# The Potential for Robotics Technology in Surgery

By Yulun Wang, PhD

In August 1993, Dr. Jonathan Sackier (formerly of Cedars-Sinai Medical Center) performed the world's first laparoscopic cholecystectomy using robotic assistance.[1] A robotic arm, shown in Figure 1 (to the left), was attached to the rail of an operating room table and was used to hold and move the laparoscope under direct commands from the surgeon. Since then, roughly 200,000 surgical procedures have been performed using varying levels of robotic assistance in nearly every surgical discipline.

Today there are more advanced surgical robots. The robotic system, shown in Figure 2, enables a surgeon to sit at a console, manipulate sophisticated joysticks that mimic the handles of surgical instruments, and control the movement of precise robotic arms that operate articulating surgical instruments.[2] Although the appearance of such a system seems like a radical change from surgery without robots, the concept is quite simple. With a standard surgical instrument, the handle is mechanically coupled directly to the instrument tip. A tele-operated robotic system replaces this mechanical coupling by a computer-controlled electro-mechanical system comprising actuators and sensors. A computer program controls the operation of the actuators in relation to the sensor signals in the electro-mechanical system and thereby effectively governs the relationship between the instrument's handle and the instrument's tip.

The placement of a programmable system between a surgical instrument's handle and tip changes the paradigm of a surgical instrument. This change is similar to the method by which the personal computer with word processing changed the paradigm of a typewriter. Immediate benefits of this change include surgical instruments that can filter the surgeon's hand tremor or scale the surgeon's hand motion, both of which can greatly enhance the dexterity of a surgeon. Dexterity enhancement via robotic surgical instruments has been shown to enable surgeons to perform procedures never before accomplished, such as endoscopic coronary-artery bypass surgery on a beating-heart.[3,4] Robotic surgical instruments allow many new capabilities in addition to dexterity enhancement. For example, a robotic system recently enabled a surgeon in New York to successfully perform a laparoscopic cholecystectomy on a patient in Strasbourg, France. Such accomplishments only demonstrate the beginnings of how robotic technology will positively impact the field of surgery.[5,6]

Before discussing concepts that will govern how surgical robots can be applied, we should first explain the definition of a robot and the inherent benefits of this technology. A robot is a computer-controlled mechanical system with anthropomorphic (or human-like) characteristics. Although many of us initially think of characters like R2D2 or C3PO from Star Wars as the prototypical robot, today most robotic systems are in fact manipulators in the shape of some type of arm. Another prevalent type of robot is the mobile robot, which resembles some type of vehicle. However, these robots are less applicable to surgery.

The intrinsic benefits of robotic systems stem from their mechanical and computer composition. Mechanisms and computers can greatly exceed the abilities of human beings in specific tasks. For example, mechanisms can have much greater manipulative precision and strength than human beings. We have built nano-structures that are precise enough to move individual cells and robots that can effortlessly lift an automobile. Mechanisms can be built from materials that are not damaged in situations that are harmful to human flesh and bones. Radiation frequently used in imaging the human anatomy is harmless to robot manipulators but harmful to clinical staff due to the accumulation of radiation dosage. We can also build computers with computational and communication capabilities greatly exceeding our own. Today's personal computers can perform billions of arithmetic calculations per second, and handle the routing and signal processing of millions of telephone conversations. Robots can leverage these tremendous capabilities because mechanisms and computers are their fundamental building blocks.

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Although robots have certain advantageous characteristics, they are unable to match human capability in a large number of areas. The number of degrees of freedom that the human arm has greatly exceeds today's robotic manipulators. The mobility of the human body through one's legs and torso is another capability far beyond the reach of today's robotic technology. The sense of "touch" received from our fingers (often called haptic feedback) comprises force feedback, as well as texture, viscosity, temperature and other characteristics that provide the surgeon with much information. The human visual processing that allows us to distinguish anatomy during a procedure greatly exceeds the capabilities of today's image processing computers. Finally, the human brain and the reasoning capability of a surgeon are far beyond the ability of today's computational algorithms and artificial intelligence technology.

Given these advantages and limitations of robotic technology, the goal is to develop systems that leverage the benefits of robotic technology such that they provide the surgeon with new manipulative capabilities. Stated another way, the robot is to become a tool for the surgeon such that it amplifies the surgeon's skills along certain dimensions, while not interfering with the surgeon's innate skills along other dimensions. This goal is much different than working towards creating a robotic system that attempts to replace the surgeon with superior technology. As discussed above, such an approach would be futile.

