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Remote Surgeon Virtual Presence: A Novel Telementoring Method for Live Surgical Training

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Purpose: We describe the first known use of telementoring in corneal surgery and technology combining a 3-dimensional microscope system, 5G live streaming technology, group chat software, and a virtual reality headset for intercontinental surgical supervision.

Methods: Three surgeons in Toronto were proctored by a surgeon in Israel in the implantation of a novel keratoprosthesis device (CorNeat KPro; Ra'anana, Israel) into cadaver eyes. In Toronto, the NGENUITY platform (Alcon) transmitted high-definition, 3-dimensional images to the proctor in Israel who viewed the live video through a GOOVIS Virtual Reality headset with subsecond latency. This was made possible by the LiveU technology (Hackensack, NJ), which is a portable device to increase the bandwidth of transmission. The primary outcome was the successful completion of CorNeat KPro implantation. After each procedure, all surgeons completed a Likert scale questionnaire that assessed opinions on telementoring.

Results: All participants implanted the CorNeat KPro device. There was significant satisfaction reported. A total cumulative score from the questionnaire was 149 of 150 from the operating surgeons, with a score of 135 of 150 by the proctor. All felt that there was excellent AV quality with no lag time and recommended the technology.

Conclusions: Telementoring is a promising tool that can traverse large distances for ophthalmic education.

Key Words: telementoring, 3-dimensional, wet laboratory, ophthalmology, keratoprosthesis

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Telemedicine has seen an unprecedented growth over the past few decades, owing to advances in key digital innovations in information and communication technology.[1] Telementoring is a branch of telemedicine, which harnesses data streaming technology to provide real-time supervision and technical assistance for surgical procedures from an expert at a remote geographical location.[1,2] It removes many of the existing issues with traditional mentoring, including travel costs, distance, and time constraints.[3] Repeated studies have demonstrated no difference in skill acquisition or knowledge when comparing traditional on-site mentoring with telementoring.[4,5] Alongside its educational advantages, telementoring can also have a direct clinical impact on patient care by providing immediate access to surgical expertise. Studies have demonstrated that telementoring can successfully guide a surgeon lacking experience in laparoscopic general surgery.[6–8] Thus, this developing technology has the potential to significantly reduce the inequalities in access to surgical care worldwide by providing surgeons from remote areas access to top surgical knowledge and talent.

The global COVID-19 pandemic has forced a shift in attention to health care systems and their need to rapidly adapt to telehealth and digital innovations to circumvent the impact caused by lockdowns, social distancing, and travel restrictions. Ophthalmology has been slow to embrace telementoring technology relative to other surgical specialties, with only a handful of previously reported studies.[9–11] This has implications on delivery of education, advancing industry and scientific innovations, and promoting quality clinical care.

We describe the first known use of telementoring in corneal surgery. This first time use leveraged technology combining a 3-dimensional (3D) microscope viewing system (NGENUINTY 3D Visualization System, Alcon, Fort worth, TX), 5G capable live streaming software/hardware device (LU600 HEVC; LiveU, Hackensack, NJ), group chat computer software (Microsoft Teams, Microsoft, Seattle, WA), and a virtual reality headset (GOOVIS; Guangdong, China) for real-time, intercontinental remote surgical supervision.

METHODS

A Remote Surgeon Virtual Presence (RSVP) solution was used in a surgical wet laboratory setting (Kensington Eye Institute, Toronto, Canada) where a novel keratoprosthesis (CorNeat KPro; CorNeat Vision, Israel) was implanted into cadaver donor eyes.[12,13] The CorNeat device was deliberately chosen to avoid bias from previous surgical experience because none of the learner surgeons had previously used this device. Hence, this provides a more robust way of assessing the educational platform of this system. The RSVP solution uses 3 main devices (Fig. 1).

The LiveU technology enables the use of several digital links (from 2 to 32) and combines them to create more than the necessary bandwidth. Should any of the links fail, the relaying technology automatically distributes the traffic across the remaining links. This automatic redistribution is accomplished in typically less than 100 ms, so no delay is noticed by end users. Data connections can include 4G/5G modems across most major local cellular carriers, as well as Wi-Fi, Ethernet, and even portable satellite links. Consequently, high data volumes such as 3D audio–visual data can be transferred with minimal latency. This offers solutions to suit any live scenario, including breaking and developing news stories, high-profile sports events, and mobile broadcasts from moving vehicles.

