm clutch button, third setup joint, and the center column (**Fig. 37**). Strive to maintain the sweet spot and alignment of the camera arm throughout the docking process.

### Docking of Instrument Arms

After docking the camera arm, instrument arms are positioned in place so as to allow maximum range of motion of the arms. It is done in following steps:

- Position the instrument arm with the arm number and sterile adaptor facing forward (**Fig. 38**)



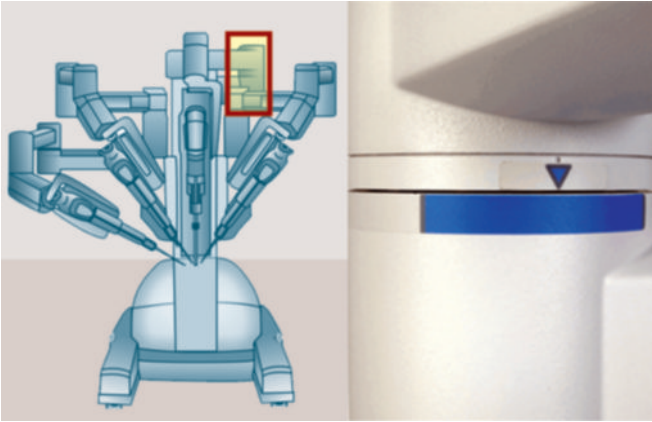


Fig. 36: Sweet spot and its alignment.

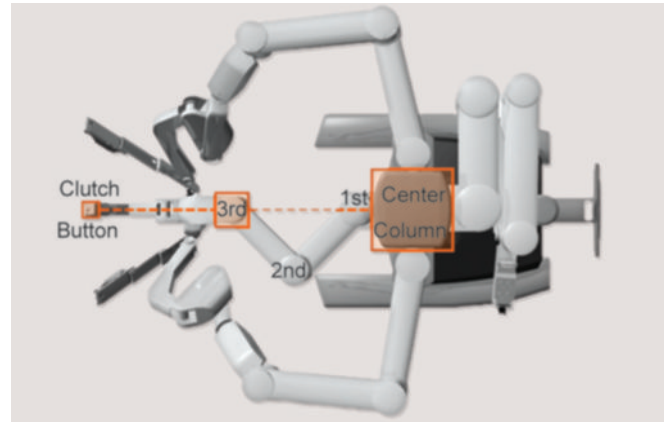


Fig. 37: Alignment of camera arm clutch button, third setup joint, and the center column.



Fig. 38: Positioning of instrument arm.

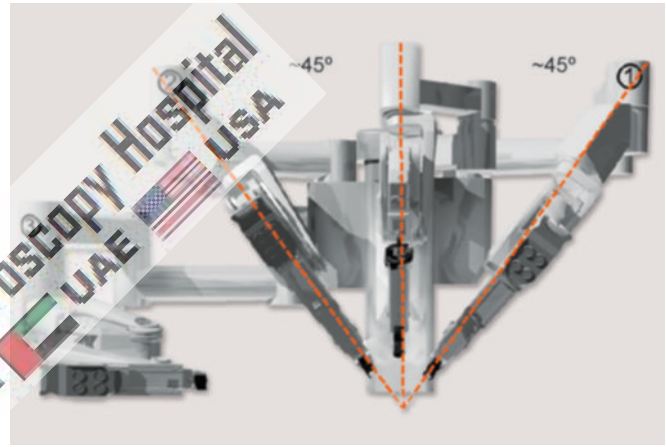


Fig. 39: Alignment of instrument arms with respect to camera arm and each other.

- Allow approximately 45° angle between each arm (**Fig. 39**). Note that the position of instrument arm 3 can vary according to patient body habitus and the procedure. After positioning, ensure that the arms will not collide with the patient or interfere with each other
- Dock the instrument arms by bringing them to the cannula using the port clutch button. Bring the instrument arm to the cannula and lock the wings of the quick click cannula mount on the arm to clip the arm to the cannula (**Fig. 40**).

Confirm that the remote center of the port is present at the desired place in the abdominal wall. Remember to stabilize the cannula with one hand at the port site while docking the instrument arm.

### Check System Setup

After docking the instrument arms, check the arm setup. Start by confirming that the sweet spot of the camera arm is in right position (i.e., arrow is pointing toward the thick blue line). If needed, move the arm back into position taking care to stabilize the cannula at the port site.

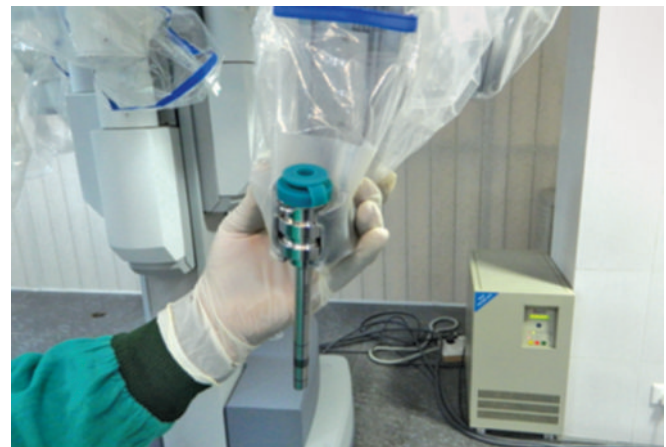


Fig. 40: Example of mounting instrument arm onto the cannula.

Next, check the alignment of the camera port, TA, and the center column of the patient cart.

Now check the instrument arm setup. Separate the instrument arms to maximize the range of motion (**Fig. 41**). Check the setup joint angles to minimize potential collisions.

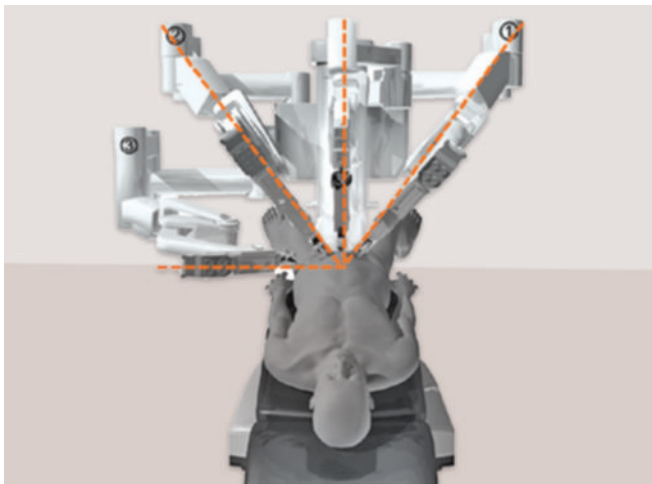


Fig. 41: Relative positions of the instrument arms.

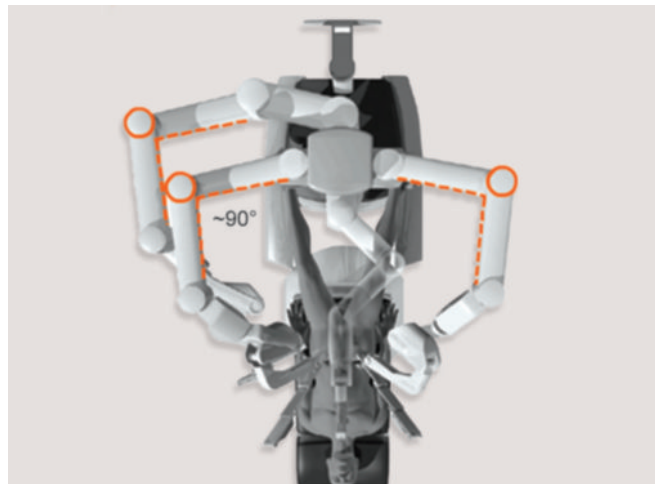


Fig. 42: Right angle at setup joint #2.

