The Role of Technology in Ophthalmic Surgical Education During COVID-19

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Abstract

Purpose of Review To describe the effect of COVID-19 on ophthalmic training programs and to review the various roles of technology in ophthalmology surgical education including virtual platforms, novel remote learning curricula, and the use of surgical simulators.

Recent Findings COVID-19 caused significant disruption to in-person clinical and surgical patient encounters. Ophthalmology trainees worldwide faced surgical training challenges due to social distancing restrictions, trainee redeployment, and reduction in surgical case volume. Virtual platforms, such as Zoom and Microsoft Teams, were widely used during the pandemic to conduct remote teaching sessions. Novel virtual wet lab and dry lab curricula were developed. Training programs found utility in virtual reality surgical simulators, such as the Eyesi, to substitute experience lost from live patient surgical cases.

Summary Although several of these described technologies were incorporated into ophthalmology surgical training programs prior to COVID-19, the pandemic highlighted the importance of developing a formal surgical curriculum that can be delivered virtually. Novel telementoring, collaboration between training institutions, and hybrid formats of didactic and practical training sessions should be continued. Future research should investigate the utility of augmented reality and artificial intelligence for trainee learning.

Keywords Ophthalmology training · Remote learning · Surgical simulators · Wet lab curriculum · Virtual education

Introduction

The novel coronavirus disease 2019 (COVID-19) was declared a global pandemic in March 2020. Its rapid and deadly transmissibility had significant implications on public health and medical education, prompting healthcare institutions to implement social distancing measures to reduce spread of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1]. Within the first month of the pandemic, ophthalmology experienced close to an 80% drop in clinic visits in the United States, the largest decrease of any medical specialty nationwide [2•]. Hospitals and ambulatory surgery centers alike experienced shutdowns with diversion of medical resources and medical personnel. In March 2020, the American Academy of Ophthalmology (AAO) urged ophthalmologists to suspend all elective cases and limit surgical activity to only urgent or emergent care [3].

With restriction of face-to-face interactions and a marked reduction of surgical volume, ophthalmology education programs found themselves with a large gap to fill in teaching their surgeons-in-training. Instructors had to quickly adapt to distance learning environments and adopt fast-tracked, innovative solutions. The role of technology and utilization of virtual learning systems became

prominent in helping trainees acquire and maintain surgical skills [4••].

Impact of COVID-19 on Ophthalmic Surgical Training

COVID-19 caused significant disruption to in-person clinical and surgical patient encounters. Upwards of 27% of ophthalmology residents worldwide were redeployed to COVID-19 wards during the height of the pandemic in 2020 [5••]. Residents and fellows faced interruptions not only in the traditional didactic classroom setting, but across all elective ophthalmic surgeries, laser procedures, and minor procedures [6].

In the United States, the total number of cases logged as primary surgeon decreased by 11.2% from 2019 to 2020 among graduating ophthalmology residents as published by the Accreditation Council for Graduate Medical Education (ACGME), with cataract surgery and keratorefractive surgery experiencing the greatest percentage decrease at over 20% each [7]. In a survey administered to American Society of Ophthalmic Plastic and Reconstructive Surgery (ASOPRS) fellowships, three-quarters of surveyed oculoplastic fellows felt their surgical confidence decline during the initial COVID-19 lockdowns and 94.4% of fellowship program directors predicted adverse effects on graduation case logs [8].

In an international survey conducted in May 2020, 74.6% of ophthalmology trainees from 32 countries reported a reduction of over 75% of their surgical training, with about half reporting that they had suspended surgical practices completely [5]. As of June 2020, 65% of ophthalmology residents surveyed across all 15 residency programs in Canada had not operated in the previous 2 weeks after returning to surgical rotations at reduced capacity [9]. 80.7% of ophthalmology trainees in India felt the 2020 pandemic lockdowns had a negative impact on their surgical training [10]. The majority of residents were more concerned about the impact of COVID-19 shutdowns on the deterioration of their surgical skills in comparison to loss of clinical skills [9–11].

