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Telesurgery: Surgery in the Digital Age

BY DYLAN CAHILL '18

Figure 1: The controls of robotic surgical systems provide surgeons with enhanced dexterity, precision, and sensitivity.

Source: Wikimedia Commons (Credit: Kemberly Groue)

Introduction

The dawn of the digital age has transformed the way we now receive and provide healthcare. Today, providers have instant access to all of their patients' information, just as patients can connect with their providers on their smartphones in minutes from nearly anywhere in the world. These advancements fall under the broad category of telemedicine, the use of communications technologies in medicine to provide healthcare remotely (Kahn et al., 2016).

Telemedicine has existed for decades, and has seen significant growth in the last 20 years (Kahn et al., 2016). More recently, advancements in both robotic surgery and high-speed data transmission have facilitated the practice of telesurgery, which allows surgeons to operate on patients remotely. Telesurgery, much like telemedicine more broadly, offers numerous healthcare benefits including more timely patient access to care, greater physician communication and collaboration, reduction in healthcare and travel costs, increased efficiency, and the ability to provide healthcare to remote and underserved areas.

What is Telesurgery?

Telesurgery, sometimes referred to as telerobotic surgery, is a specialized form of telemedicine, featuring robotic surgical devices that enable surgeons to operate on patients remotely. Most telesurgical devices consist of two main components common to all robotic

surgical systems: a "master" control unit where the surgeon operates using hand and foot controls while watching the surgery on a high-quality 3D monitor, and a "slave" unit containing robotic arms that operate on the patient (Benyó et al., 2011; Johnson and Somu, 2016). In the case of telesurgery, the master control unit may be located hundreds to thousands of kilometers away from the patient in the operating room. Though the concept of telesurgery may appear novel or risky, the basic idea of using robots to carry out complex tasks from great distances is nothing new; it has been nearly two decades since NASA began operating its first Mars rover, Pathfinder, over 225 million km from Earth (Allaby, 2013).

The concept of telesurgery originated with NASA in the 1970s as the space program began considering the possibility of operating on astronauts remotely (Benyó et al., 2011; Corleta and Ghezzi, 2016). At the time, the military was also keenly interested in the development of a platform that could be used to provide surgeries to soldiers in battlefield clinics. In the following decade, the field of telesurgery became a rich area of research along with initiatives promoting the development of minimally invasive surgery techniques and robotic surgical devices (Benyó et al., 2011). The first "master-slave system" was developed in the 1990s, and various robotic surgery devices were tested before the da Vinci® Surgical System gained FDA approval in 2000 (Corleta and Ghezzi, 2016). Today, the da Vinci surgical system is the most widely used robotic

surgery system, with nearly 4,000 units installed worldwide, though nearly all are exclusively used for on-site surgeries (Benyó et al., 2011). Most telesurgeries performed to date have used robotic surgical systems that operate using principles similar to da Vinci, such as ZEUS®, RAVEN, and M7 (Benyó et al., 2011; Corleta and Ghezzi, 2016).

‘Far-Reaching’ Benefits

Many of the benefits of telesurgery are comparable to those of telemedicine in general. Telesurgery extends a surgeon’s sphere of influence from his or her local community to patients across the globe. Patients can now be connected with world-class surgeons from their local operating room, provided it is equipped with the telesurgery slave unit. This benefit is particularly valuable in remote areas, such as in developing countries where surgeons and other medical experts are in short supply (Marescaux et al., 2002). Many rural clinics, underserved communities, and military sites are short-staffed, and complex emergency operations often first require the transport of patients to far-away medical centers; telesurgery allows surgeons to provide immediate care in these time-critical situations (Marescaux et al., 2002).

Because telerobotic surgery operates through robotic surgical systems, it also takes advantage of all existing benefits of general robotic surgery. These benefits include increased dexterity, more natural hand-eye movement than traditional laparoscopic surgery, filtering of hand tremors, customizable sensitivity settings, and high-quality 3D visualization with up to 10X magnification (Corleta and Ghezzi, 2016). Additionally, telerobotic surgery simulators, such as the Virtual Reality Simulator dV-Trainer®, have been developed to generate immersive virtual reality experiences for training both novice and expert surgeons (Felblinger et al., 2014). These training opportunities allow surgeons to limitlessly practice realistic operations prior to making the first incision on a patient.