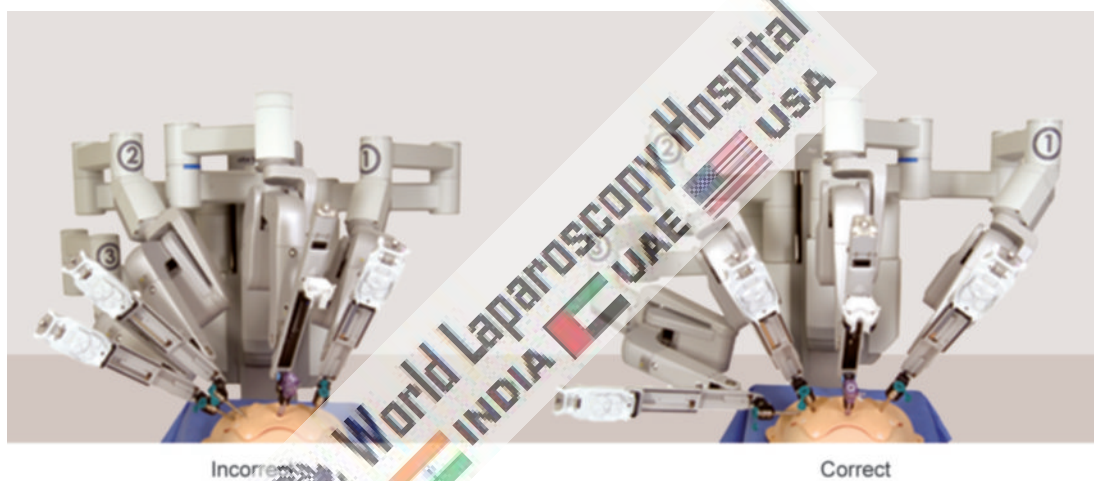


Fig. 43: Depiction of the correct method of docking of patient cart.

The angle at the setup joint #2 should be approximately  $90^\circ$  (Fig. 42). Figure 43 depicts the correct method of docking the patient cart.

### Endoscope Insertion and Removal

First, insert the endoscope into the cannula keeping the intuitive logo on the camera head facing the camera arm. Place the body of the endoscope into the camera arm sterile adaptor making sure that the body of endoscope is fully connected (Fig. 44). Give it a gentle turn to ensure it is locked in place.

Next, secure the camera cable using the camera cable clip and drape the cable across the instrument arm (Fig. 45).

Push the endoscope into the cannula by pressing the camera arm clutch button till it is past the cannula tip toward the TA. Press the clutch button again to lock the camera assembly into place.

To remove the endoscope, remove the camera cables from the clip on the camera arm. Then, unlock the endoscope



Fig. 44: Endoscope insertion into camera arm sterile adaptor of the camera arm.

by opening the two latches on the camera arm sterile adaptor. Then, remove the endoscope.





Fig. 45: Camera cable clip highlighted.

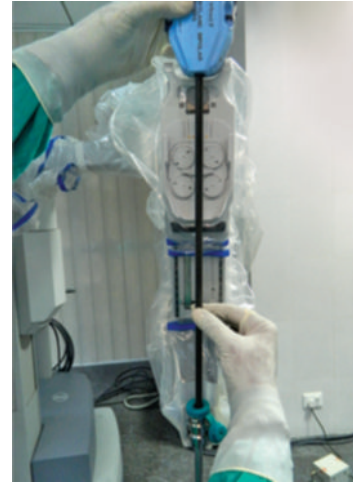


Fig. 46: Inserting the instrument into the cannula.



Fig. 47: Sliding the instrument into sterile adaptor on the instrument arm.



Fig. 48: Light-emitting diode (LED) turning blue indicating proper insertion.

## Instrument Insertion

Begin by straightening the instrument tip. Insert the instrument into the cannula (**Fig. 46**). Slide the instrument housing into the sterile adaptor (**Fig. 47**) sandwiching the instrument housing and the instrument arm between both hands. Press the arm clutch button and push the instrument into the surgical field, keeping the tip under endoscopic vision.

If there is any resistance while inserting the instrument, one should stop and check for the reason. When the LED lights turn blue (**Fig. 48**), the surgeon can take control of the instrument and start operating.

## Instrument Removal and Guided Tool Change

For removing the instruments, surgeon should straighten the instrument tip and open the jaws of the instrument to ensure that it does not hold any tissue (**Fig. 49**). Then, press the release levers on the instrument housing and simply pull off the instrument (**Fig. 50**).

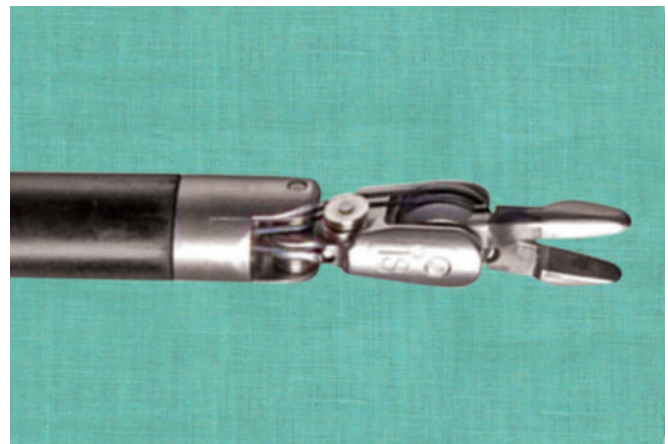


Fig. 49: Straightening the instrument tip and opening of jaws of the instrument before removal.

Removal of the instrument should be done with utmost care and with complete knowledge of the operating surgeon, so as to prevent any inadvertent injury to the tissues.

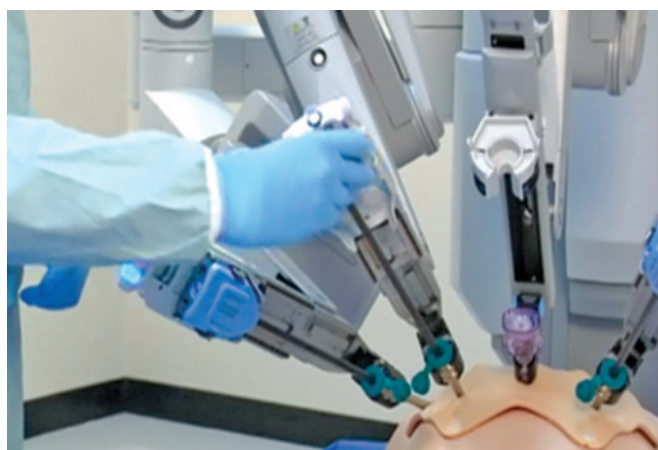


Fig. 50: Pressing the levers to remove the instrument.



Fig. 51: Light-emitting diode (LED) blinking alternately white and green indicating activation of guided tool change.

### Guided Tool Change

This feature helps in aligning a new instrument in the same position as the previous one removed. It adapts the replaced instrument tip just short of the position of previously placed instrument tip.

When this feature is activated, the LEDs on the instrument arm alternately blink white and green (Fig. 51). Just push the instrument with one finger (Fig. 52) and guided tool change (GTC) will guide it into correct position. Stop as soon as you encounter any resistance.

This function is disabled when there is a change in the position of instrument arm during changing the instrument. This is because the position memory of the instrument arm is reset when the position is changed.

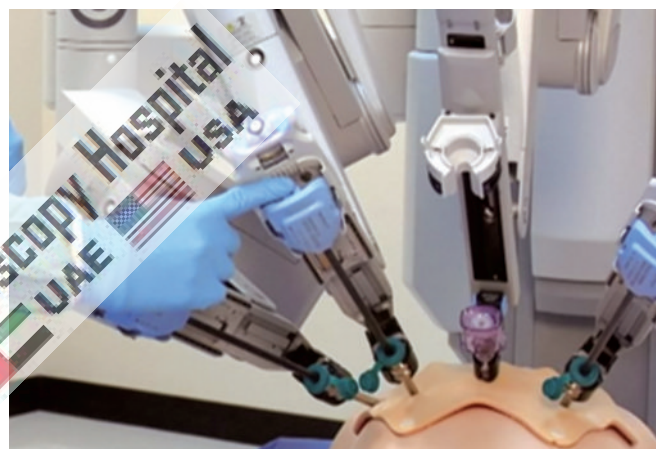


Fig. 52: Pushing the instrument with one finger.

