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In Brief

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Over the past decades, rapid advancements in computer technology, robotics, and telecommunications have enabled novel improvements in medical training and the expansion of the technological tools available to physicians. The ever-growing telecommunications network makes medical information instantaneously accessible for both the doctor and the patient, allowing many aspects of medicine to overcome the restrictions of geography. Telemedicine has proven useful in improving accessibility to specialist care, breaking geographic barriers of surgical training, and has additionally provided novel teaching methods in medical education. For patients, it has improved access to specialty care for vulnerable populations, reduced resource burden of clinic visits, and improved efficiency of postoperative follow-up.

Telementoring facilitates the knowledge transfer from an experienced surgeon to a trainee and can take on different forms depending on the degree of involvement of the mentor. The most basic level, verbal guidance, involves real-time feedback from a mentor observing a video stream of the trainee in the operating field. At the next tier, a mentor may provide guidance using telestration, a method in which the mentor can annotate and comment on the real-time video of the operation through a visual overlay on a monitor that is displayed to the trainee in the operating room. Telestration may take place in 2-dimensional (2D) or 3-dimensional (3D) forms. In the 2D modality, the telementor may annotate within the plane of the video screen. The use of 3D telementoring is one of the newer topics of ongoing research and developments to create new ways of more immersive learning. A computer program has been developed that can transpose the 2D annotations from a mentor directly onto the trainee's 3D field of view using the da Vinci robot. Other technologies involve using motion controllers and 3D mapping software to overlay virtual tools onto stereoscopic images from the trainee's video

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feed. Through these varied approaches, telementoring can provide increasingly immersive and directed training experiences for the surgical trainee.

Telementoring is becoming commonly implemented and investigated in surgical training across a wide variety of subspecialties. In the field of neurosurgery, long-distance telementoring was implemented to assist in craniotomies, carotid endarterectomies, and lumbar laminectomies. A study has demonstrated the feasibility of a remote mentor controlling a surgical robot to aid in pedicle screw placement in patients undergoing spinal surgery. Within the field of obstetrics and gynecology, studies involving remote reviewing of tele-colposcopies and telementoring of an operative fetoscopy have been published in recent literature. Otolaryngology is another surgical subspecialty experiencing a rising interest in telementoring, with recent studies reporting successful telementoring of endoscopic endonasal procedures.

With the increasing availability and affordability of mobile devices and advancements of internet infrastructure, telementoring is becoming more accessible across the world. For example, the virtual interactive presence and augmented reality system utilizes a commercialized tablet at the local station and remote mentoring station to form a single merged surgical field display, which can be streamed to the local surgeon's operating room via remote wireless networks in real time. Development of network infrastructure such as the next generation 5G mobile network reduces latency time and improves the quality and speed of the telementoring process. Taken together, these advancements in modern technologies have made telementoring much more affordable and available.

Traditional forms of telementoring relied on annotated video displays from the remote surgeon. The next generation of immersive telementoring involves wearable augmented reality devices, which provide a real-time 3D view of the local surgical site while incorporating the annotation from the remote mentoring surgeon directly onto the surgical view of the local surgeon. The device can also be equipped with a fully functioning microphone and headset, allowing direct communication between the 2 parties. Microsoft's HoloLens, a device that enables manipulation of holograms and 3D images, has been investigated as an option in augmented reality telementoring. When worn by both the local and remote surgeon, the remote surgeon can demonstrate complicated surgical maneuvers in 3D, which is then transmitted to the local surgeon and displayed on their HoloLens device in real time. Having been tested in vitro, further research is needed to translate the utility of these newer technologies into clinical practice.

Thanks to continuous improvements in robotic technology, a telementor may even extend their assistance physically into the operating room; the robot may participate in the procedure by adjusting camera angles or by providing lighting or retraction. Beyond the realm of medical training, telesurgery may even encompass an entire surgical procedure start-to-finish by a surgeon in a remote location. This has been tested mostly in animal and simulation models but also utilized in direct patient care through some minimally invasive procedures such as laparoscopic cholecystectomy and ultrasound-guided prostate biopsy. Haptic feedback technology enables the surgeon to feel the tensile strength, depth, and texture of the surgical tissue without being in the local operating room and is an area of ongoing development. Complete telesurgery is still an active topic of research, and the legal and ethical dilemmas of its application in clinical medicine may prove to be a barrier in its future development.