Telesurgery has also been demonstrated as a useful platform for surgical training. Soon after the first successful demonstrations of telerobotic surgeries, a hospital-to-hospital laparoscopic telesurgery clinic was established in Canada to provide care to patients in a rural community 400 km away (Anvari et al., 2005). In the clinic’s first two years, surgeons completed 21 successful remote surgeries, nearly all of which involved some form of collaboration between the telerobotic surgeon and local laparoscopic surgeon (Anvari et al., 2005). The clinic noted that the greatest advantage of the technology was the ability for local surgeons, who lacked a formal fellowship in laparoscopic surgery,

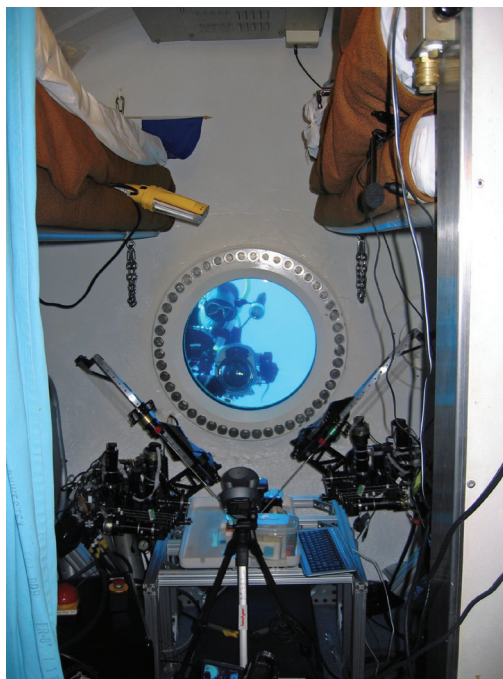


Figure 2: A surgeon in Seattle remotely guides the slave unit of RAVEN, a telerobotic surgical system, on Aquarius, 19 m below sea level off the coast of Florida.

Source: Flickr (Credit: NASA Johnson)

to request and benefit from the guidance of an expert surgeon (Anvari et al., 2005; Anvari, 2007). Local surgeons completed the surgeries with confidence and most importantly great outcome; there were no major intraoperative complications and all patients had uneventful recoveries (Anvari et al., 2005). In addition, patients were enthusiastic about the ability to receive expert surgical care from their home community. All patients offered telesurgery accepted, and other patients began requesting telesurgery even when it was unnecessary (Anvari, 2007).

Telesurgery is more complex in under-resourced and underserved communities, however, as many currently lack robust and reliable networks (Felblinger et al., 2015). Here, telemonitoring may serve as a transition phase before full-scale robotic surgical systems are made available. In surgical telemonitoring, an expert surgeon remotely guides an inexperienced or untrained surgeon over live videoconferencing (Gambadauro and Torrejón, 2013). Studies have shown that junior surgeons can carry out telemonitored laparoscopic operations with outcomes comparable to those of operations performed with an expert surgeon physically present (Gambadauro and Torrejón, 2013). In 1999, five telemonitored laparoscopic surgeries were carried out aboard the USS Abraham Lincoln, preventing the need for an emergency evacuation or a trip to the shore (Gambadauro and Torrejón, 2013). The main advantages of telemonitoring over telesurgery are that it can be performed at a much-reduced cost and that it puts patients at less risk in the case of network outages.

The benefits of telesurgery extend beyond

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the typical hospital setting. Experiments evaluating the performance of telerobotic surgeries have already been performed aboard one of NASA's "Zero Gravity" aircraft to study how weightlessness affects the prospect of telesurgery on astronauts (Benyó et al., 2011). Several telemedicine and telesurgery experiments have also been performed on Aquarius, NASA's underwater research station 19 m below sea level off the coast of Florida. Most of these experiments focused on testing the effects of time delay on human performance (Benyó et al., 2011). In 2007, a surgeon in Seattle performed a simulated surgery over 4500 km away via a telerobotic system on Aquarius (Benyó et al., 2011). These experiments are important milestones in demonstrating the feasibility of telesurgery not only in space and underwater laboratories, but also in remote and underserved areas which may lack traditional operating rooms or full-scale telerobotic surgical systems.

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Current Obstacles

Despite its many promises, telesurgery currently faces several limitations preventing its wider use. The most significant issue is latency, the time from the surgeon's initiation of a movement to the corresponding movement appearing on the surgeon's screen (Marescaux et al., 2002). More colloquially known as "lag time," latency demonstrably impacts surgical performance, and has therefore been the focus of the majority of telesurgery feasibility experiments to date (Marescaux et al., 2002; Felblinger et al., 2014; Felblinger et al., 2015). Latency is largely dependent on the distance between the master and slave units (Benyó et al., 2011). Until research demonstrates that telerobotic surgeons are consistently able to

provide the same quality of care with existing latencies as local robotic surgeons, telesurgery will be limited in influence to nearby hospitals rather than a global network.

A 2014 study evaluated the performance of 16 medical students in completing a series of simulated telesurgery tasks, including dissection and suturing (Felblinger et al., 2014). Latencies between 0 and 1000 ms were randomly introduced, and subjects were evaluated in categories including task completion time, number of errors, and fluidity of motion. The study found that overall performance decreases exponentially with increasing latency. The researchers concluded that latencies ≤ 200 ms are ideal for telesurgery, and latencies up to 300 ms, roughly the length of a blink, are suitable (Felblinger et al., 2014, Goldstein et al., 1984). Other studies have found that task completion time increases significantly only at latencies ≥ 500 ms, but that error rate remains low (Croome et al., 2006). More research is necessary to determine guidelines for acceptable latencies in clinical practice.