## ROBOTIC CHOLECYSTECTOMY

### Introduction

In general surgery, advanced robotics will likely find its place in the most complex laparoscopic procedures where the enhanced dexterity and superior visualization will extend the feasibility of the minimally invasive approach, particularly in patients requiring advanced suturing and precise tissue dissection. Robot-assisted laparoscopic cholecystectomy is a safe and effective bridge to advanced robotics in general surgery.

Laparoscopic cholecystectomy is a prime operation with which to begin robot applications for several reasons. First, gallstone disease is the most common of all abdominal diseases for which patients undergo a laparoscopic procedure. Moreover, it is an operation with a very standardized approach to prevent complications. This standardized approach has an added advantage of having aspects that may be more broadly applied to other more complex minimally invasive operations. For example, the dissection of the Calot's triangle is analogous to dissection and isolation of vasculature, the cystic duct and artery can

be tied instead of using clips, and removal of the gallbladder from the gallbladder fossa requires a vascular dissection and the appreciation of tissue planes. Therefore, robotic cholecystectomy may allow general surgeons to acquire clinical da Vinci experience in a familiar setting.

### Segments of Robotic Cholecystectomy

#### Segment Operative Tasks

- Skin incision, port placement, exploration, adhesiolysis, patient positioning, and robotic arm draping
- Positioning of da Vinci, docking of robot arms, and camera
- Initial dissection of gallbladder until placement into endoscopic bag
- Gallbladder extraction, performance of additional procedures, and incision closure.

### Preoperative Preparation

Indications and preoperative preparation are similar to conventional laparoscopic procedure. An informed consent is to be taken from the patient explaining the new technology



and its possible complications. A prophylactic dose of intravenous antibiotic is given just prior to commencement of surgery.

An orogastric or nasogastric tube is placed prior to creation of pneumoperitoneum to decompress stomach. Sequential compression devices are placed on legs for deep vein thrombosis (DVT) prophylaxis. Footboard is placed to keep patient from sliding off table. A seat belt is tied at midhigh region.

### Patient Position

Patient is placed in a supine position and right arm is tucked by the side of the patient. Standard surgical preparation is done from nipple line to thigh. A standard protection bar over the patient's head may easily block the robotic arms, giving protection to the head. Convex protection shields or bars that protect the patient's nose and the ventilation tube are good protection for robotic-assisted surgical interventions.

Pneumoperitoneum is created with closed (Veress needle) or open technique. A 12-mm camera port is inserted at the umbilicus, which should be around 20 cm away from the TA (cystic pedicle). A diagnostic laparoscopy is done. Then, a mild left tilt of the table is done with reverse Trendelenburg position.

### Port Position (Fig. 53)

Three 8 mm da Vinci ports are inserted at least 10 cm apart for the robotic arm placement. The remote centers of the ports are placed at the level of abdominal wall.

- **Robotic arm 1:** Left midclavicular line, below the subcostal margin

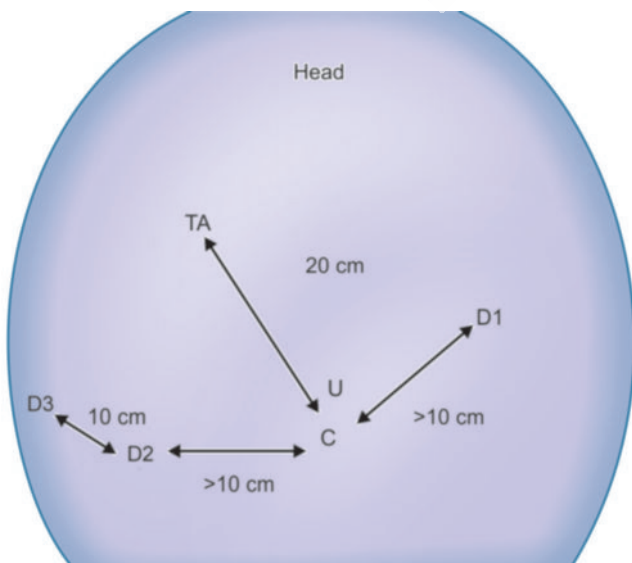


Fig. 53: Port positioning.  
(TA: target anatomy)

- **Robotic arm 2:** Right midclavicular line, 5–10 cm below the subcostal margin
- **Robotic arm 3:** 10 cm below and lateral to robotic arm 2 (optional, some surgeons use a 5/12 mm assistant port rather than a robotic arm as the third port).

### Docking and Operating Room Setup

The arms are draped with disposable sterile drapes. The patient cart is brought over the patient's right shoulder (Fig. 54). This implies that the robot is located behind the operating field and that the robotic arms cross this area and seem to work in a backward direction. The center column of the robotic cart acts as the vertical central axis of the robot. This column should be positioned at the far end of an axis running from the umbilicus through the hilar region of the liver.

The patient table should be tilted according to the surgeon's choice before docking. Align the "sweet spot" for proper camera arm positioning. Align the clutch button, third setup joint, and the center column. Allow 45° angle between each arm. Dock the camera arm and other arms to the respective ports. Camera and the instruments are placed in the ports.

The operating room setup is shown in Figure 55.

### Operative Technique

#### Step 1 (Diagnostic Laparoscopy and Port Position)

Patient is kept in supine position. Parts cleaned and draped from nipple line to midhigh. Pneumoperitoneum is created with Veress needle at umbilical position. A 12-mm camera port is inserted at the umbilicus using Optiview cannula (Fig. 56).

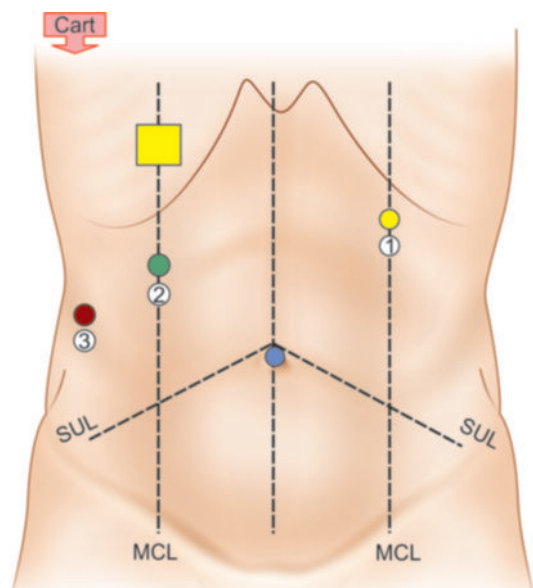


Fig. 54: Position of patient cart and ports.  
(MCL: midclavicular line; SUL: spinoumbilical line)

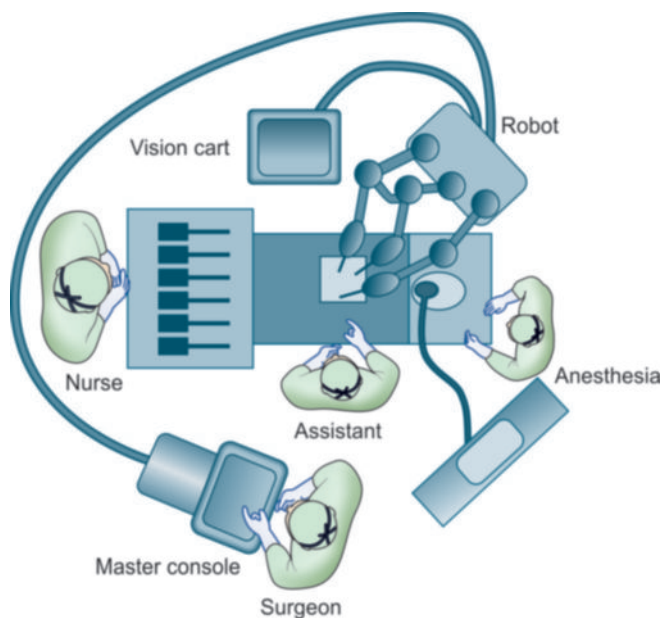


Fig. 55: Operating room setup for cholecystectomy.