The LiveU portable device was then linked using HDMI to a 3D visualization platform (NGENUITY, Alcon, Fort Worth, TX). The LiveU streaming device sent the images that the surgeon experiences on the 3D monitor to the virtual reality headset (GOOVIS) worn by the instructor with nondetectable delay. An immersion, instantaneous, and comprehensive audio–visual experience is achieved for both surgeon trainers and trainees in 3D. This setup effectively replicates the day-to-day, on-site, teaching experience where both trainee and mentor are in the same operating room. In fact, anyone wearing 3D glasses in the operating room was immersed in the same view and was able to provide additional feedback. Everyone connected could provide seamless, instant feedback and advice regardless of the geographical location.

With the above-mentioned equipment setup, a wet laboratory training session was performed in real time between Toronto and Ra'anana, a geographical distance of 9,263 km. Three expert corneal surgeons (D.S.R., C.C., and A.I.) in Toronto were supervised in their training by G. Litvin in the CorNeat head office in Ra'anana, Israel. To familiarize themselves with the technique and operative steps, the surgeons participated in a preliminary presentation given by G. Litvin through MS Teams before the surgery in a wet laboratory.[14] The presentation included specifics on all relevant surgical steps and a video displaying the procedure in rabbits.[15] Throughout the wet laboratory session, frequent dialog and monitoring of the steps were directed by the proctor. Audio was provided with the built-in speakers from the laptop, which also displayed a live image of the instructor through group chat software (Microsoft Teams; Microsoft, Seattle).

The primary outcome was the successful completion and insertion of the CorNeat KPro device in human cadaver eyes. After each procedure, both the surgeons in Toronto and the proctor at the CorNeat Headquarters in Ra'anana completed a Likert scale questionnaire (with possible responses ranging from 1 for "strongly disagree" to 5 for "strongly agree") that assessed their reaction to the RSVP platform based on 3 categories: efficiency, safety, and teaching. Cumulative scores were then calculated for surgeon

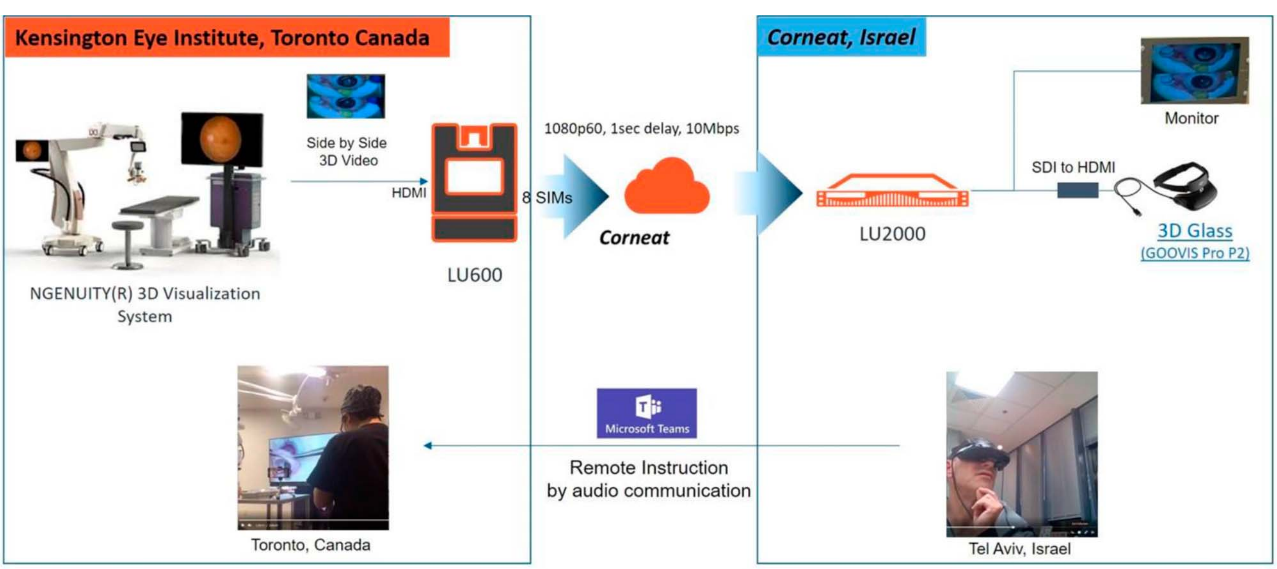

FIGURE 1. Flowchart showing a surgeon using the NGENUITY 3D visualization system in Toronto, which links with the LiveU high-bandwidth system, to transmit 3D images and audio to the GOOVIS headset in Tel Aviv. (The full color version of this figure is available at www.corneajrnl.com.)

