Published in final edited form as:
Asia Pac J Ophthalmol (Phila). ; 11(3): 267–272. doi:10.1097/APO.0000000000000484.

Digital Education in Ophthalmology

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Abstract

Accessibility to the Internet and to computer systems has prompted the gravitation towards digital learning in medicine, including ophthalmology. Using the PubMed database and Google search engine, current initiatives in ophthalmology that serve as alternatives to traditional in-person learning with the purpose of enhancing clinical and surgical training were reviewed. This includes the development of tele-education modules, construction of libraries of clinical and surgical videos, conduction of didactics via video communication, and the implementation of simulators and intelligent tutoring systems into clinical and surgical training programs. In this age of digital communication, teleophthalmology programs, virtual ophthalmological society meetings, and online examinations have become necessary for conducting clinical work and educational training in ophthalmology, especially in light of recent global events that have prevented large gatherings as well as the rural location of various populations. Looking forward, web-based modules and resources, artificial intelligence–based systems, and telemedicine programs will augment current curricula for ophthalmology trainees.

Keywords

artificial intelligence; surgical simulation; tele-education; web-based learning

I. Introduction

With the evolution of technology, the options for delivering educational instruction have subsequently expanded. There has been a transition to online learning, whether as part of live-streaming sessions or self-paced courses, in many fields of study, including medicine.[1] In the realm of surgery, hands-on, simulated learning has become implemented in residency and fellowship training programs.[2–4] In addition, systems powered by artificial intelligence (AI) are being developed to facilitate clinical and surgical experiences.[5–8]

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There are many benefits to online learning compared to in-person learning, as well as several potential drawbacks. Some downsides that have been described include the increased time it takes educators to prepare online material, the loss of interpersonal interactions that facilitate discussion, and the potential for difficulty in navigating online platforms and simulators, as well as the need for support to troubleshoot these barriers.[1] The counterargument to these concerns include the benefit of decreased travel time for both educators and learners, the subsequent elimination of travel expenses, reduction in cost of conducting a training course, the multiple features that have been added to learning platforms to engage audiences, as well as the increased ease of access and use that has been developed in recent years.[9] Additionally, web-based sessions and instruction improve outreach and have an essential role in remote regions, war-stricken zones, and during global events, such as the COVID-19 pandemic.[10–12]

The COVID-19 pandemic demonstrated the multiple benefits of online learning, as well as its necessity in an interconnected global learning environment. Many of the tools that educators relied heavily on during the pandemic for continued learning without congregation, including videoconferencing and sharing of imaging via web-based platforms, were already present prior to the global lockdown; however, they were utilized more frequently and with a larger scope. This larger community utilizing online education technology allowed for increased access to resources and lectures, adding to the expertise and discussion during educational events. It will be beneficial to continue those aspects of online learning that have demonstrated added value to in-person education.

The purpose of this review is to 1) explore current tele-education platforms and flipped classroom approaches in ophthalmology, 2) identify the role of AI in promoting training tailored to the learner, 3) highlight the vital role of telemedicine and the utility of its inclusion in curricula, and 4) discuss delivery of education in low-resource settings.

II. Methods

A review of published articles on digital education in ophthalmology was conducted between April and May of 2021. The PubMed database was utilized to search for works in ophthalmology on web-based educational programs, surgical simulation, telemedicine, and intelligent tutoring systems (ITS) and other AI-based systems. Terms, including but not limited to, “digital education,” “ophthalmology,” “web-based learning,” “tele-education,” “surgical,” and “simulation” were searched using the PubMed search engine. Articles that discussed the use of updated technology for education in ophthalmology were included in the study, and by extension, articles that were not pertinent to ophthalmology or surgical subspecialties were excluded. The Google search engine was also used to search for and review online resources published on the websites of national and international ophthalmologic associations, as well as acquire updated information from examination entities. With regard to ITS in medical education, a PubMed search yielded 59 articles, of which none were specific to ophthalmology. A search of “intelligent tutoring systems ophthalmology” yielded 2 articles, which were included in this review article.