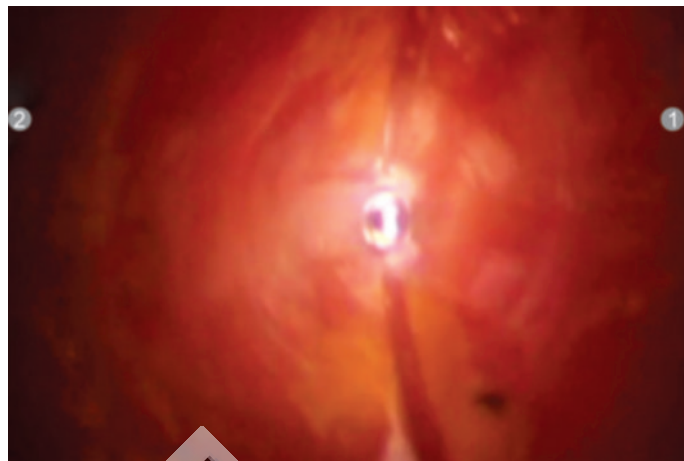


Fig. 56: Camera port insertion under vision with 0° endoscope and Optiview cannula.

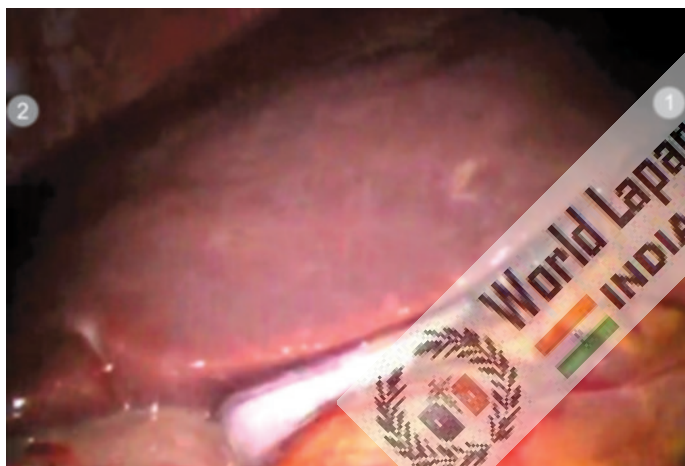


Fig. 57: Diagnostic laparoscopy.

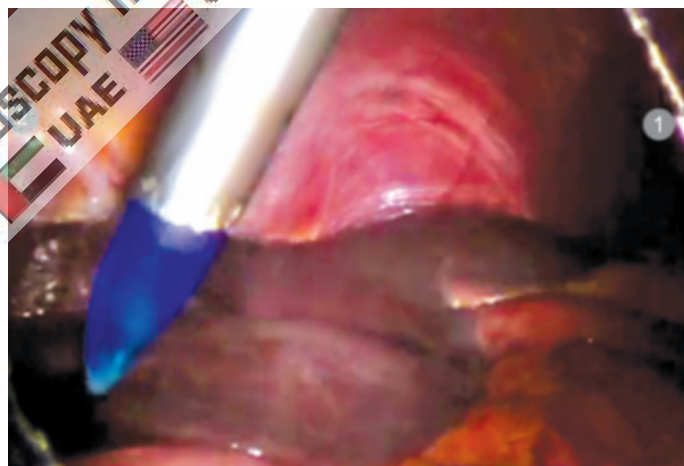


Fig. 58: da Vinci port placement under vision.

A diagnostic laparoscopy is done and gallbladder is visualized (**Fig. 57**).

Patient is positioned in reverse Trendelenburg position with left tilt. Three da Vinci 8 mm ports are inserted under vision as per the guiding principles described above (**Figs. 58 and 59**).

Any adhesiolysis, if required, is done at this particular time with standard laparoscopic instruments.

### Step 2 (Docking of Robotic Cart)

Patient cart is brought over the right shoulder of the patient. Docking of camera arm is done first followed by instrument arms. The principles of docking are kept in mind and system checkup is done after docking is complete. Instruments are inserted under endoscopic vision such as R1: Maryland dissector and R2 and R3: Prograsp forceps (**Figs. 60 to 62**).



Fig. 59: Final port position for robotic cholecystectomy.



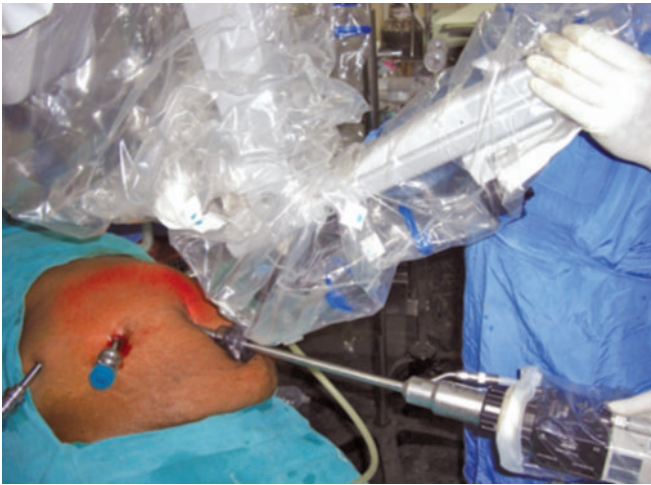


Fig. 60: Docking the camera arm.



Fig. 61: Docking the instrument cannula to the instrument arm.

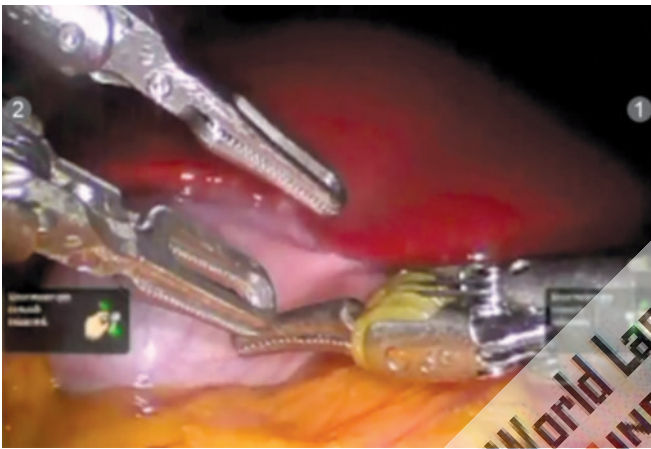


Fig. 62: Insert the instruments under endoscopic vision.

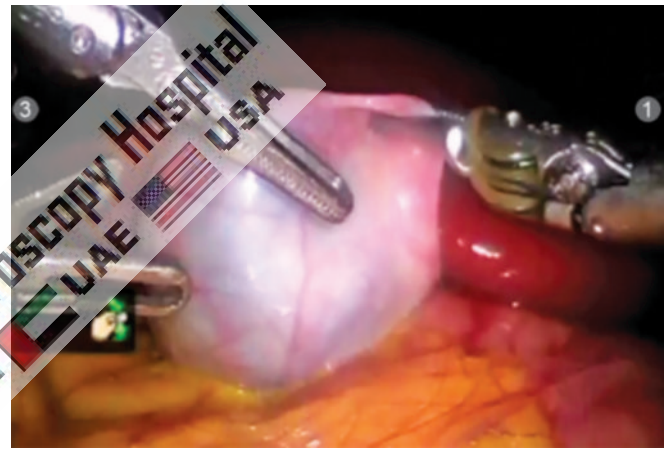


Fig. 63: Holding the fundus with R1 Maryland dissector so as to enable R3 grasping forceps to retract it.