The ongoing research in telementoring and telesurgery is proving to be even more relevant in the era of the coronavirus disease 2019 pandemic, during which in-person mentorship may not be possible due to travel restrictions and social distancing.

Telemedicine is also emerging as a versatile tool for improving access to care. In one study, audiovisual technology connected patients in Georgia with clinics operated by pediatric neurosurgery specialists from the University of Florida through virtual encounters. These specialists cared for patients through the telemedicine clinic and ordered appropriate tests while trained nurses at the location of the clinic distributed care and facilitated referrals. Telemedicine can also be implemented for preoperative and postoperative visits, which in turn may alleviate travel-related expenses for the patient. Patients can use their smartphone camera to take photos of their surgical incision and send it to the surgeon to monitor for infection. A study utilized telehealth in follow-up visits for more than 100 patients who underwent hernia repair and cholecystectomies, showing that a set of directed questions pertaining to wound healing

and postoperative activity can be used to appropriately triage patients into higher and lower risk groups. The higher risk group were offered clinic visits with the surgeon. This study suggested that patients can be safely followed up through telehealth with minimal complication rates, while reducing the need for patients to travel. Regarding current clinical application of telemedicine, it is not surprising that its beneficiaries are often the patients with the most limited access to care, such as those who live in rural areas or areas of conflict. Appropriate use of telehealth may also alleviate significant time and financial burdens that may occur from a doctor's visit. For the health care provider, use of telemedicine opened appointments for the surgical specialist to see new patients, and by decreasing postoperative clinic visits, likely reduces the cost to the health care system overall.

Telemedicine has also shown great promise in screening programs, such as in the realm of ophthalmology. Diabetes is one of the leading causes of blindness in the United States. The increasing population of diabetic patients may pose a significant demand on the health care system, and early screening for diabetic eye disease is crucial in saving vision. New imaging technology is already being used to automatically determine the presence or absence of diabetic retinopathy and place a referral for a full eye examination if indicated. These imaging units may be handled by a trained nurse or technician, and some do not require eye dilation. A problem that then arises is the image burden that could accumulate from universal image-based diabetic retinopathy screening; this could yield up to 1 billion images annually worldwide, which greatly outnumbers the number of trained personnel needed for expert reading and interpretation. In response to this, developments in artificial intelligence and machine learning have shown promise in automated basic screening of images for disease, only referring patients with signs of disease to an eye care provider. The combination of these telescreening technologies also introduces the potential for non-ophthalmologic providers to initiate diabetic eye screenings, which greatly improves access to care. Other studies show the promise of telescreening for glaucoma, macular degeneration, and retinopathy of prematurity. These screening programs show promise in leading to timely referrals, improved patient follow-up, and adherence to care.

Although the rapid development of new technology and the internet has introduced great potential in the domain of telemedicine, considerations towards patient safety and privacy, costs of implementation, and themes of legality and medical ethics should be kept in mind.

The involvement of the internet is a key component in delivery telemedicine to patients. Maintaining patient safety should be a top priority in telehealth, as it does in all aspects of health care; however, cyberattacks and unstable internet connections may complicate telementoring during surgery or telesurgery, especially when there is limited available infrastructure to prevent against malicious attacks. Maintaining patient privacy, especially when massive amounts of sensitive images and patient data are transferred through the internet, should also be a priority.

Additionally, telemedicine may cause confusion for patients regarding the identity of their health care provider. For a patient undergoing surgery that is overseen by telementoring, should the telementor be considered the patient's surgeon? If the patient experiences a bad outcome from the surgery, should the mentor be held responsible even though they were not physically in the operating room? Additionally, yet to be clarified is the financial relationship between the patient and the telementoring physician. Furthermore, no standard operating procedures exist for patient consent of telesurgical procedures. In the best interest of the patient, these ethical and legal considerations should be investigated further before telesurgery and telementoring can be implemented on a wider scale.

Due to advancements in medical engineering and communication technology, it is becoming easier to share knowledge with medical trainees across the world through telementoring. Telemedicine has also been proven to benefit patients through effective screening programs and providing simple postoperative care and triage services, especially to those with poor access to care. Despite the benefits, telemedicine, telementoring, and telesurgery also carry unique challenges to patient safety and the doctor-patient relationship. This is an area of active research and its possible applications may be a shaping force in the future of modern medicine.