III. Web-based Learning

Tele-education utilizing web-based modules serves as one alternative to in-person instruction, and this strategy has been used in the field of ophthalmology to promote self-guided, problem-based learning remotely. One example of this is the Global Education Network for Retinopathy of Prematurity (GEN-ROP). This program consists of traditional didactic material using lecture slides followed by training cases, as well as pre- and post-assessments to measure knowledge acquired.[2] These training cases allow users to select all present features of disease along with a management plan and subsequently provides feedback tailored to the user. For example, if a feature of treatment-requiring retinopathy of prematurity, such as plus disease, is missed by the user, fundus photographs with this specific finding are subsequently displayed to the user upon completion of the case. GEN-ROP has been piloted among the US and Canadian ophthalmology trainees, as well as among trainees in varying geographic locations around the world.[13,14] The findings demonstrated significant improvement in trainees' diagnostic accuracy after participation in the program, suggesting the utility of structured online case-based learning.[13,14]

Similarly, a diabetic retinopathy platform utilizing a comparable instructional setup has been built on iTeleGEN, a web-based platform, and trialed among medical students.[15] This training method was positively viewed by the students as an alternative educational means to formally learn how to identify the presence of retinopathy and categorize the disease by severity.[15] Moreover, the Virtual Ophthalmology Clinic program consists of case-based scenarios that are commonly encountered.[16] The program has a dynamic interface that allows for the collection of historical data and for the performance of virtual examination maneuvers via the computer.[16] Compared to medical students who received a traditional clerkship experience, which was randomly assigned, those participating in the program scored 7.5% higher on assessment (95% CI 0.8–2.3, $P < 0.001$).[16]

One fundamental change in educational methodology during the past few decades has been the "flipped classroom" model, which relies on students to review materials in advance to support classroom discussion. This concept has been piloted by Tang and colleagues for an ocular trauma educational initiative.[17] The authors found that medical students who viewed the video lectures and reviewed the educational resources prior to the scheduled class time had higher scores compared to those receiving traditional didactics (16.91 vs 14.92, respectively, $P = 0.01$).[17] This is an example of how education has been evolving to include technology even before the COVID-19 pandemic forced the move to online education.

While the advent of the Internet promoted the concept of online learning, virtual training has recently become increasingly more prevalent. The COVID-19 pandemic has caused learners to rely on such means and has prompted the development of novel curricula for various fields, including ophthalmology. Web-based curricula for ophthalmology clerkships in medical school have been developed and commonly involve using Zoom (Zoom Video Communications, Inc, San Jose, CA) to virtually meet with mentors to discuss the material and reference YouTube videos to provide step-by-step instruction on the use of examination instruments such as the direct ophthalmoscope. Similarly, Wendt et al created a virtual neuro-ophthalmology rotation for medical students during the COVID-19 pandemic which consisted of web-based didactics using online websites and videos along with a weekly assessment, participation in morning lectures, preparation of grand rounds presentations, writing of research articles for publication, and experiencing mock oral ophthalmology boards through simulation.[18]

Despite the continued development of digital education in ophthalmology, there are implications to its adoption. There is a correlation between the use of digital devices, such as computers and tablets, and the diagnosis of myopia and its advancement in severity.[19] In addition, the limitations of such methods include the loss of in-person interactions and the ability to practice the skills hands-on, which require fine-tuning.[18] However, there are several computer-based programs that allow for virtual practice, including the EyeSi Direct Ophthalmoscope, OphthoSim Ophthalmoscopy Training & Simulation System (OtoSim, Toronto, Canada), Digital Eye Examination/Retinopathy Trainer (Nasco, Wisconsin, US), and the EYE Examination Simulator (Kyoto Kagaku Co Ltd, Kyoto, Japan).[18]

A series of surveys have been conducted to assess the role of virtual learning during the COVID-19 pandemic. Of 504 international ophthalmology trainees surveyed, the majority indicated a significant drop in clinical experience and procedures performed; however, 92% found online presentations to be effective for clinical knowledge acquisition, and 86% found benefit in reviewing video recordings of procedures.[20,21] In a survey of 321 ophthalmology trainees and faculty globally, Chatziralli and colleagues identified that 60% of participants believed online learning is equally as affective as an in-person diadactics.[21] Similarly, Canadian medical students reported that webinars were an effective alternative to traditional teaching methods.[22]

Furthermore, there is a range of online resources available for ophthalmology trainees that allow for efficient referencing of material. The American Academy of Ophthalmology (AAO) ONE Network online site provides members with access to thousands of videos by topic, including introduction to surgical approaches for varying ophthalmic procedures, along with a host of practice questions and photographs of differing ocular pathology.[17] Moreover, the Pan-American Association of Ophthalmology (PAAO) has online courses available in Spanish and Portuguese that span several weeks. These provide trainees with guidance on the utilization of different ophthalmic testing methods, including visual field testing and optical coherence tomography, instruction on approaching surgical complications, and recommendations for the care of common clinical conditions.[18] Additionally, Cybersight by ORBIS International has curated a collection of educational resources, including videos by subspeciality, simulated surgical footage, online assessments, as well as didactic instruction on new advancements, such as AI in ophthalmology.[19,20] Additional courses on ophthalmic disease and non-ophthalmic medical care (relevant to the management of patients with ocular disease) are available in different languages and are eligible for Continuing Medical Education credits.[19]