### Step 3

Fundus is grasped with prograsp forceps (R3) and pushed toward the right shoulder of the patient (**Figs. 63 and 64**). This traction is constant once the arm is locked unlike in laparoscopy where it depends on the expertise of the holding assistant. Care should be taken to avoid injury to diaphragm because of inadvertent slippage of fundus from the grasper. Due to lack of haptic feedback to the main surgeon, it can go unnoticed and cause trauma to diaphragm.

### Step 4

Hartmann's is grasped with prograsp forceps (R2) and Calot's triangle is dissected with Maryland EndoWrist instruments (R1). Seven degrees of freedom in the EndoWrist instruments give a distinct advantage in this dissection (**Figs. 65 to 69**).

### Step 5

Cystic duct and artery are dissected completely. Clips are applied with EndoWrist hemlock clip applicator (R1) (**Figs. 70 to 73**).



Fig. 64: Pushing the fundus toward the right shoulder.

### Step 6

The cystic duct and artery are divided with the EndoWrist scissors (R1) in between the clips (**Figs. 74 to 78**). The EndoWrist movements enable the surgeon to cut precisely in the direction required.



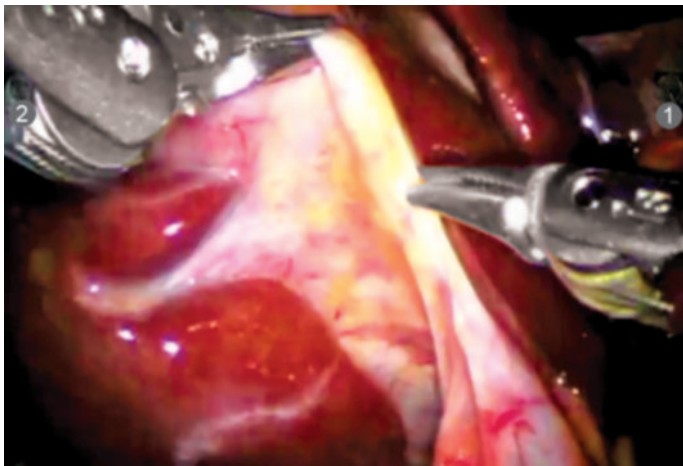


Fig. 65: Hartmann's is grasped by R2 and Calot's triangle being dissected by Maryland in R1.

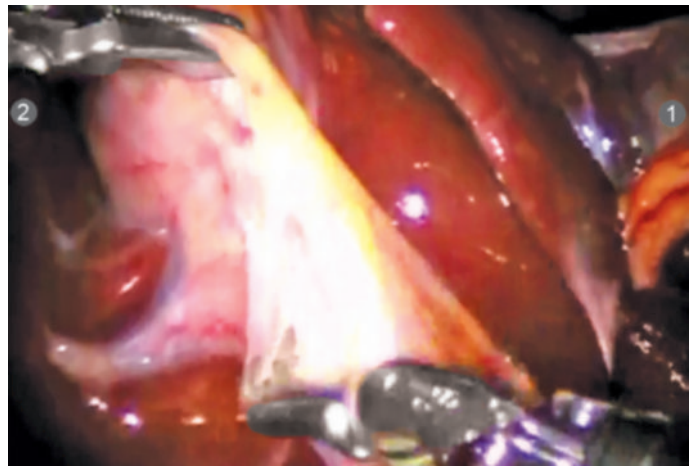


Fig. 66: Posterior peritoneum being dissected off the Calot's triangle.

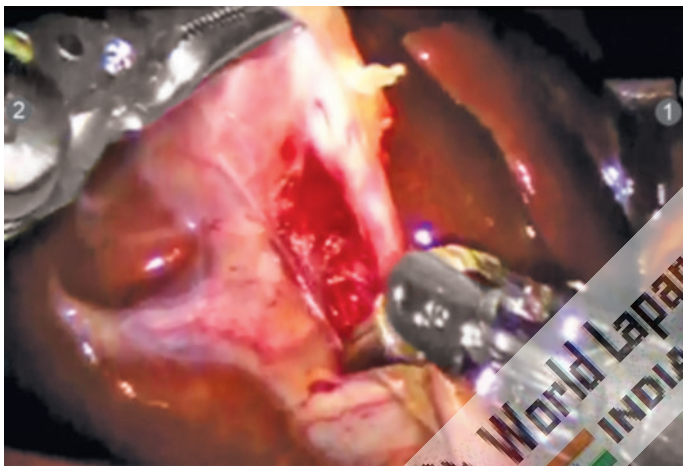


Fig. 67: Posterior window creation.

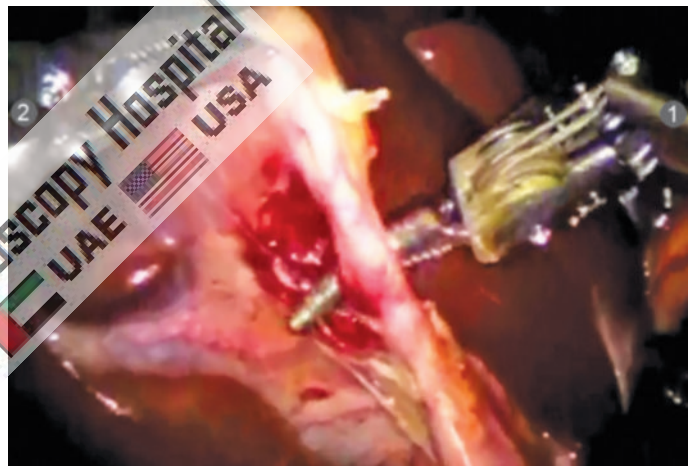


Fig. 68: Cystic duct being dissected using the degrees of freedom of the Maryland dissector.



Fig. 69: Window made posterior to cystic duct.

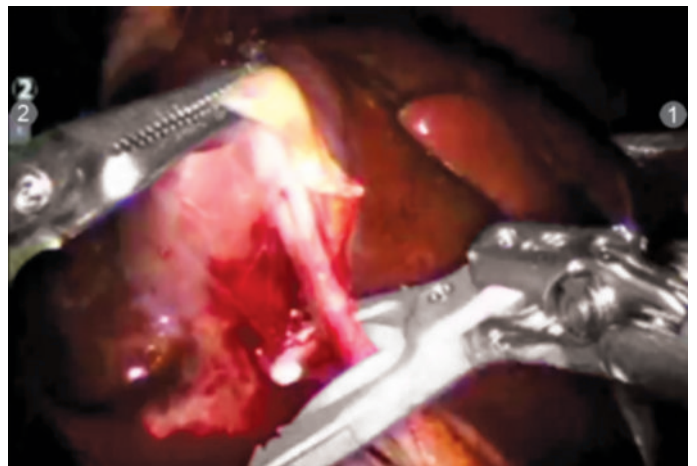


Fig. 70: Clip being applied by robotic clip applicator. The degrees of freedom can be used for optimum clip application.

### Step 7

The gallbladder is dissected off the gallbladder fossa (**Figs. 79 and 80**) with the help of hook electrode with

monopolar cautery (R1). The EndoWrist function of the hook provides a great deal of versatile movements, which aid in this step of surgery.



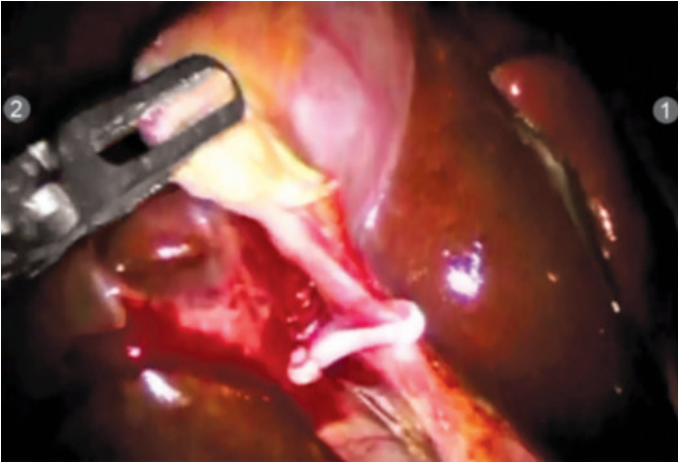


Fig. 71: Clip applied to cystic duct.