and proctor. In addition to the Likert scale survey, an opportunity to provide a response to the questions was available to help gain a qualitative perspective on the primary research question.

RESULTS

The primary outcome of successfully implanting the CorNeat KPro was achieved by all participants. Table 1 summarizes the cumulative questionnaire results from all 3 surgeons. In all 3 categories, efficiency, safety, and training, there was significant satisfaction and strong support of the setup. A total cumulative score of 149 of 150 was achieved.

When the proctor completed his questionnaire of the 3 separate wet laboratory sessions, the cumulative score was lower at 135 of a maximum of 150 (Table 2). The highest scoring outcomes were sufficient image resolution, reliability of the RSVP setup, no significant lag time, and providing feedback was considered easy. Both sets of surgeons in Toronto and Israel felt comfortable performing surgery with this format and would recommend it as a new mode of teaching practice.

In the free text comments of the questionnaire, both the surgeons and the proctor saw advantages of this platform. The expert surgeon had an amplified 3D visual field and was able to convey a sense of progress while the proctor felt his interactive experience was akin to physically being present. Both parties felt communication was excellent because there was no significant lag time.

In the operating room at an ambulatory surgical center in Toronto (Kensington Eye Institute), the CorNeat keratoprosthesis device was successfully implanted into a cadaveric eye by each surgeon (Fig. 2A,B). The instructor (G.L.) was able to witness the microscope view with negligible delay and provide immediate assistance to guide surgical maneuvers, troubleshoot any complications, discuss overall surgical strategy, and, with his high-resolution virtual reality headset, was able to check the correct placement of the device (Fig. 2C). G. Litvin was able to answer queries about the surgical technique without any delay or interruption in sound or video quality (Fig. 2D) by using the LiveU device (Fig. 2E) and Microsoft Teams for audio. The 3 separate wet laboratory live streaming sessions lasted between 2 hours 15 minutes and 3 hours, and there were no technical issues encountered throughout.

DISCUSSION

The Toronto–Israel RSVP wet laboratory provides proof of concept that a long-distance and real-time 3D telementoring service is now readily feasible. Current advances in the speed of digital and telecommunication technologies in hardware and software have allowed for a remote trainer–trainee experience with high-resolution imaging and audio with nondetectable lag time, necessary for supervising a surgical procedure in real time over long distances.

There have been limited studies on telementoring in ophthalmology. Ye et al[9] successfully demonstrated a low-cost solution by using an iPhone adapted into a surgical microscope in China with a laptop receptor in Miami, FL. Three cataract surgeries were performed with both opposing parties conversing smoothly and no lag time or distortion perceived. Camara et al[10] reported the successful removal of a lateral orbital tumor from a site 210 miles away by a general ophthalmologist who was proctored by a specialist orbital surgeon. A 3-mm endoscope connected to a digital video camera and attached to a Concorde 4500 PictureTel videoconferencing system was used to transmit images at a rate of 384 kb per second. All these techniques used a 2-dimensional view. Previous attempts at using a 2-dimensional platform using the LiveU system to instruct learner surgeons were found to be unsuccessful citing difficulties in appreciating the operative field. However, with the 3D capable NGENUITY platform, the resolution and depth perception allows a greater ability for the trainer to instruct. About costs, the LiveU business model is lease-based where a single monthly payment covers the unit, server, cellular data, and 24/7 customer support, including software and hardware upgrades. The price is determined by the unit that is required and varies