IV. Virtual Examination and Conferences

The COVID-19 pandemic has forced a shift in the paradigm of formal examination of ophthalmology trainees, as well as participation and presentations at conferences. For example, the administration of the Ophthalmic Knowledge Assessment Program (OKAP) was shifted to a web-based format; new virtual proctoring procedures were put in place, but noticeable limitations were discovered related to troubleshooting the exam while it was being administered.[21] The American Board of Ophthalmology Oral Examination was also moved online but conducted in a similar interactive manner as the original format.[22]

Similarly, ophthalmology annual meetings were adapted to a virtual setup. Different ophthalmological societies developed their own platforms to allow for meeting participants to either join through live streaming or view the presentations at leisure, where poster presentations were uploaded and oral presentations were prerecorded.[23] There was also the option to join virtual office hours with the authors of the study. While an in-person event may allow for more fluid participant exchanges, the virtual conferences attract larger audiences, particularly of professionals who are overseas and unable to travel. This promotes greater input from international ophthalmologists who may practice differently or have varying clinical, surgical, and research experiences. Additionally, virtual conferences can be a time- and cost-saving alternative to traditional meetings. Gupta et al further highlight that a segmented virtual event allows for participants to tune in periodically and focus on the content in small increments of time.[23] The drawback is that this may take away from the interactions that result from a full-day event. Other aspects to consider include registration fees, making the meeting programs available to non-members, and providing a platform for industry.[23]

V. Virtual Mentorship

Technological advancements have been implemented to promote surgical training, such as through telesurgery. ORBIS International developed a mentorship program that connects local ophthalmologists with remote experts internationally to provide guidance on the surgical approach to cases.[24] Communication is conducted via their web-based platform, Cybersight and technical equipment required includes establishing an Internet connection via ethernet, a surgical microscope that accommodates a high-definition camera, video capture cards, and a microphone.[24] Despite the cost of the initial setup, virtual, interactive mentorship eliminates the cost and time burden required of specialists to conduct training on the ground.[24] Similarly, the Armenian EyeCare Project launched a real-time surgical training program, where ophthalmologists communicate with local providers overseas.[25] Furthermore, with the emergence of the NGENUITY 3D Visualization System (Alcon, Geneva, Switzerland), the 3-dimensional and 4K features allow for the precise viewing of vitreoretinal pathology. There have been successful efforts reported by Miller and colleagues in the ability to stream the footage via a 5G cellular network; once this technology is further optimized, one can imagine virtual consultation with a remote specialist during surgery.[26] Further considerations include the type of equipment required on the receiving end, taking into account the cost, and whether additional training in device operation is warranted.

Additionally, the Alcon Retina Fellows Institute is an event that has been held for retina fellows to gain exposure to various surgical techniques, such as performing membrane peals and sutureless intraocular lens fixation via virtual reality (VR) and simulations, with experts available for guidance.[27]

There have been efforts to allow for objective evaluation of ophthalmology residents' surgical outcomes.[28] Dang et al report on the Insight system that was developed for residents to log patient results following cataract surgery, including complications as well as refraction and best-corrected visual acuity.[29] The program produces an individualized report for trainees to assess their performance.[29] Similarly, the residency training program at Aravind Eye Hospital in India utilizes the Cataract Quality Evaluation Registry, a database for the documentation and review of postoperative data used during discussion of trainees' competency.[30]

VI. Artificial Intelligence for Education and Evaluation

The progression of technology has paved the way for the integration of AI into the practice of ophthalmology and into medical education. There have been a myriad of studies that have evaluated the various automated systems for retinopathies, glaucoma, refractive error, pediatric ophthalmology, and ocular pathology.[31,32] It has been shown that the majority of ophthalmologists are willing to incorporate AI into their practice.[33] These current AI programs designed to guide diagnosis and management have the potential to be adapted for educational purposes. ITS has emerged as a means to provide automated, tailored feedback to the program user based on individual performance.[34] ITS has been utilized in various surgical specialties for the Da Vinci operating system and for cryosurgery.[34–36]