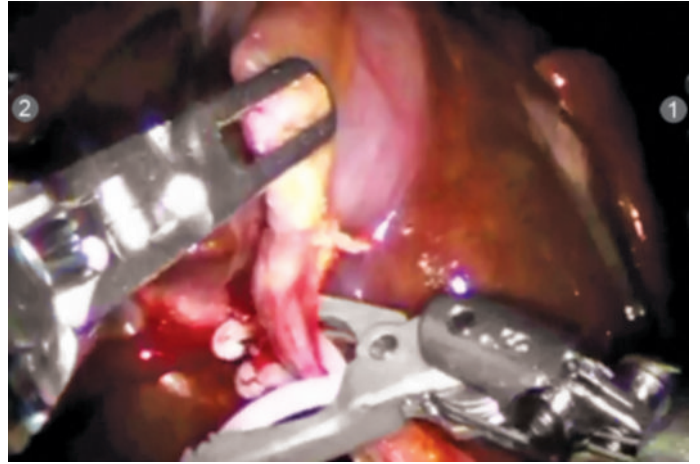


Fig. 72: Second clip being applied.

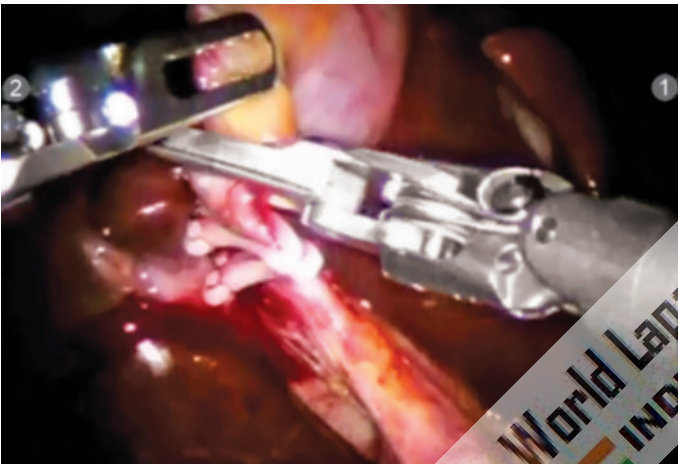


Fig. 73: Third clip being applied.

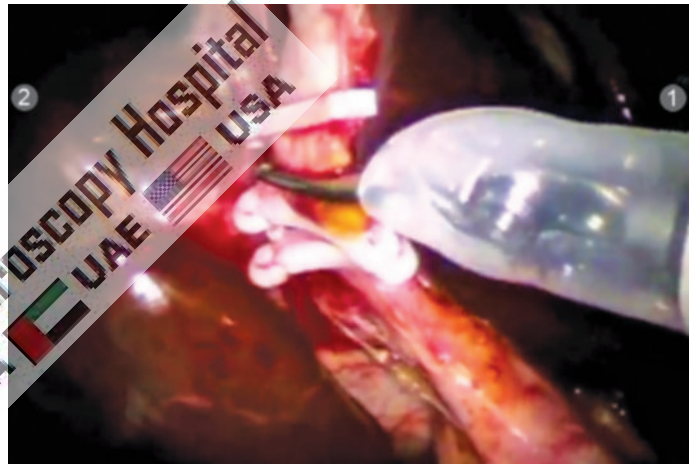


Fig. 74: Cystic duct being divided with scissors.

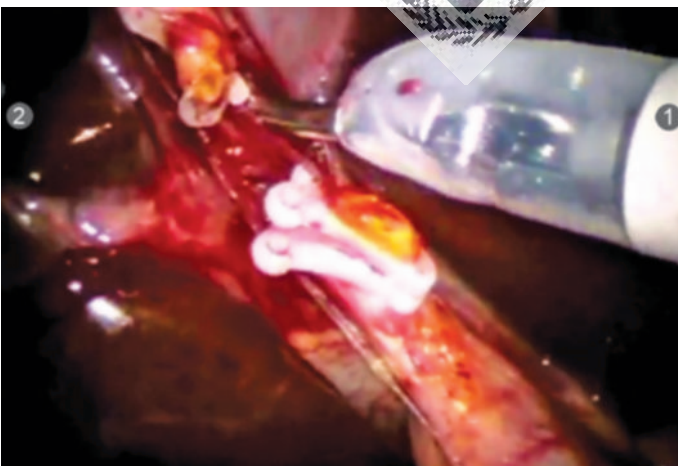


Fig. 75: Cystic duct divided.

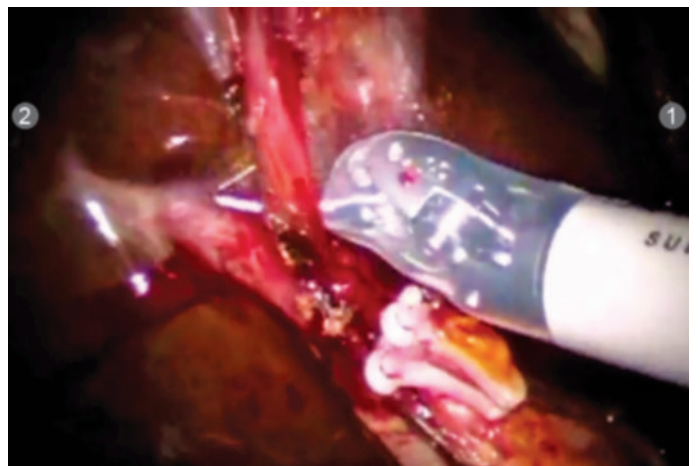


Fig. 76: Cystic artery dissected.

### Step 8

Just before taking off the gallbladder from the fossa, it is retracted cephalad and the gallbladder fossa is inspected for any bleed or bile leak (**Fig. 81**).

### Step 9

The R3 arm is undocked and Endobag is inserted by the patient-side assistant surgeon using standard laparoscopic grasper. Any suction/irrigation can also be done by the

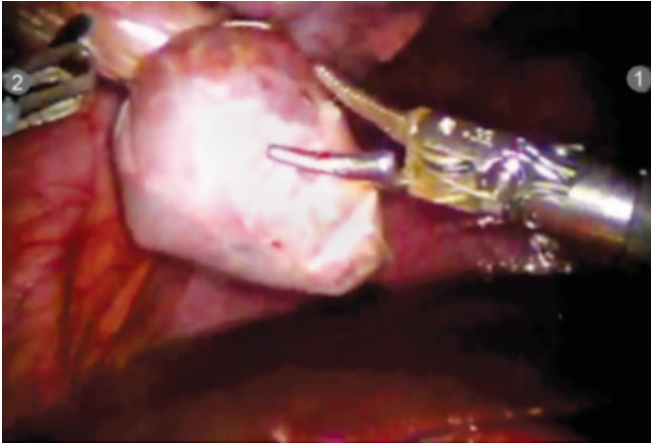


Fig. 83: Gallbladder (GB) being extracted out.

while advantages of such tools are hard to prove for this specific procedure.

There are two situations in which robotics can be applied to this particular procedure:

1. Complicated gallstone disease such as acute cholecystitis, common bile duct (CBD) exploration, or choledochenterostomy
2. Ideal learning and teaching environment for gastrointestinal robot-assisted surgery.

## Advantages

Robotic instruments clearly provide superiority in some aspects of the surgery. The increased degrees of freedom (wrist action) allow the surgeon to easily reach behind structures and negotiate difficult surgical angles. The ergonomics of the operating surgeon can be significantly improved by operating in the sitting position and facing directly forward toward the 3D operative image. These can be of value in cases of acute and chronic cholecystitis, where vision is impaired by inflammation, where there is an increased tendency for diffuse bleeding in the dissection field, and edema and fibrosis make the dissection difficult.

