Introduction to the Robotic System

2

Monika E. Hagen, Hubert Stein,
and Myriam J. Curet

Historical Overview

The da Vinci® Surgical System (Intuitive Surgical Inc., Sunnyvale, CA, USA) is currently the most frequently used computer-enhanced endoscopic instrument control system capable of laparoscopic surgery. The US Food and Drug Administration (FDA) has cleared this system for use in urological surgical procedures, general laparoscopic surgical procedures, gynecologic laparoscopic surgical procedures, transoral otolaryngology surgical procedures restricted to benign and malignant tumors classified as T1 and T2, general thoracoscopic surgical procedures, and thoracoscopically assisted cardiotomy procedures. Additionally, the system is approved to be employed with adjunctive mediastinotomy to perform coronary anastomosis during cardiac revascularization (as of July 2012).

The design of the da Vinci® is the result of a long developmental process which integrated many ideas and technologies to produce a functional system. Much of the early work on telerobotic surgery was funded by the US Department of Defense, with the aim of providing injured soldiers with a frontline surgical suite controlled by surgeons operating from a safe remote location. Although at the time this proved impractical with the technology available, several prototypes showed promise and Intuitive Surgical International was founded in 1995 to license and develop this technology for civilian use. The ultimate goal of the company was to produce a reliable, intuitive system which would deliver the benefits of minimally invasive surgery to patients while preserving the benefits of open surgery to surgeons. The goal was to enable many difficult surgeries (such as cardiac surgery) to be performed through small incisions and also achieve better results for procedures already performed through ports. The technology specifically aimed to address port-access limitations in dexterity, intuitiveness, visualization, and ergonomics through advances in telepresence and stereoscopic capture as well as display.

After securing venture capital, the relevant technologies were licensed from MIT, IBM, and SRI International and a team of engineers set to work on producing a prototype. Initial efforts using off-the-shelf and custom-built components that were passed on from SRI yielded a device

M.E. Hagen, M.D., M.B.A.
Intuitive Surgical International, Sunnyvale, CA, USA

Department of Digestive Surgery, University Hospital Geneva, 14, rue Gabrielle-Perret-Gentil, Geneva 1211, Switzerland
e-mail: monikahagen@aol.com

H. Stein, DIPL.-ING. B.M.T.
Clinical Development Engineering, Intuitive Surgical Inc., 1266 Kifer Road, Sunnyvale, CA 94107, USA
e-mail: Hubert.Stein@intusurg.com

M.J. Curet, M.D. (✉)
Intuitive Surgical International, Sunnyvale, CA, USA

Department of Surgery, Stanford University School of Medicine, Stanford, CA, USA
e-mail: myriam.curet@intusurg.com

K.C. Kim (ed.), *Robotics in General Surgery*, DOI 10.1007/978-1-4614-8739-5_2,

called "Lenny," which was used in animal trials to inform further design. These trials clearly demonstrated the promise of seven-degrees-of-freedom manipulators as well as the need for a mobile patient-side manipulator platform. The next major design iteration was called "Mona," and featured exchangeable sterile components, which allowed human trials to proceed in 1997. The experience gleaned from these trials enabled the design to be refined further into the first generation "da Vinci®" Surgical System platform that is still in use today. In December 1998, the first commercial version was delivered to the Leipzig University Heart Center in Germany.

Further product developments were delayed due to a legal battle with Computer Motion Inc. (Santa Barbara, CA, USA) over intellectual property rights. In 2003, Intuitive Surgical Inc. merged with Computer Motion Inc., and their Zeus telepresence system, which was the competitive product to the da Vinci Surgical System, was discontinued. Refinement of the original da Vinci design continued with the addition of a fourth manipulator arm and expansion of the instrument families. These changes were fully integrated into the simplified and streamlined "da Vinci® S" model, which takes less time to set up and has improved range of motion manipulators; the latest product iteration is the "da Vinci® Si" (released in 2009), which features improvements to the vision and control system and ergonomic improvements and allows two surgeons to share control of manipulators (dual-console mode). This allows all four manipulators to be controlled simultaneously during complex operations and greatly improves the training paradigm for computer-enhanced surgery.