Moreover, this concept has been applied for surgical simulation training in ophthalmology. Simulated learning can be classified under dry or wet lab.[37] The former relies on the use of various nonliving material for the creation of test specimens.[37] This includes the use of aluminum foil and methacrylate for capsulorhexis practice, rubber spheres and elastic bands to resemble the eye and extraocular muscles, respectively, for strabismus simulation, and 3D-printed structures that mimic the schematic of the orbit.[37] Practicing with the ophthalmic examination instruments also falls under this category of lab work.[37] On the contrary, human or animal eyes acquired for the practice of a variety of ocular or orbital surgeries represents the wet lab.[37]

Furthermore, with regard to simulation in ophthalmology, Ropelato et al developed a 3-dimensional microsurgical simulator designed to improve technical skills in internal limiting membrane peeling using an augmented reality headset.[38] The simulator activity consists of a micromanipulator modeled after actual surgical instruments, the augmented reality headset for the creation of a stereoscopic view, and a tracking apparatus that consists of 2 perpendicular cameras that capture the movements of the micromanipulator which are subsequently analyzed by a computer software.[38] The user's performance during the simulation was calculated based on objective measurement of how well the micromanipulator maneuvered by the user corresponded to the optimal movements in each step of the procedure.[38] Using the Zone of Proximal Development and Empirical Success algorithm introduced by Clement and colleagues, an algorithm was constructed that selected the degree of complexity of the upcoming task based on the user's performance.[38] When the system was piloted among undergraduate and master's students, the ITS improved the technical performance of users.[38] Using this system, Menozzi et al found that implementing ITS-based surgical simulation training compared to conventional stepwise approaches led to more rapid acquisition of motor skills, although the ultimate training outcome was comparable among both groups.[39]

Additionally, the EyeSi surgical simulator (VR Magic, Mannheim, Germany), a VR simulator for phacoemulsification surgery, has been trialed among 265 surgical trainees in order to assess variations in posterior capsule rupture rates during cataract extraction.[40] It was shown that rates of posterior capsule rupture in 2016 dropped by 38% following the introduction of the EyeSi system compared to rates in 2009.[40] In addition, the EyeSi simulator has been shown to initially decrease the time it takes for residents to perform the procedure before expertise develops. Users' performance on the simulator was consistent with actual surgical performance measured by the Objective Structured Assessment of Cataract Surgical Skill scale.[28,41] Lowry et al conducted a cost-benefit analysis on implementing the EyeSi system into residency programs and found that offsetting the initial cost of purchasing the device ($150,000) is dependent on the number of residents participating in the simulations.[42] Cost reduction was calculated relative to operating room time; however, future work analyzing the cost-saving benefits with regard to preventing operative and postoperative complications is warranted.[42]

Furthermore, VR headsets have been designed for visual field testing in glaucoma, strabismus evaluation, and amblyopia treatment, as well as for other surgical specialties.[28] More specifically, FundamentalVR, in collaboration with ORBIS International, has developed an educational tool known as Fundamental Surgery, which is a VR headset and simulator program that relies on haptic technology.[43] This device is more portable and is at a reduced price compared to pre-existing products.[43] The headset has the potential to improve access to educational opportunities in low-resource settings, along with the goal of providing structured evaluations for the users.[43] There is also the HomeVR program that relies less on sensory feedback but is suitable for at-home training.[43,44] Likewise, Genentech has reported on preparing a VR educational program to assist with surgical placement and clinical management of ports in the third phase for neovascular age-related macular degeneration.[28]

Moreover, deep learning programs have been developed for application in intraoperative settings.[28,45,46] Kim et al found that a deep learning system can categorize users' level of expertise and rate their competency in performing the capsulorhexis during cataract surgery.[45] The ability to design a system for automated segmentation of a cataract surgery video at a rate comparable to real-time sets the stage for the generation of additional automated analyses of surgical methods and techniques. These AI-based means allow for numerical data to be collected for trainee evaluation, as well as have the potential to surveil trainees' skillsets in surgery with the goal of preventing adverse surgical outcomes.[45,46]

In addition to surgical training, AI-based learning has been incorporated into programs that assist trainees in arriving at a clinical diagnosis. Bergeron and colleagues assessed the impact of an ITS when providing primary care physicians with educational material on diagnosing retinopathies through the presentation of fundus images.[47] This was compared to conventional didactical methods. Their findings suggest that an ITS may aid in enhancing the rate of learning, although there were no statistically significant differences in recall of information in the longterm.[47] Wu et al evaluated the impact of the CC-Cruiser, an AI-based system for the diagnosis of congenital cataracts, on medical students' ability to identify pathology clinically. When compared to students who alternatively received conventional didactic material, those utilizing the CC-Cruiser had significantly higher scores with regard to diagnostic competency on pre- and post-assessment.[48] However, the ability to construct a treatment plan was similar among both groups.[48]

