History of Telesurgery

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Hippocrates (480–390 B.C.) defined surgery as the therapeutic activity practiced by the means of the "hands." The figure of the ancient surgeon was surrounded by a kind of mysticism because they touched the inside of the sacred human body with naked hands. The early Greek surgeons reported the use of limited surgical tools to assist with surgical procedures beginning the separation of the surgeon's hands from the patient. Halsted pioneered the use of the surgical glove in 1894 and separated the surgeon a little further form the patient. The twentieth century has seen the addition of laparoscopic surgery that moved the surgeon's hand outside the body to reduce surgical trauma and improve patient outcomes. Despite these advances, some form of physical contact between the surgeon and patient has always remained. Surgical robotics at the turn of the twenty-first century has produced the technology to disrupt even the paradigm of surgeon-patient proximity.

Robotics entered the operating room in 1985 with the PUMA 200 industrial robot adapted for CT-guided brain biopsy [5]. In 1988, the PROBOT was an ultrasound-guided system used to perform prostatic resections [4]. The first commercially available medical robot came in 1992 with the ROBODOC (Integrated Surgical Systems, Sacramento, CA). The system was designed and approved to precisely mill the femur for hip replacements. This first generation of surgical robots was notable for performing image-guided precision tasks but was limited by the need for preoperative planning and basic computer interfaces.

The evolution of surgical robots has led to a current generation of real-time telemanipulators. The AESOP® (Automated Endoscopic System for Optimal Position, Computer Motion Inc., Goleta, CA) was the first robotic system approved for general surgery [1, 9]. In the emerging era of laparoscopy, the system was designed to assist the surgeon by taking control of the laparoscopic camera and responding to voice

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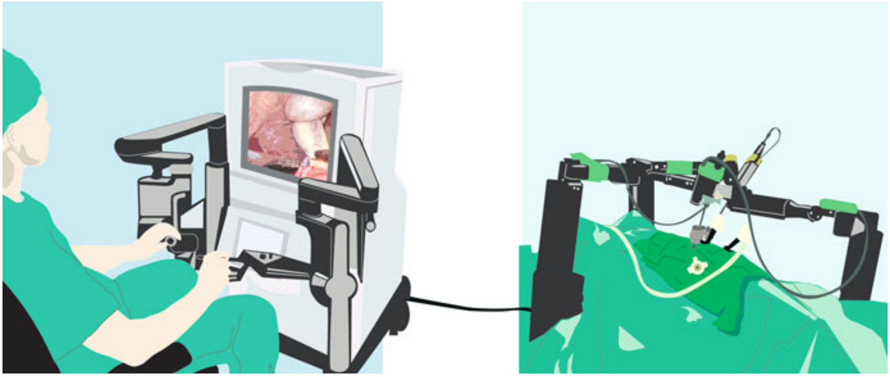

Fig. 2.1 The fundamental configuration of a surgical robot that enables telesurgery. The surgeon and control panel are separated from the patient and robotic arms

commands [8, 11, 14, 15]. The next step was to create telemanipulation machines where the robot mimics the gestures of the surgeon (Fig. 2.1). In these units, the "master" control console, from which the surgeon operates, is physically separated from the "slave" unit, composed of the robotic arms performing surgery on the patient.

The development of telesurgery arose in the 1970s with the aim to replace the surgeon physical presence in situations of mass casualties in hostile environments such as war or natural catastrophes. While the foundation of telemanipulation surgical systems can be traced back to the United States National Aeronautics and Space Administration (NASA), their major development was funded by DARPA (Defense Advanced Research Project Administration) as a potential military tool for remote surgical care of the injured soldier. Two main teleoperator surgical robots were developed from the research: the da Vinci® Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA) and the ZEUS® system (Computer Motion, Goleta, CA). Intuitive Surgical and Computer Motion merged in 2003, resulting in a single FDA-approved robotic platform on the market today that carries the name da Vinci®.