System Overview

The da Vinci® Surgical System is built following an anthropomorphic principle or a humanoid concept. That means that the motion capabilities of the system are designed to mimic those of its human operator. The mechanical components of the system have physical limitations of reach and range of motion. Whenever possible, these limits are designed to meet or exceed the way the human hand and arms work. For instance, the EndoWrist® instrument wrist will run out of ability to flex when the user's wrist is most flexed. In addition, the systems are designed to offer hand–eye alignment which means that the EndoWrist instruments move in the same way with respect to the camera as the hands of the surgeon move with respect to the surgeon's eye. The orientations of the instrument tips mimic the surgeon's hand alignment inside the master controller joysticks. These two properties establish a strong sense of eye-hand coordination and natural, intuitive motion, promulgating the illusion that the robotic instruments are his/her fingers. The EndoWrist instruments that are inserted into the patient move around a fixed point in the body wall that is established by a mechanical remote center concept. This enables the system to maneuver instruments and endoscopes into and within the surgical site while exerting minimal force on the patient's body wall.

Three different commercial models currently exist: the da Vinci Standard System represents the first generation of the da Vinci® Surgical System and was marketed in Europe in late 1998. This model is no longer commercialized, but it is still in use and being supported by Intuitive Surgical. The next generation of da Vinci® Surgical Systems is the da Vinci® S which offers a newer and slimmer robotic arm design that facilitates the surgical cart setup and enables a greater reach within the abdomen when compared to the earlier version. It also contains a superior vision system with HD, a streamlined user interface and some other soft- and hardware innovations. The most current model is the da Vinci® Si Surgical System which was launched in April 2009. The da Vinci® Si introduces several enabling features, including dual-console capability (two surgical consoles can be attached to a single surgical cart) to support training and collaboration during minimally invasive surgery (for details, see Chap. 33), enhanced high-definition 3D vision, improved ergonomics, an updated user interface for streamlined setup and OR turnover, and extensibility for digital OR integration.

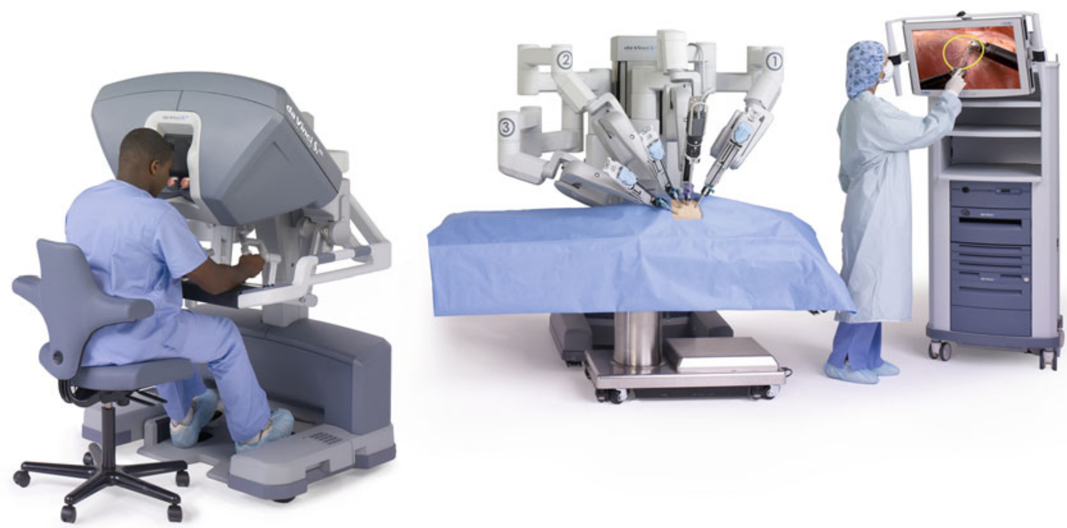

Fig. 2.1 The da Vinci® Surgical System with its main components (courtesy of Intuitive Surgical, Inc.)

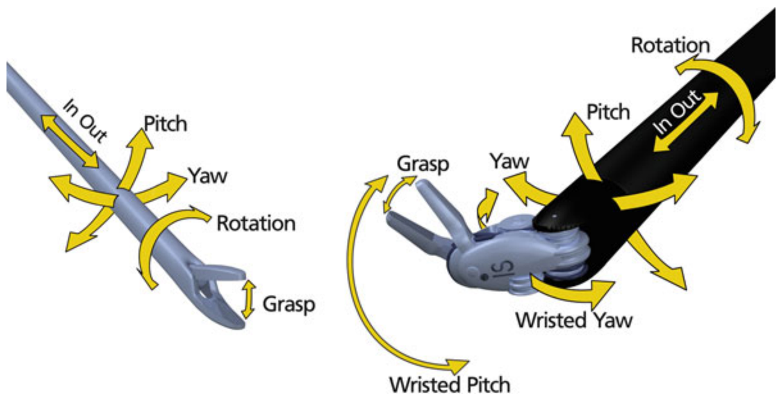

Fig. 2.2 Range of motion of robotic instruments (courtesy of Intuitive Surgical, Inc.)