A February 2021 survey found that 89% of ophthalmology residents in Poland felt that the COVID-19 pandemic had negatively impacted their surgical training; 99.2% of these participants responded positively to the substitution of traditional lectures with virtual platforms and 79% reported a desire to continue remote training courses and video conferences in the future [6]. Because of the drastic reduction in elective surgeries and in-person surgical experiences, the role of surgical simulators in ophthalmology training significantly increased [12].

Distance Learning and Remote Conferencing

During the pandemic, sharing of online resources and videoconferencing became more widespread on a global scale [13•]. Didactic lectures, journal clubs, and grand rounds were shifted to remote streaming; academic conferences and society meetings were converted to virtual formats [2]. Web-based learning modules and online surgical video libraries gained increasing popularity. Residency programs have been able to supplement their curricula with online lectures, surgical videos, and virtual training modules from national societies, such as those available on the AAO Ophthalmic News and Education (ONE) Network [2]. The Association of University Professors of Ophthalmology (AUPO) developed a virtual Surgical Curriculum for Ophthalmology Residents (SCOR) with online modules for learning advanced cataract surgery concepts and anterior segment surgery skills [14]. Programs have also increasingly utilized a "flipped classroom" format by instructing trainees to review pre-recorded materials and online videos for self-guided learning [13, 15].

Training programs were also able to share resources through remote conferencing and recorded lecture sessions. In New York City, an epicenter of the COVID-19 outbreak in Spring 2020, ophthalmology residency programs created alternatives in their surgical teaching methods to combat the decrease of in-person surgical cases [16]. New York-area ophthalmology faculty collaborated between institutions to develop a series of shared didactic webinars and a combined core education curriculum; the program directors voiced the value of shared conferencing and crowd-sourced education solutions beyond the pandemic environment [16]. 87.5% of ASOPRS fellows participated in collaborative virtual education sessions between different institutions and desired to continue this collaborative curriculum after COVID-19 restrictions were lifted [8].

A global survey conducted by Chatziralli and colleagues found a statistically significant increase in the use of Zoom (Zoom Video Communications, San Jose, CA, USA, $n = 179$, 55.8%, $p < 0.001$) and Microsoft Teams (Microsoft Corporation, Redmond, WA, USA, $n = 48$, 15.0%, $p = 0.018$) among 321 ophthalmology trainees and faculty in April 2020, whereas prior to the pandemic, 48% of respondents had not used any platform for the purposes of virtual learning [17]. 60% of participants believed that online learning is equally as effective as face-to-face lectures, and 83% believed that tele-education measures used during COVID-19 would continue for ophthalmology training in the future [17].

An ophthalmology department in Italy used Microsoft Teams to organize public virtual channels with lesson plans, surgical videos, and an asynchronous surgical

simulator curriculum for residents to practice skills on simulators and synthetic eye models [18]. Gupta and colleagues described virtual surgical skills sessions using Zoom breakout rooms; they instructed trainees to create a surgeon's view by tilting the camera device (typically a laptop) and angling the camera toward the trainees' hands while an instructor observed and provided individualized feedback [19]. They advised tips on enhancing the virtual experience, such as using a dark multi-braided suture with light-colored fruit for higher-contrast image streaming and using features such as "pin video" for the instructor to observe individual students more seamlessly [19].

The pandemic also opened the door for surgical telementoring and real-time virtual presence workshops. Oribis International developed a virtual surgical mentorship program to connect ophthalmologists with remote experts overseas via Cybersight, their web-based platform [13]. Din and colleagues demonstrated the use of a novel telementoring program in which an Israeli expert surgeon proctored surgeons in Toronto for the implantation of keratoprostheses using real-time streaming technology of three-dimensional (3-D) images [20]. This remote surgeon virtual presence system was configured using the NGENUITY 3-D Visualization System (Alcon Laboratories, Inc., Fort Worth, TX, USA) for trainees with live video streamed to the remote proctor through a GOOVIS virtual reality headset (Shenzhen NED Optics Co., Ltd., Guangdong Province, China) and a portable LiveU device (LiveU Inc. US & International, Hackensack, NJ, USA) to increase the bandwidth of image transmission [20].