The 2014 simulation study also found that after 20 hours of training, subjects became experts conducting telesurgery with the full range of latencies, an effect that has been demonstrated in other telesurgery experiments on latency (Felblinger et al., 2014, Felblinger et al., 2015, Doarn et al., 2014). These findings are in contrast with other reports that contend effective sensory motor adaptation cannot occur at > 300 ms (Croome et al., 2006). Robot-assisted telesurgery is a proposed theoretical solution for cases in which latencies are greater than 300 – 500 ms. Robot-assisted telesurgery relies on predictive algorithms that combine information about the environment with the surgeon's movements (Benyó et al., 2011, Croome et al.,

Figure 3: A surgeon (not shown) operates on a patient via the four surgical arms of the da Vinci Surgical System at William Beaumont Army Medical Center in the Department of Defense

Source: Wikimedia Commons (Credit: Marcy Sanchez)





Figure 4: Dr. George Kallingal performs a pediatric robotic surgery at Brooke Army Medical Center while Dr. Thomas Novak observes.

Source: Flickr (Credit: Army Medicine Flickr)

2006). This added information facilitates the surgeon's efforts to create more fluid movements (Benyó et al., 2011, Croome et al., 2006). With current technologies, telesurgeries could feasibly be performed on astronauts at distances up to 380,000 km, roughly the distance to the moon (Benyó et al., 2011). The main limitation with telesurgeries at these distances is light-speed data transmission, leading to latencies of 500 – 2000 ms; telesurgery would be limited to simple procedures in cases of emergency (Benyó et al., 2011; Johnson and Somu, 2016).

Though measurable, latencies from some of the first successful telesurgeries fall well within acceptable limits. The first transatlantic robot-assisted telesurgery occurred in 2001 when surgeons in New York removed the gallbladder of a patient in France (Marescaux et al., 2002). Latency was a constant 155 ms throughout the 54-minute procedure (Marescaux et al., 2002). About 80 ms of the latency was due to round-trip delay and the rest was due to either video coding and decoding or conversion of the data stream for transport over internet (Marescaux et al., 2002). Ultimately, the patient suffered no post-operative complications and all three surgeons in New York rated their perception of the operation's safety a 10/10 (Marescaux et al., 2002). Similarly, latency for more than 20 surgeries in Canada's first telerobotic clinic averaged between 135 – 140 ms, though only 14 ms was due to round-trip delay (Anvari et al., 2005). The surgeons reported this delay to be noticeable but easily adapted to, and felt well-equipped to carry out the full range of complex surgical tasks required (Anvari et al., 2005).

Along with latency, bandwidth limits the

use of telesurgery in environments lacking robust communication networks. Bandwidth refers to the amount of data transmitted per given amount of time. An insufficient amount of bandwidth leads to buffering and incomplete data transmission, an obvious safety concern for telesurgery. Given current limitations in latency and bandwidth, telesurgery effectively requires dedicated networks (Felblinger et al., 2015). In Canada's first dedicated telesurgery clinic, the system operated using an Internet Protocol-Virtual Private Network (IP-VPN) with Quality of Service (QOS) (Anvari et al., 2005). This system is designed such that telesurgery communications take priority over all other network traffic, and features a fully redundant backup line. Another reliable and secure networking solution for telesurgery is asynchronous transfer mode (ATM) technology, which features exceptionally high speeds and large bandwidth capabilities of 10 Mbps or more (Marescaux et al., 2002). However, ATM technology requires additional infrastructure, unlike IP-VPN with high priority QOS.

A final, major limitation that telesurgery faces is its prohibitive cost. ATM lines cost \$100,000 to \$200,000 and telerobotic surgical systems range from \$1-2 million (Marescaux et al., 2002). These high costs are difficult to justify based on clinical outcomes alone, and are far too high for many rural and underserved clinics (Corleta and Ghezzi, 2016). However, improved access to surgical care, expansion into a global patient base, and increased efficiency all have the effect of lowering overall cost. Moreover, as with other expensive technologies, such as air travel and rockets, reusability effectively

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Figure 5: Robotic surgery simulators are routinely used to create immersive, realistic training experiences. Here, resident Bruce Rivers uses a virtual reality surgical simulator to practice an ophthalmology surgery.

Source: Flickr (Credit: Army Medicine Flickr)



lowers net cost per use. Finally, the cost of the technology is expected to decrease in coming years, making telesurgery systems accessible to a wider number of institutions and patients (Corleta and Ghezzi, 2016).

Future Directions

Telesurgery, a specialized form of telemedicine, enables surgeons to operate on patients remotely via robotic surgical systems. Telesurgery provides improved patient access to surgical care while facilitating surgical collaboration and training opportunities. Applications of telesurgery extend to aquanauts in underwater laboratories and astronauts as far as the moon. The biggest challenge telesurgery faces today is latency, and while a consensus has not yet been reached on acceptable latencies for operating, dozens of successful telesurgeries have already been performed around the world. In addition, the networking infrastructure requirements and telerobotic surgical systems are currently prohibitively expensive for many clinics. As technologies continue to improve, including the development of faster computer networks with higher bandwidth capabilities, and costs fall, telesurgery is likely to become more widely used. **D**

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