By adjusting movement scaling, surgeon tremor can be significantly reduced; thereby, increasing operative precision. The translation of the surgeon's hand and wrist movements is reliable and can be scaled down to improve precision and increase steadiness.

## Limitations

There is a need for more variety in type and size of robotic trocars. The robotic arms are bulky, taking up significant space and limiting the capability of the surgical assistant. Furthermore, the da Vinci system is not attached to the operating table, so the position of the table cannot be changed without undocking the instrument and camera. The robotic arms lack haptic feedback, so the surgeon must rely on visual cues to avoid stretching and damaging tissue

or suture. Financially, surgical robotic systems remain quite expensive and are associated with significant operating cost. Current robotic systems and instrumentation are still considered to be first generation and should improve as the technology evolves.

## Conclusion

Robotic cholecystectomy is feasible and safe. There is a significant learning curve (around 20–30 cases) to gain experience for setting up the robotic instrumentation, which appears to be much less steep for the actual use of the machine.

It is unlikely that robotic cholecystectomy will be routinely performed in the near future. Further studies are needed to identify the benefits to the patient and compare it to the additional cost of robotic cholecystectomy before routine application of this technique can be justified. However, robotic cholecystectomy may prove its value in cases of complex gallstone disease and is an excellent procedure for teaching the basics of robotic surgery.

## ROBOTIC CORONARY BYPASS SURGERY

Four ports are used and robotic arm is introduced. One of the arms contains telescope, which sends 12–15 times magnified clear image on the monitor. Another arm is for a stabilizer, which is used to hold the diseased coronary artery in place while bypass is performed. The other two remaining right and left instrument is used to perform microvascular anastomosis. Currently, robotic coronary bypass surgery should be considered only for the patient who have single vessel disease but in near future, we have hope to perform double or even triple bypass surgery (Fig 84).

The attached instruments are controlled by the surgeon, who sits at an adjacent console. 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.

More and more surgeries from prostate to heart are being performed by doctors remotely guiding robotic arms. In such procedures, the surgeon's hands never enter the patient. After the initial incisions are made, robotic arms wielding a tiny camera and surgical tools make the snips, stanch the blood flow, and sew up inside when all is done. The surgeon sits at a console usually in the operating room, although the technology would allow a doctor to operate on a patient on the other side of the world peering into binocular-like lenses at views provided by the camera inside the patient. The doctor guides the robot's work by twisting his wrists in stirrup-like handles, moving his thumb and forefinger in scissor-like loops, or tapping foot pedals to focus the camera or move a robotic arm.



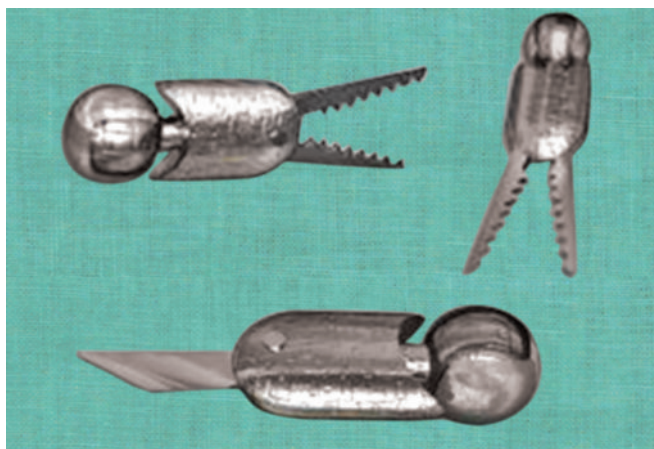


Fig. 84: Instruments used by the da Vinci surgical system.

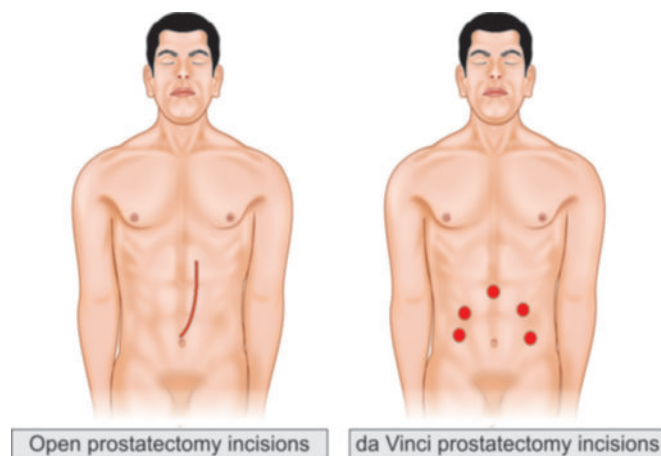


Fig. 85: Comparison between open and da Vinci prostatectomy.

## ROBOTIC PROSTATECTOMY

The most common robotic surgery is radical prostatectomy. Its use has grown from just 1,500 procedures in 2000 to an estimated 20,000 last year. More than 8,000 prostate glands were removed robotically last year, up from 36 in 2000. The procedure accounted for >10% of the 75,000 prostatectomies done in 2004. Busy professionals like the fact that they can be out of the hospital in a day, versus two or three for open surgery, and resume normal activities in 1 week rather than 6 weeks. Cutting nerves around the prostate can lead to incontinence or impotence, so precision is important. Between 25 and 60% of conventional prostatectomy, patients suffer from postoperative impotence. Small studies of robotic surgery have shown at least a short-term benefit in terms of impotence and incontinence.

Not every patient is a candidate. Complicated cases when the patient is very sick, needs multiple procedures, or has had previous chest surgery are not suited to robotics. Nor can a heart transplant or artificial heart implant be done this way. If the complication arises, the patient may wind up being opened. So, patients who want robotics smaller scars and quicker recovery times will need to ask hard questions. Find out how many times, the procedure you need has been done robotically and what the advantages and disadvantages are. Just as important, ask how many robotic surgeries, the doctor who will do yours has performed. In real life, you want the force of experience to be with you.

For qualified candidates, the robotic prostatectomy offers numerous potential benefits over the traditional open prostatectomy, including (Fig. 85):

- Shorter hospital stay
- Less pain
- Less risk of infection
- Less blood loss and transfusions
- Less scarring
- Faster recovery
- Quicker return to normal activities.

While still a technology that is in its infancy, the use of robots to assist in surgery is becoming more and more widespread. There are now large case series reported in the literature that show possible benefits to the patient in terms of recovery from such surgeries as prostate and cardiac procedures. Additionally, as these systems continue to develop, improved technology and software provide the surgeon with “assistance” that improves precision and accuracy (Figs. 86A to D).