The past eight years of practical clinical experience with robotic surgical systems in the marketplace has yielded an initial understanding as to robotic technology's effective application to surgery such that it benefits patients, healthcare providers and society in general. We have identified six capabilities that highlight specific value propositions for robotics in surgery: 1) robotic augmentation, 2) dexterity enhancement, 3) improved ergonomics, 4) image-guided positioning, 5) hazardous environment removal and 6) tele-collaborative surgery. To prove beneficial, we believe that surgical robotic systems should focus on one or more of these capabilities and target new applications in surgery.

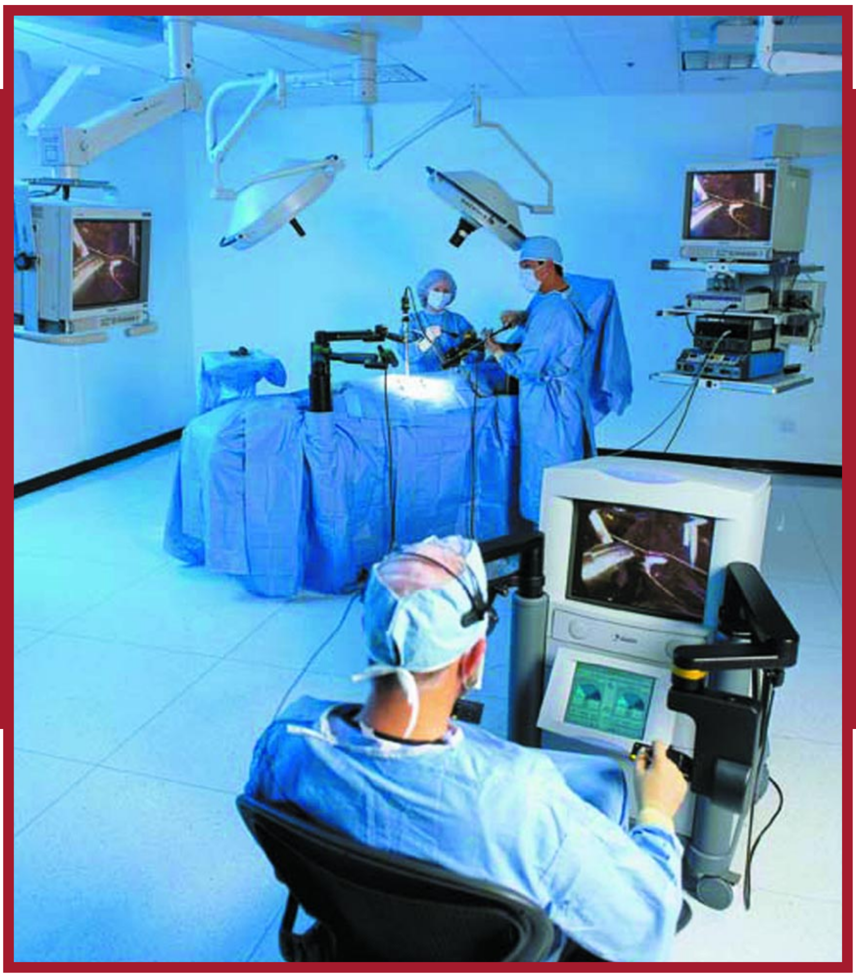

**Figure 2. Surgeon seated while using ZEUS robotic system to operate.**

**Robotic Augmentation** enables one or more robotic manipulators to be controlled by the surgeon such that the surgeon is "augmented" by having control of additional manipulation capability. Robotic augmentation gives the surgeon more arms with which to operate. For example, a voice-controlled AESOP provides surgeons with a "third arm," which is capable of manipulating the laparoscope and in turn augmenting the surgeon.[7,8,9,10]

**Dexterity Enhancement** improves the surgeon's precision and dexterity by computerizing the surgical instrument and creating a software program that controls the relationship between the instrument's handle and tip. This program would incorporate algorithms like hand-tremor filtering and motion scaling to increase precision and dexterity. More degrees-of-freedom can also be seamlessly incorporated into these surgical instruments to further improve dexterity.[11,12,13,14]

**Improved Ergonomics** improves the ergonomic environment for the surgeon and other operating room staff by leveraging the capabilities of robotics. An example is to take advantage of the fact that robotic surgical instruments enable the surgeon to be removed from the side of the patient, allowing the surgeon to sit in a more ergonomic position while operating. This is illustrated in Figure 2.

**Image Guided Positioning** "registers" a robotic manipulation system with an imaging system such that the robot can automatically identify the location of specified anatomy shown on the image. With image-guided positioning the surgeon can issue commands with respect to the image, which in turn manipulates the robot to perform the command. For example, the surgeon can command "go there" on the image, and the robot would automatically know where "there" is, and move accordingly. This capability eliminates the translation error inherent in the task of a clinician to correlate a location displayed on an image to the actual location inside the patient's body.