All above-mentioned systems have three major components: the surgeon's console, the surgical cart, and the vision cart (Fig. 2.1).

The shared core technology of all systems offers the following distinguished features:

- Physical separation of the surgeon from the patient by operating at a console rather than at the patient's side
- A three-dimensional stereoscopic image (HD for the S and Si model) with up to ten times magnification
- Wrist action of the robotic instruments providing seven degrees of freedom (compared with five degrees of freedom for standard laparoscopic instruments), a range of motion greater than the human hand and with intuitive control (Fig. 2.2)
- Software features such as tremor elimination and optional motion scaling up to 3:1

The following description of the main da Vinci® components are based on the da Vinci® Si Surgical System.

The da Vinci® Surgical System: The Surgical Console

The surgical console is the workplace of the robotic surgeon and contains the following core elements: master controllers, stereo viewer,

Fig. 2.3 Master controllers (courtesy of Intuitive Surgical, Inc.)

touchpad for preference and feature selection, left-side pod for ergonomic controls, right-side pod for power and emergency stop, and a footswitch panel for operative mode selection and energy actuation.

The *master controllers* (Fig. 2.3) or masters are the joysticks of the robotic surgeon. Two fingers of each hand are placed inside the Velcro straps to control the movements of the patient cart instruments.

The masters are built essentially like a human arm, with a wrist portion (orienting platform) and the elbow/shoulder joints for positioning. The wrist portion orients the instrument tip in the surgical environment. The elbow and shoulder joints move the instrument to the appropriate location in the surgical field and can be scaled to a 3:1 (fine), 2:1 (normal), or 1.5:1 (quick) ratio. The master controllers also possess finger clutches, which decouple the master from control of its instrument to allow for ergonomic repositioning of the master controllers during surgery. Research on learning curves has indicated that appropriately frequent use of master clutching appears to be a crucial part of mastering the da Vinci Surgical System as it results in workspace and ergonomic optimization.

The *stereo viewer* provides the video image to the surgeon including the image of the surgical site and extended system information. With the head in the viewer, the surgeon can view the 3D image in full-screen mode or can choose to swap to TilePro™ mode, which displays the 3D image along with up to two auxiliary images. Icons and text messages are overlaid on the video to provide extended information to the surgeon. The system provides 2-way audio communications with the patient cart operator by a microphone located under the viewport and a pair of speakers located in the headrest.

The *touchpad* is the main control interface at the Surgeon Console for system functions. The touchpad home screen provides system status, including instrument arm selection, and control selections. In dual-console mode, the surgeon can use the touchpad to assign robotic arm control between the two consoles. The center of the touchpad provides three quick setting buttons indicating settings for scope angle, zoom level, and motion scaling.

The *left-side pod* provides the ergonomic adjustment controls for the Surgeon Console. Choosing the correct ergonomic setup is particularly important in order to avoid unnecessary physical strain during the surgical procedure and time should be taken to do so before the actual procedure starts. The *right-side pod* provides Power and Emergency Stop buttons (Fig. 2.4).

The *footswitch panel* (Fig. 2.5) is located at the base of the console directly beneath the surgeon and provides the interface for various system functions without removing the head from the stereo viewer.

The footswitch panel features two groups of footswitches. The three switches on the left control system function such as camera control,

Fig. 2.4 *Left-side* and *right-side* pod (courtesy of Intuitive Surgical, Inc.)

Fig. 2.5 Food switch panel (courtesy of Intuitive Surgical, Inc.)

master clutch, and arm swap. The four pedals on the right side of the footswitch panel are used for energy activation and are arranged as a left pair of pedals and a right pair of pedals. Cautery, ultrasonic shears, suction/irrigation, and other advanced instrumentation are available for control.

The da Vinci® Si Surgical console can be augmented for training by attaching the da Vinci® simulator to its back. For details see Chap. x: simulation. Additionally, up to two surgical consoles can be attached to a single surgical cart for dual-console surgery, which is particularly useful for teaching purposes.

The da Vinci® Surgical System: The Patient Cart

The patient cart (Fig. 2.6) is the operative component of the da Vinci Si System, and its primary function is to support the instrument arms and camera arm. It contains five main components: the setup joints, instrument arms, camera arm, EndoWrist instruments, and an endoscope.