Early systems required the surgeon to be in the same room as the patient. However, with the use of telecommunications, both telementoring and telemanipulation were attempted from remote locations [2, 3]. One early report from 1996 demonstrated the ability of a surgeon in the same city to successfully mentor another surgeon as well as manipulate an endoscopic camera [7]. While successful, it was felt that latency in data transmission limited telemanipulation to a distance of a few hundred kilometers [12].

Fortunately, the telecommunications industry has also seen significant improvements since the invention of the telephone in 1876. Modern fiber-optic global connections allow reliable high-bandwidth data transmission with delays of less than 500 ms. The combination of high-speed telecommunications and a modern telemanipulator enabled all limitations on global telesurgery to be broken by "Operation Lindberg," the first transatlantic surgical procedure. Using advanced asynchronous transfer mode (ATM) telecommunication technology, a surgeon

Fig. 2.2 Operation Lindberg: the first transcontinental telesurgical procedure

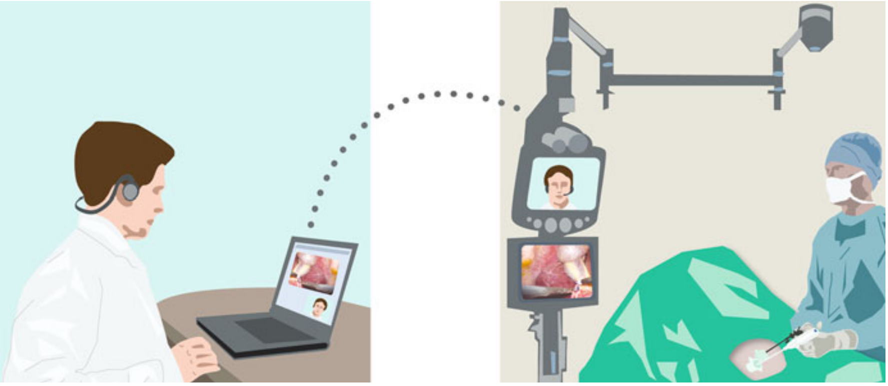

Fig. 2.3 Surgical telementoring enables a specialist surgeon to remotely assist in complex procedures

worked from a control panel in New York, United States, to successfully perform a complete cholecystectomy on a patient in Strasbourg, France (Fig. 2.2) [6].

The routine use of telesurgical applications is still under development. In addition to technical challenges, there are many medical-legal, billing, and liability issues that must be resolved to enable telesurgery across state and national boundaries. Progress has been made in telementoring, where specialist surgeons can mentor local surgeons through telepresence. Telementoring programs that allow rural hospitals access to specialists are being established worldwide (Fig. 2.3). Early reports shown that specialist surgical skills can be disseminated effectively using telementoring [13].

Telesurgery remains in its infancy. Significant challenges remain for the field including the cost-effectiveness, access to bandwidth, regulations, and adoption. Telesurgery in extremely remote locations is limited by the availability of advanced telecommunications. However, recently work on satellite-based telecommunications has shown feasibility for telesurgery despite higher latency than Internet-based data transmission [10]. Another current limitation is the lack of tactile feedback that removes the key aspect of feel from the surgeon's hands.

Despite current limitations, the potential of surgical robotics and telesurgery is enormous. The ability to deliver surgical expertise to distant locations will benefit patients worldwide. Surgical robots additionally hold the promise of more than just master–slave configurations for a remote surgeon to operate in real time. One day, patient-specific models may be created from advanced imaging. Such models could allow a surgeon to remotely simulate a procedure prior to operating and determine the best surgical strategy. Ultimately, if a robot can be preoperatively trained by a remote surgeon to do the procedure, the robot may be able to autonomously perform surgery. While the future is hard to predict, one thing is for sure, the paradigm of physical contact between the surgeon and patient has been broken leading to an era where surgeons can operate from across the room, across the country, and even across continents.

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