**Hazardous Environment Removal** takes advantage of the inorganic characteristic of a robot and removes a clinician from a hazardous environment. For example, robots are immune to the caustic effects of radiation and toxic chemicals on people. Enabling a surgeon to manipulate an instrument during radiation or chemical treatment, via a robot, removes the surgeon from such harmful effects.

**Tele-Collaborative Surgery** combines robotic manipulation with telecommunications to enable remote surgical interaction. For the past few decades, tele-operated robots have been used to bridge distance barriers and enable physical interaction in space, undersea and in nuclear environments. Tele-collaborative surgery uses robotics to enable surgeons who are not physically present to participate interactively in surgical procedures. Proctoring, mentoring and assisting are all possible tele-collaboratively.[5,6,15,16]

The above capabilities are six distinct value propositions for surgical robots. It is important to note that they are not mutually exclusive but are synergistic. Most clinical applications leverage more than one of these capabilities simultaneously. The goal of surgical robotics is to create systems and products that can improve the quality of surgery by leveraging the maximum number of these advantages.

Robotics has yet to have a focused effort in the field of neurosurgery. However, the advantages of robotics are also applicable to neurosurgery and should be explored.

Technical advancement in clinical medicine is best measured by superior patient outcomes. Advancement in robotic technology and products should therefore be continually examined from this perspective. Clearly more quantitative outcomes are preferred, such as procedures that are measurably less invasive, have faster patient recovery times, cost less and offer less procedural complications. However, outcomes that are not always easily quantified should not be ignored. Examples include improved ergonomics for the surgeon, more stable visualization and improved retraction. How would an outcomes study quantify the advantages of enabling the surgeon to operate while sitting rather than standing? Yet we intuitively know that fatigue and discomfort negatively impact human performance. With the large number of variables impacting the ultimate outcome of procedures, often the shear size of a study that can statistically isolate a single variable is cost prohibitive. Therefore, robotic systems must exist in a manner that surgeons want to use them because they ultimately believe in the value they provide.

Another key application area for robotic systems is surgical training and education. There are three immediate applications that offer significant advantages over today's training and education methodologies: 1) tele-collaborative surgery, 2) surgical simulation and 3) quantified analysis of surgical performance. An important attribute of developing these capabilities is that they potentially benefit all surgical disciplines, all surgical procedures and, therefore, all patients.

Tele-collaborative surgery uses robotics in combination with telecommunication to enable remote surgical interaction. The surgeon's training process is never ending because of the constant advancement and improvement in technology and surgical techniques. Consequently, surgeons must continually learn from one another by exchanging their knowledge on new techniques and procedures. The optimal environment for such interaction is when two surgeons operate together. The challenge becomes one of geographic separation. Tele-collaborative surgery offers the ability to overcome geographic separation, enabling training and education to occur between surgeons while separated geographically.

Surgical simulation is another significant opportunity that will improve the process of surgical training. This concept is analogous to flight simulators that help train airline pilots. If we assume that surgery in the future will be performed from a "cockpit" like control console, then one can see how surgeons could learn and refine their skills sitting at a control console operating on computer-based simulation programs. When programs can closely replicate the human anatomy and physiology, surgeons could ultimately be trained entirely by computer simulation. Future simulators could even enable surgeons to experience wide ranges of surgical complications,

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> TECHNICAL ADVANCEMENT IN CLINICAL MEDICINE IS BEST MEASURED BY SUPERIOR PATIENT OUTCOMES. ADVANCEMENT IN ROBOTIC TECHNOLOGY AND PRODUCTS SHOULD THEREFORE BE CONTINUALLY EXAMINED FROM THIS PERSPECTIVE.

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which would usually take years of clinical practice to experience. Surgical simulators would also allow surgeons to become more skilled before operating on actual patients.

Robotic systems also enable the analysis of surgical performance. In today's surgical education model, the manipulative skills of a surgeon are neither quantified nor specifically tested against some specified level of competency. Robotic systems offer the ability to record and analyze the surgical manipulations during a procedure. This type of analysis could prove valuable in enabling a surgeon to improve one's skills, as well as test surgeons as to whether or not their manipulative skills are at an acceptable level of performance for a given task.

In summary, the future of robotics in surgery is very bright. This article has highlighted some fundamental advantages that robotics brings to the operating room and the benefits healthcare providers and their patients will experience. The introduction of the first commercial robotic product into surgery was nearly a decade ago. However, it is clear that significant advancement of this technology is still ahead of us, and the clinical application and benefits from this technology remains in their formative years. I hope that readers of this article become encouraged by the diverse and significant opportunities for this technology and would be willing to lend a hand in shaping the future of this exciting new industry.

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