TABLE 1. Questionnaire Response From Surgeons Being Proctored in Toronto

Efficiency	There were no issues with the flow of the surgery?	15
Efficiency	There was no lag/delay in transmission?	15
Safety	Image resolution was sufficient?	15
Safety	Audio quality was sufficient?	15
Safety	The surgeon felt safe while performing the surgery?	15
Safety	The setup did not interfere with my surgery?	14
Teaching	The anatomy was easily evaluated?	15
Teaching	I would recommend this method of learning a new surgical technique to others	15
Teaching	I would feel comfortable performing surgery on a live patient after this wet laboratory session?	15
Does the surgeon feel comfortable performing surgery on a live patient after this wet laboratory session?		15
Cumulative score		149/150

Table 2. Questionnaire Response From the Proctor Based in Tel Aviv

Efficiency	Progress of the procedure was easy to follow?	12
Efficiency	No significant lag/delay was noted in transmission?	15
Safety	There was sufficient image resolution?	15
Safety	For reliability, the 3 cases proctored were similar in audio–visual quality?	15
Safety	Audio quality was sufficient?	12
Safety	Supervising the surgeries was safe?	12
Safety	The technical setup did not interfere with my proctoring of surgery	12
Teaching	The anatomy on screen was easy to evaluate?	12
Teaching	Providing feedback was easy to do?	15
Teaching	Would the surgeon recommend this method of teaching a new technique to others?	15
Cumulative score		135/150

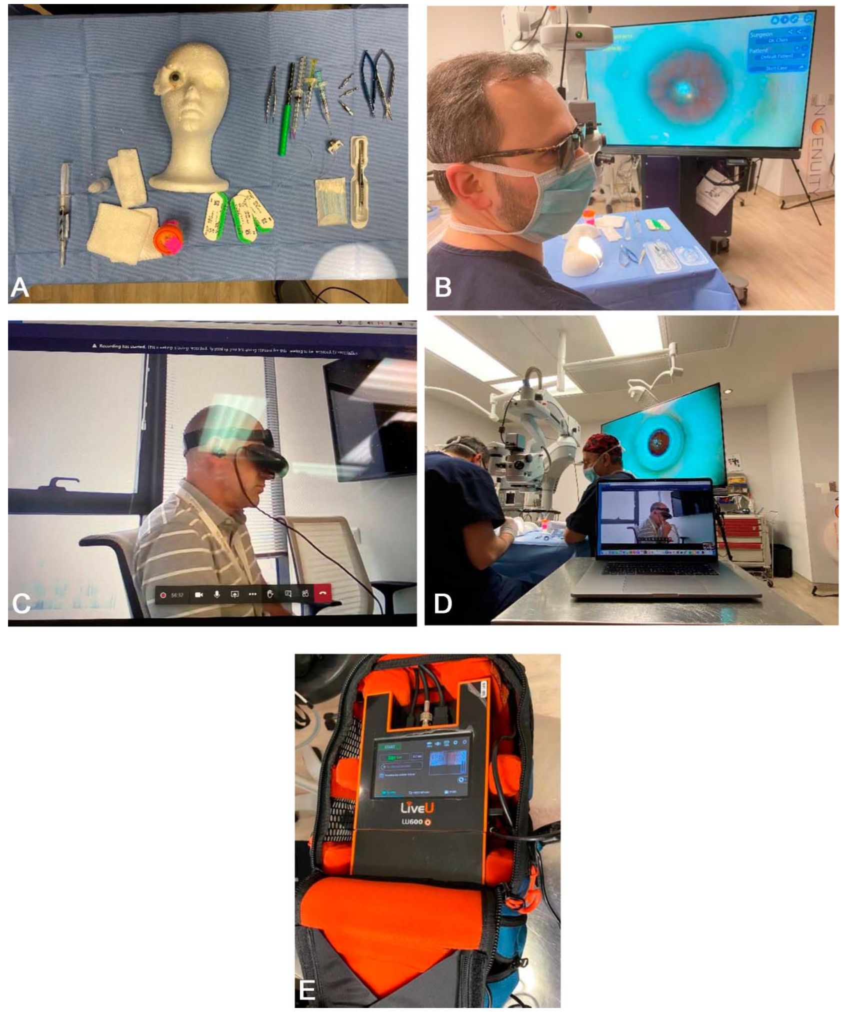

FIGURE 2. RSVP. A, Assembly of wet laboratory with mannequin head, novel artificial cornea device CorNeat KPro, and instruments in Toronto. B, Surgeon in Toronto listening to instructions from G. Litvin instructor at CorNeat Headquarters in Israel while wearing 3D glasses for the NGENUITY visualization platform connected to the Zeiss operating microscope. (C, D), Instructor in Tel Aviv wearing the GOOVIS virtual reality headset providing real-time audio and visual instruction to train through Microsoft Teams group chat software. E, The LiveU platform in a portable case providing 5G 4K—enabled live streaming and remote production. (The full color version of this figure is available at www.corneajrnl.com.)

between $1,000 per month and $1,500. This is both financially and environmentally cost-effective compared with in-person training.