The *setup joints* enable movements of the instrument and the camera arm to position them for sterile draping and docking of the system to the patient. Clutch buttons are used by the patient-side assistants to free the setup joints, which is applied in some cases to readjust instrument arms if needed during the procedure. To help ensure patient safety, any actions of the patient cart operator will always preclude simultaneous telepresence actions from the Surgeon Console operator.

While the *instrument arms* hold the EndoWrist instruments, the camera arm holds the endoscope during surgery. As described above, all arms can be controlled within their range of motion by the surgeon from the surgical console. The setup is performed by the bedside assistant using the clutch buttons to release the setup joints.

EndoWrist instruments are installed onto the instrument arms after the system is docked to ports that are inserted into the patient. Most instruments offer 7 degrees of freedom and ±90 degrees of articulation in the wrist. The arsenal of instruments includes advanced energy instruments (monopolar cautery shears, hooks, spatulas,

Fig. 2.6 Patient cart (courtesy of Intuitive Surgical, Inc.)

bipolar shears, bipolar graspers, Harmonic™ ACE, PK™ dissecting forceps, and laser), different types of forceps, needle drivers, retractors, and other specialized instruments such as clip appliers, probe graspers, and cardiac stabilizers. The most common instruments have a diameter of 8 mm. A selection of 5 mm instruments is available for use with smaller access ports.

Most instruments contain the following elements:

- A tip that represents the appropriate end effector for a specific surgical task such as different type of graspers, dissectors, cautery tips, and scalpels
- An articulating wrist designed to mimic the wrist of the human hand (some instruments are not wristed as required by the underlying technology, such as the Harmonic™ ACE which is a long ultrasonic horn that cannot be bent)
- A shaft that represents the rotating "arm" of the instrument and through which the motive force is transferred from the robotic arms to the wrist tips
- Release levers which are the mechanism for removal of the instrument
- An instrument housing which is the portion of the instrument that engages with the sterile adapter of the instrument arm

The EndoWrist instruments are reposable, which means that the main component needs to be replaced after a certain number of surgeries.

The *da Vinci® Si HD Vision System* uses a 12 mm or 8.5 mm 3D rod lens endoscope with either a straight (0°) or angled (30°) tip. Light from the illuminator is sent down the shaft of the endoscope via fiber optics and projected onto the surgical site. The video image of the surgical site captured by the endoscope is sent back through the left and right channels to the camera head. The camera head connects to the camera control unit, as well as the illuminator. In keeping with the anthropomorphic principle, the endoscope contains two separate optical chains and focusing elements, and the camera head contains two separate cameras. When displayed on two monitors to the left and right eye of the surgeon, a true and natural 3D image is recreated.

The da Vinci® Surgical System: The Vision Cart

The vision cart (Fig. 2.7) houses the system's central processing and vision equipment. It includes a 24″ touch screen monitor used to control system settings and view the surgical image.

It also provides adjustable shelves for optional ancillary surgical equipment such as insufflators and electrosurgical generators. The da Vinci® Si core on the vision cart is the system's central connection point where all system, auxiliary equipment, and audiovisual connections are routed. The core also is the "brain" of the system where all computer calculations are processed to control

Fig. 2.7 Vision cart (courtesy of Intuitive Surgical, Inc.)

the motions of the instruments inside the body. An integrated illuminator on the vision cart provides lighting for the surgical field. A camera control unit on the vision cart is connected to the camera and controls the acquisition and processing of the image from the camera.

Conclusion

The da Vinci Surgical System is a success story of visionary concepts brought into wide clinical adoption to improve clinical outcomes through the interdisciplinary work of many different specialties. However, this is just the beginning of an exciting journey that might change the surgical landscape sustainably. New robotic platforms for the use in surgical specialties will emerge down the line and distinct new features will enable more procedures to be performed with the help of computer-enhanced systems. Further technology adopted into currently existing or new robotic platforms will evolve and transform these systems into surgical cockpits that hold the promise of becoming the central workstation of surgical care. Integrated diagnostics and real-time imaging will enhance training, diagnostic assessment, and therapeutic treatment in unforeseen new ways for the benefit of many patients in the years to come.

Robotics in General Surgery
Kim, K.C. (Ed.)
2014, XVII, 511 p. 411 illus., 403 illus. in color.,
Hardcover
ISBN: 978-1-4614-8738-8