Use of Cadaveric Eye Models (Wet Labs)

Prior to the pandemic, ophthalmology training programs conducted wet labs to help trainees gain essential microsurgical skills in a low-risk environment using goat, pig, or human eye tissue [4]. Due to COVID-19 social distancing restrictions, in-person wet labs were canceled. As a solution, the University of California, San Francisco developed a remote corneal suturing wet lab using virtual lectures to instruct ophthalmology residents on placing the four cardinal sutures of a penetrating keratoplasty using 10–0 nylon suture in pig eyes [21]. Residents and faculty who participated in this remote wet lab reported that the distance learning session was equally or more effective than previous in-person wet labs [21].

In lieu of a canceled in-person skills transfer lab at a large international conference, a novel virtual wet lab for Descemet membrane endothelial keratoplasty was developed using smartphone camera adapters and a video conference platform in September and October 2020 [22]. Participants connected with remote proctors via two video-

streaming devices simultaneously: one (laptop, tablet, smartphone) to communicate with their instructor and view didactic materials, and one (smartphone) attached at the operative microscope assistant oculars using a Snapzoom Universal Digiscope adapter (HI Resolutions Enterprises, Honolulu, HI) [22]. Wet lab materials and instruments were mailed to each participant with instructions on how to access the virtual session for their real-time surgical instruction [22].

Using goat eyes, an ophthalmology program in Northern India developed a wet lab curriculum to learn phacoemulsification, trabeculectomy, full-thickness keratoplasty, scleral buckling, pars plana lensectomy, pars plana vitrectomy, and open globe repair techniques [23]. Of note, not all models allow for accurate reproduction of an entire surgical procedure. For instance, it was noted that the continuous curvilinear capsulorhexis was difficult to practice on goat eyes due to the shallow anterior chamber. 83.3% of ophthalmology residents agreed that suture training on goat eyes had improved their surgical skill and had high transferability to real patient surgical encounters [23].

Use of Synthetic Tissue Models (Dry Labs)

The use of synthetic tissue eye models for ophthalmic surgical instruction has gained popularity in recent years due to reproducibility, reusability, and potential cost savings. Programs have incorporated dry labs into their virtual teaching curricula during COVID-19 with remote instruction on surgical techniques for trainees to practice at home while distancing restrictions were in-place [4, 18].

A recent study by Raval and colleagues evaluated different ophthalmic surgical training models for integrity and likeness to human tissue in creating the continuous curvilinear capsulorhexis [24]. Three tissue simulators were used: the Kitaro DryLab model (Frontier Vision Co., Ltd., Hyogo, Japan), SimulEYE SimuloRhexis model (InsEYEt, LLC, Westlake Village, CA, USA), and the Bioniko Rhexis model (Bioniko Models, Miami, FL, USA). The authors found that creating the capsulorhexis on the SimulEYE SimuloRhexis and Kitaro DryLab models were more accurate and more realistic than the Bioniko Rhexis as performed by 7 expert surgeons over 63 trials; however, making the clear corneal incision in the Bioniko model was felt to resemble wound creation in human cornea tissue more closely [24]. The cost of these models to perform 100 capsulorhexes was $970 USD for Bioniko, $995 USD for Kitaro, and $715 USD for SimulEYE [24].

Chhabra and colleagues developed a low-cost, reusable 3-D printed model eye (RetiSurge) for vitreoretinal surgery dry labs using interlocking synthetic pieces and polyethylene terephthalate glycol film with a printed fundus

image [25]. They proposed methods to use the RetiSurge model to practice intraoperative visualization, bimanual instrument manipulation, and endolaser photocoagulation during COVID-19 shutdowns [25].

Use of Virtual Reality Surgical Simulators

Surgical simulators offer several advantages as they offer trainees a more uniform experience and infinite trials to learn fine motor skills in the setting of a stereoscopic ocular systems [26•]. As of 2017, 73% of ophthalmology residency programs in the United States had access to a virtual reality (VR) surgical simulator, up from 23% in 2011 [27].