The telementoring setup in our study has the potential to change surgical training practice. The high-bandwidth network provided by the LiveU system allows for a cost-effective and portable solution. With transmission speeds up to 70 Mbps, this allows for the facilitation of live 3D feeds to large conferences, or groups on individual computers, which has become even more pertinent in the present COVID-19 era and in the future. Our study was performed with 4G technology; however, with the increasing use of 5G technologies, the RSVP experience will be enhanced even further to the advantage of both learner and trainer. It can facilitate greater accessibility and knowledge transfer to developing rural areas while also supporting the acute on-call setting. For instance, the time to transport a patient for emergency surgical intervention may exceed the time of optimal intervention. Hence, the remote expert surgeon can then guide the local surgeon during the procedure. This concept can be expanded further where expert surgeons can train surgeons in the developing world, expanding their knowledge and skill base. Rather than the traditional expeditions that often span a few weeks a year, with appropriate technological investment, access to the expertise of renowned surgeons can occur on a cost-effective, frequent basis. This allows greater equity of surgical skills training worldwide. The authors are now setting up a phacoemulsification facility to train cataract surgeons in Honduras remotely from the United States

There have been conflicting messages regarding the utility of telementoring. In a systematic review of 66 studies, of which 71% were conducted in general surgery and urology, 58% of the studies did not show a difference between on-site mentoring and telementoring.[16] Furthermore, no study found telementoring to result in poorer postoperative outcomes. In a separate study focusing on robotic-assisted laparoscopic radical prostatectomy, it was found that there was no significant difference between clinical outcomes for telementoring or on-site mentoring.[17] However, in a recent survey of UK trainee ophthalmologists, telementoring was considered uncertain or not useful. It might be argued that the results of this particular survey may be attributable to the limited current role of telementoring in ophthalmology.[18] It is conceivable that in the future, the use of telemedicine within formalized training programs can allow increased autonomy for trainee surgeons alongside appropriate existing levels of in-person supervision.

Augmented reality remains the next step in telementoring in ophthalmology whereby symbols and pointers can be overlaid over the live feed to further assist the student surgeon. As described by Vyas et al,[19] cleft lip surgery was performed remotely from California to 2 Peruvian surgeons treating cleft lip. This combined remote yet live and interactive digital presence so that expert surgeons could use pointers and simultaneously annotate diagrams to enhance the trainee surgeons' experience. In orthopedics, a similar remote process occurred using interactive virtual processing and was found to be an efficient, safe, and effective teaching tool. Both attending and resident surgeons agreed that training was enhanced especially with the use of a "finger pointer" for identification of anatomy.[20] Similar practices have been seen in neurosurgery, breast surgery, and urology.[21–23]

The global COVID-19 pandemic has led to a shift in clinical, investigational, and commercial practices. As a case example, the biotechnology company featured in this study, CorNeat Vision, had intended to launch their flagship cornea prosthetic device in 2020. However, with travel restrictions in play, the solution brought forward by RSVP allowed for a more cost-effective, environmentally friendly and arguably faster delivery of innovative devices from industry to the clinic or operating room and has not delayed the research rollout timeline.

However, there are some weaknesses to this technology. Because the instructor is not physically present in the room, they may not be able to make comments on what is occurring out of the microscopic field of view. Hence, the setup described in this study is likely best reserved for experienced rather than novice surgeons who are proficient in their basic surgical skills, such as knowing which instruments to use for various surgical steps, holding instruments, and loading a suture, although this is partially compensated for by the added use of teleconferencing software, such as Zoom or Teams.

In conclusion, this study demonstrates that telementoring is a promising clinical and educational tool that can traverse international borders to facilitate knowledge and skill transfer. Further studies are necessary to explore its full potential in ophthalmology and other areas of medicine.