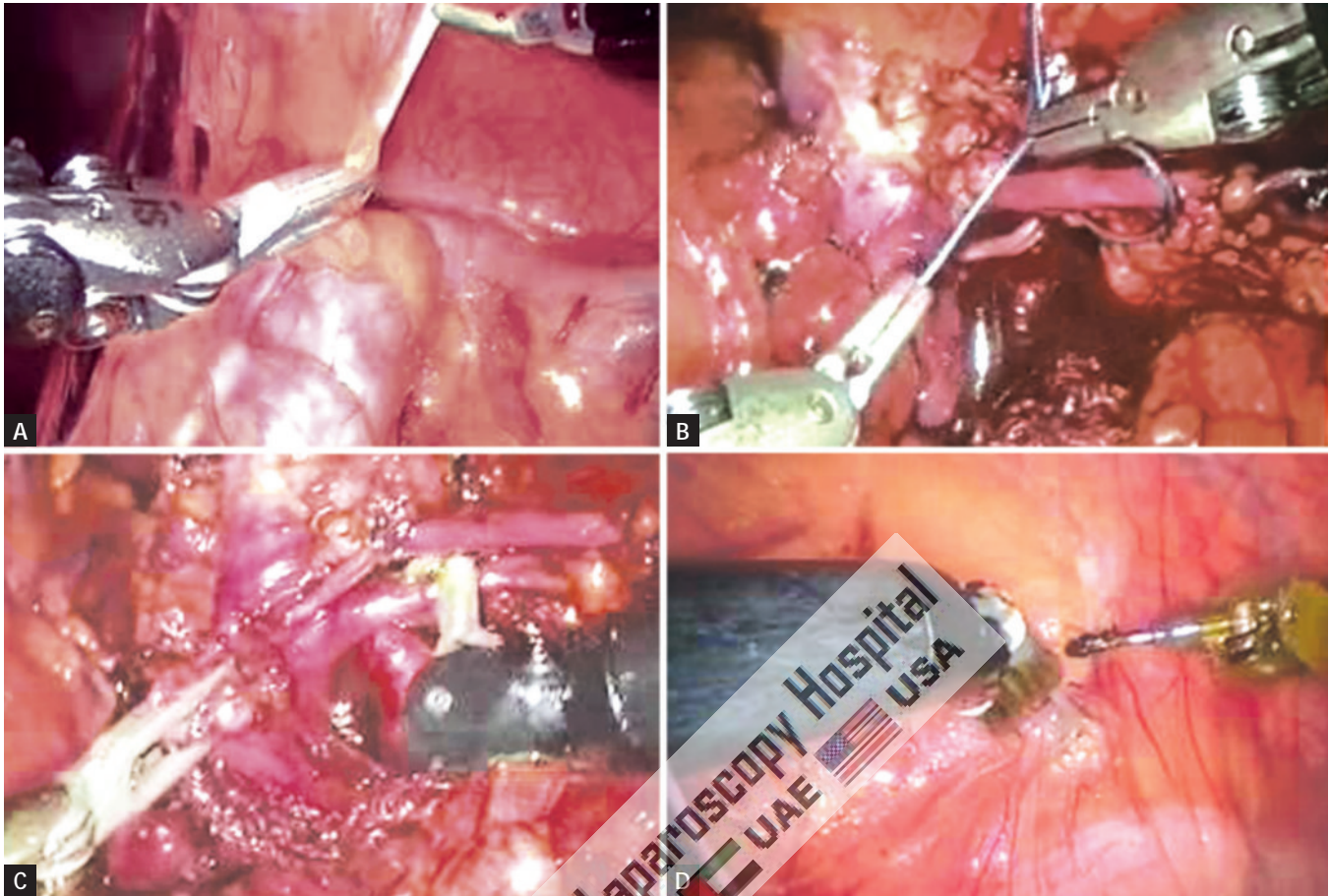
Robotic technology requires a tremendous financial investment, so you might not see it at every community hospital in the near future. However, as with all technology, the price will likely fall quickly as the applications are expanded, as more widespread adoption occurs and as the field of robotics experiences additional breakthroughs. For now, many major academic institutions are beginning to purchase and deploy these systems.

Technology allows amazing things to be accomplished. Robotic surgery is a new and expensive tool that is beginning to see adoption. MIS with a robot and without bypass is the next logical step in the development of cardiac surgery. It is beginning to show clear benefits for patients and this means that it will likely become more and more popular with time and as the price falls.

## ROBOTIC VERSUS LAPAROSCOPIC PROSTATECTOMY

In laparoscopy, the surgeon uses long instruments through small openings and maneuvers them with direct hand contact. Robotic systems use even more delicate instruments that possess two additional degrees of movement excursion (for a total of six, as with a human hand). Comfortably seated at the robot console, the surgeon can maneuver the instruments via a computer interface.

Laparoscopic radical prostatectomy is associated with a steep learning curve. Even in the hands of expert surgeons, laparoscopic radical prostatectomy requires extensive



Figs. 86A to D: Robotic-assisted nephrectomy.

learning; approximately 40 cases are needed to master this technique. In contrast, the learning of robotic prostatectomy seems to be more intuitive and less demanding.

Robotic prostatectomy is a safe, effective, and reproducible technique for removing the prostate. In most patients, it can be performed within 1.5–2 hours with minimal blood loss and few complications. The procedure incorporates principles of both laparoscopic and open radical prostatectomy. The patients enjoy benefits of surgical treatment in the setting of less invasion, minimal pain, limited blood loss, and early functional and overall recovery.

## ■ NEW SURGICAL ROBOTS

### Senhance Surgical System

Robotic-assisted digital laparoscopy (Senhance Surgical System) provides a digitized interface between the surgeon and the patient designed to increase surgeon control and reduce surgical variability. The physical open architecture of the system is composed of independent robotic-assisted manipulator arms that are compatible with conventional trocars and familiar laparoscopic instruments and, thus, taking advantage of the existing operating room and surgical suite ecosystem (Fig. 87).

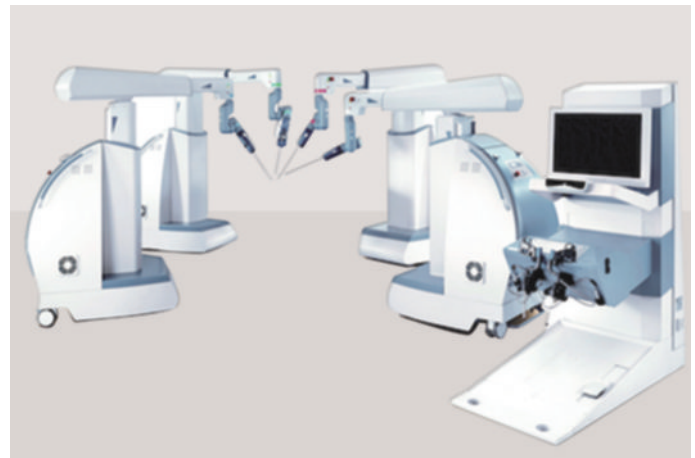


Fig. 87: Senhance surgical robot system.

### Avatera Surgical System

The Avatera robotic surgical system gained CE mark last month for use in keyhole surgery, with its initial focus on gynecology and urology. It consists of the main surgical robot and its control unit and various endoscopes and instruments (Fig. 88).



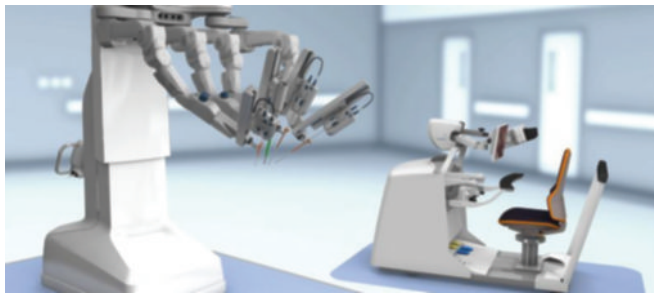


Fig. 88: The Avatera robotic surgical system.

## Indian Robotic Surgical System

The SSI MANTRA is made in India. Surgical robot is the brainchild of cardiac surgeon Dr Sudhir Srivastava and was developed in an Atal Incubation Centre. It has conducted 18 successful surgeries and the cost is likely to be one-fourth of leading global competitor, da Vinci robot (Fig. 89).

Artificial intelligence is a buzzword on everyone's lips today. Johnson & Johnson has partnered with Google to form Verb Surgical, which is developing a "digital surgery program". While it is still quite early in development, it is expected to include advancements in data analytics, machine learning, and connectivity. A recent study from this device reported on completely autonomous suturing using the robot in an animal model. Artificial intelligence could also potentially play a significant role in presurgical planning, intraoperative 3D imaging, and navigation allowing for even more precise and subtle operations. People expect that ultimately robots will replace surgeons and actually perform the surgery. Nevertheless, it is believed that this still remains well in the future. However, given the speed at which artificial intelligence research is progressing, you never know when surgeons' jobs could be under complete hand of surgical robot.

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Fig. 89: SSI MANTRA is made in India surgical robot.




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## Contact us

 World Laparoscopy Hospital  
 Cyber City, Gurugram, NCR Delhi  
 INDIA : +919811416838

 World Laparoscopy Training Institute  
 Bld.No: 27, DHCC, Dubai  
 UAE : +971523961806

 World Laparoscopy Training Institute  
 8320 Inv Dr, Tallahassee, Florida  
 USA : +1 321 250 7653