There are currently four VR simulators available for learning cataract surgery: Eyesi (VRmagic Holding AG, Mannheim, Germany), MicroVisTouch (Immersive Touch, Chicago, IL, USA), PhacoVision (Melerit Medical, Linköping, Sweden), and the Help Me See (HMS) Eye Surgery Simulator (HelpMeSee Inc., New York, USA). Although these platforms existed and were utilized by ophthalmology training programs prior to the pandemic, there was an increased need for surgical simulators during COVID outbreaks to substitute experience lost from live patient surgical cases [6, 12].

The Eyesi features an eye model attached to a patient head model, pedals, three handheld instruments, two VR oculars, and a virtual binocular stereoscopic image. Programs acquired the Eyesi during the pandemic to teach residents fine motor dexterity and have trainees practice cataract surgery steps spanning over four modules from CAT-A (Introduction) to CAT-D (Advanced) [28]. Trainees can learn capsulorhexis, hydrodissection, hydrodelineation, phacoemulsification, intraocular lens insertion, chopping techniques, and challenging scenarios with white cataracts, zonular weakness, and posterior capsule tears.

The PhacoVision also features an eye model, pedals, instrument handpieces, VR oculars, and a virtual stereoscopic image, however, training modules are limited to the phacoemulsification and capsulorhexis steps [29]. The MicroVisTouch features a single handpiece attached to a robotic arm and is reportedly the first ophthalmic surgical simulator to have an integrated tactile feedback system for the three of its modules: the clear corneal incision, capsulorhexis creation, and phacoemulsification [26, 30]. The Help Me See Eye Surgery Simulator is a simulator for manual small-incision cataract surgery using 3-D virtual reality graphics and a tactile feedback system [10].

The Eyesi remains the most widely used and evaluated cataract training model in the current literature, including randomized control trials of transfer skills in capsulorhexis performance [26, 31, 32]. Surgical simulator training with the Eyesi has been associated with reduced rates of live cataract surgery intraoperative complications among novice ophthalmology residents [33]. A recent study conducted in China showed that second-year ophthalmology residents trained on the Eyesi chopping modules (Intermediate Level) had decreased corneal injury and reduced ultrasonic energy when performing the chopping technique as compared to residents that were trained in wet labs with pig eyes [34].

A survey of young ophthalmologists in Egypt found that 66.7% would favor continuing surgical simulator training if lockdown restrictions continued; the majority of elective surgeries at Cairo University Hospitals had decreased by 75–100% during March to May of 2020 [35]. While many agree that simulator training is useful, access to VR equipment remains a challenge. The initial cost of acquiring the Eyesi is $150,000 USD [13]. Less than 20% of Canadian ophthalmology residents had access to a surgical simulator (Eyesi) during the pandemic [9].

Augmented Reality, Artificial Intelligence, and Future Considerations

There have been several publications on the applications of emerging technologies in ophthalmology, including the use of augmented reality (AR) and artificial intelligence in surgical training [13, 36].

Recently, Roplato and colleagues found significant improvement of microsurgery skills using an AR headset and intelligent tutoring system (ITS) to optimize the learning of internal limiting membrane peeling in a group of 50 participants with no ophthalmology background or previous surgical experience. [37]. They used the Microsoft HoloLens (Microsoft Corporation, Redmond, WA, USA), a headset with a stereoscopic see-through display so that participants can utilize real surgical instruments in their local environment to manipulate a simulated 3-D image [37]. An ITS algorithm was used to provide an automated, tailored sequence of subtasks and difficulty level that adapted to each individual's performance. The use of AR and ITS improved overall performance and combined, was a more efficient method of microsurgical training [37]. In addition to learning through simulated practices, AR headsets can also offer a novel means to for trainees to observe surgery through high-quality, 3-D images in real-time in remote locations [36].