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REFERENCES

1. Huang EY, Knight S, Guetter CR, et al. Telemedicine and telementoring in the surgical specialties: a narrative review. *Am J Surg*. 2019;218: 760–766.
2. Thomsen ASS, Saleh GM. Telementoring and remote training in the present era. *Acta Ophthalmol*. 2021;99:e617–e618.
3. El-Sabawi B, Magee W III. The evolution of surgical telementoring: current applications and future directions. *Ann Transl Med*. 2016;4:391.
4. Moore RG, Adams JB, Partin AW, et al. Telementoring of laparoscopic procedures: initial clinical experience. *Surg Endosc*. 1996;10:107–110.
5. Rosser JC, Wood M, Payne JH, et al. Telementoring. A practical option in surgical training. *Surg Endosc*. 1997;11:852–855.
6. Singh S, Sharma V, Patel P, et al. Telementoring: an overview and our preliminary experience in the setting up of a cost-effective telementoring facility. *Indian J Surg*. 2016;78:70–73.
7. Sebajang H, Trudeau P, Dougall A, et al. Telementoring: an important enabling tool for the community surgeon. *Surg Innov*. 2005;12:327–331.
8. Li JO, Liu H, Ting DSJ, et al. Digital technology, tele-medicine and artificial intelligence in ophthalmology: a global perspective. *Prog Retin Eye Res*. 2020;82:100900.
9. Ye Y, Wang J, Xie Y, et al. Global teleophthalmology with the smartphone for microscopic ocular surgery. *Eye Contact Lens*. 2016; 42:275–279.
10. Camara JG, Zabala RR, Henson RD, et al. Teleophthalmology: the use of real-time telementoring to remove an orbital tumor. *Ophthalmology*. 2000;107:1468–1471.
11. Bandhu SD, Raje S. Experiences with E-learning in ophthalmology. *Indian J Ophthalmol*. 2014;62:792–794.
12. *CorNeat Vision Partners with LiveU and Alcon for Remote Surgeon Virtual Presence*, PR Newswire, Available at: https://www.prnewswire.com/il/news-releases/corneat-vision-partners-with-liveu-and-alcon-for-remote-surgeon-virtual-presence-301242450.html. Accessed April 5, 2021.
13. Litvin G, Klein I, Litvin Y, et al. CorNeat KPro: ocular implantation study in rabbits. *Cornea*. 2021;40:1165–1174.
14. *Product Animation*, CorNeat KPro, Available at: https://www.corneat.com/corneat-kpro. Accessed August 10, 2021.
15. *CorNeat KPro NZW Implantation*, CorNeat KPro, Available at: https://www.corneat.com/kpro-nzw-implantation. Accessed August 10, 2021.
16. Erridge S, Yeung DKT, Patel HRH, et al. Telementoring of surgeons: a systematic review. *Surg Innov*. 2019;26:95–111.
17. Hinata N, Miyake H, Kurahashi T, et al. Novel telementoring system for robot-assisted radical prostatectomy: impact on the learning curve. *Urology*. 2014;83:1088–1092.
18. Ferrara M, Romano V, Steel DH, et al. Reshaping ophthalmology training after COVID-19 pandemic. *Eye (Lond)*. 2020;34:2089–2097.
19. Vyas RM, Sayadi LR, Bendit D, et al. Using virtual augmented reality to remotely proctor overseas surgical outreach: building long-term international capacity and sustainability. *Plast Reconstr Surg*. 2020;146: 622e–629e.
20. Ponce BA, Jennings JK, Clay TB, et al. Telementoring: use of augmented reality in orthopaedic education: AAOS exhibit selection. *J Bone Joint Surg Am*. 2014;96:e84.
21. Shenai MB, Tubbs RS, Guthrie BL, et al. Virtual interactive presence for real-time, long-distance surgical collaboration during complex microsurgical procedures. *J Neurosurg*. 2014;121:277–284.
22. Venkata HS, Alsadoon A, Prasad PWC, et al. A novel mixed reality in breast and constructive jaw surgical tele-presence. *Comput Methods Programs Biomed*. 2019;177:253–268.
23. Hung AJ, Chen J, Shah A, et al. Telementoring and telesurgery for minimally invasive procedures. *J Urol*. 2018;199:355–369.