At the time of writing, AI is not currently used as a part of the Basic and Clinical Sciences Course by the AAO or tested on the OKAP exam.[49] However, AI in ophthalmology has been covered at conferences, such as at the Association for Research in Vision and Ophthalmology (ARVO), AAO, and the AI in Ophthalmology Symposium at the University of Illinois at Chicago.[49] Valikodath et al discuss a curriculum for AI in ophthalmology, emphasizing the importance of acquiring a basic knowledge of how an AI system functions, developing the ability to analyze outcomes, and applying them to a clinical setting and communicating them to patients and colleagues.[49] There are have been several publications that provide basic instruction on AI in medicine and ophthalmology.[50] There may be a benefit in introducing an AI curriculum during medical school prior to transitioning to a curriculum tailored to each subspecialty during residency.[49]

In addition to using AI to train learners how to identify pathology, AI can be used to obtain automatic consults in rural settings. Cybersight supports virtual consultations such as these using AI-based evaluation of fundus photographs for the inspection of retinal and glaucomatous disease, a process referred to as "machine mentoring".[19,20] This automated program analyzes the ophthalmic images, identifies and labels key clinical features, and generates a diagnosis.[20] Remote consultation and automated diagnostic methods may benefit providers in underserved regions in particular by enhancing knowledge and efficiently identifying cases requiring urgent referral.[19]

VII. Telemedicine

The role of telemedicine and its potential to promote high quality care has been well-established, and it lends itself to the expansion of web-based educational efforts. For example, the Scottish Eyecare Integration Project was created in order to expedite the referral of urgent cases.[51] This program functions using imaging and clinical data uploaded to a web-based platform. Over the years, the data collected culminates into a repository of information that can be easily extracted for educational purposes.[51] As a result, 2 online master's degree courses were created, one geared towards ophthalmology trainees and a second towards allied professionals.[51] Furthermore, with regard to education and telemedicine, the Accreditation Council for Graduate Medical Education set milestones for ophthalmology residents, which includes telehealth as one component. Cole et al iterate that the role of telemedicine extends beyond triage and diagnosis and is a powerful tool that serves as a medium to address patient concerns, provide education, and ensure medical management is followed. During the COVID-19 pandemic, telemedicine was utilized more as a medium of patient care as there was a need for minimal direct in-person contact to reduce potential exposure to COVID-19. Given the success of this model for certain medical specialties, it is likely to become an important part of medical care. Ultimately, a standardized curriculum for teleophthalmology should be developed and implemented as part of residency training requirements.[52] As AI-based telemedicine programs become more prevalent, a specific curriculum should be developed for ophthalmology trainees.[49]

VIII. Recommendations

Based on the above review of the current modalities for digital learning in ophthalmology, we suggest that there may be potential benefits to implementing the following educational methods. First, problem-based learning via online platforms has shown to statistically improve diagnostic competency of users. Remote learning via commercially available telecommunication technology, without the incorporation of a flipped classroom approach, provides passive learning at most. Interactive programs, whether virtually or in-person, should be the mainstay of education during training. Second, surgical, as well as clinical, simulators allow for a hands-on experience to repeatedly practice diagnostic and interventional techniques. Automated feedback allows users to immediately identify and reform their performance. This may reduce cost to the system, as well as complications in patient care, in the long term.

IX. Conclusions and Future Directions

The key findings of this review are as follows: 1) web-based programs have shown to be an effective means for acquiring knowledge in ophthalmology, 2) virtual ophthalmic training curricula, web-based society meetings, and online examinations serve a role as additions to in-person activities and may replace certain activities in the future, 3) telesurgery and surgical simulators, including AI-based systems, have been developed for ophthalmologists and trainees, and 4) there is a need for trainee education in the operation of teleophthalmology programs.

The development of the Internet and computer-based programs has brought about the generation of tele-education systems and VR simulators in ophthalmology education. In addition, there has been a recent shift towards the use of online resources to obtain clinical and surgical knowledge. This technology provides opportunities to improve quality and accessibility of educational materials across international boundaries and to those in rural environments. As virtual methods continue to have a more prominent presence in medical training, curricula must be established for virtual medical school clerkships, simulated surgical training, teleophthalmology, and AI programs. These methods have the potential to reach ophthalmology trainees around the world in order to supplement their training experiences and strengthen their skillsets.

Funding Sources:

This project was supported by R01EY029673 grant from the National Institutes of Health (Bethesda, MD) and by unrestricted departmental funding from Research to Prevent Blindness (New York, NY). The sponsor or funding organizations had no role in the design or conduct of this research.

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