FundamentalVR and Orbis International have developed Fundamental Surgery, a portable and low-cost VR headset and simulator program with haptic feedback technology to teach the steps of MSICS, including the capsulorhexis [13, 38]. Genentech has reportedly included VR headset-based training sessions in a phase III study of a port delivery system with ranibizumab to teach

ophthalmologists device administration [36]. In April 2022, Alcon announced the planned release of the Alcon Fidelis Virtual Reality (VR) Ophthalmic Surgical Simulator (Alcon Laboratories, Inc., Fort Worth, TX, USA), a portable VR simulator for learning cataract surgery [39].

Broad potential uses of 3-D printing for ophthalmology educational models, tissue bioprinting, surgical bioprinting have also been described but are not yet widespread [40].

Use of Technology in Other Surgical Subspecialties During COVID-19

The rise of technology in surgical training during COVID-19 was not unique to ophthalmology, as shutdowns to contain SARS-CoV-2 caused unprecedented interruption to education across all medical specialties [41]. With lack of access to in-person cadaver labs, Suzuki and colleagues described a remote training course between otolaryngologists in Japan and Australia for functional endoscopic sinus surgery utilizing real-time supervision of step-by-step dissections of 3-D printer models of patients with chronic rhinosinusitis [42]. This study demonstrated benefit for remote audience members, for which the skills workshops were recorded and streamed. Ally and colleagues described using video-assisted telescope operating monitor (VITOM) 3-D alternative to microscopic surgery, integrating a high-definition view and 3-D technology for middle ear surgery [43]. This 3-D heads-up exoscope system has previously been evaluated in retina surgery settings with improved visualization by multiple observers and increased intraoperative learning experience compared with the traditional operative microscope [44, 45].

Jack and colleagues described an inexpensive remote learning solution to live-stream neurosurgery operations with real-time communication between surgeons and trainees [46]. Similarly, Cooper and colleagues described the use of a cloud-based AR platform (Proximie; Proximie Limited, London, UK) via remote operative live-streaming at a plastic surgery training program in the United Kingdom [47]. The platform uses multiple interactive tools to point, overlay, and type over live-streamed images and utilizes a two-way audio system with the trainee audience. Other plastic surgery programs have described utilizing touch-screen-based applications for virtual cadaver images and steps of surgical procedures [48].

Conclusions

COVID-19 caused significant disruption to in-person clinical and surgical patient encounters. With suspension of all non-emergent patient care, trainees lost both observational and practical experience in lieu of social distancing measures. Ophthalmology residency programs were faced with the challenge of developing novel adaptations and education solutions for their surgical trainees.

The pandemic was a catalyst in promoting trainees to rely more on self-guided curricula and remote learning solutions. More than ever, ophthalmology trainees now have robust online surgical resources and inter-institutional collaborations, which many have favored to continue using after the pandemic. These novel teaching methods should be adopted long-term to better prepare for training deficiencies that may arise with future pandemics—including the use of technology for clinical skills training and surgical skills transfer [4, 23]. The use of technology in surgical teaching is promising as it is exciting, however, its impact can only reach as far as the educators that are trained in new modalities of surgical instruction. Successful integration of new technologies and teaching methods depends on faculty acceptance, trainee application, program engagement, and administrative support [4].

Skills transfer labs and simulation technology have been important concepts in the field of ophthalmology even prior to COVID-19. As is somewhat unique to our microsurgical subspecialty, the primary surgeon and assistant operate in a small surgical field, making it challenging for trainees to assist in major steps. Ophthalmology patients are often awake during surgery with minimal sedation in the operating room—as such, there are implications and expectations of trainees to achieve baseline microsurgical skills and knowledge of surgical steps prior to performing them on live patients. There has been a wealth of wet lab, dry lab, and surgical simulator techniques developed and described during the COVID-19 era, which should continue to further novel methods of microsurgical training in our field.

Although several of these technologies were incorporated into ophthalmology surgical training programs prior to COVID-19, the decrease in live patient surgical volume accelerated their widespread use and has highlighted the importance of developing a robust curriculum for surgical training that utilizes multiple types of instruction and simulation [2, 6].

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