4

Telehealth in Ophthalmology

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Abstract: Ophthalmology is a suitable field for telehealth integration given technology's advancement in capturing images and transmitting data. Since the 19th century, with the first photograph of a retina in a living human, the utilization of technology in delivering remote eye care, known as teleophthalmology, has evolved rapidly with smartphones, 5th generation wireless communication, and artificial intelligence. These widespread applications have been used both asynchronously (store-and-forward) and synchronously (real-time) in the screening, diagnosis, monitoring, and treatment of eye diseases such as diabetic retinopathy, age-related macular degeneration, glaucoma, anterior segment and oculoplastic diseases, neuro-ophthalmic disorders, and pediatric ocular diseases including retinopathy of prematurity. With demonstrated clinical efficacy, patient satisfaction, and ongoing advances, telehealth in ophthalmology has strong potential in improving access to eye screenings and treatments as well as expanding the geographic coverage of eye care globally.

Keywords: digital imaging; tele-ophthalmology; tele-screening; telehealth in ophthalmology; telemedicine

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INTRODUCTION

Telehealth, the remote delivery of clinical services through electronic communication and other technological tools, is feasible in ophthalmology given the field's image-based nature. The application of telehealth in ophthalmology, known as teleophthalmology, has been used for remote screenings, treatment monitoring, post-operative care, and in some cases for diagnosis and management. Though interest in teleophthalmology has significantly increased since the Coronavirus Disease 2019 (COVID-19) pandemic, given the vulnerability of viral transmission in eye exams, telehealth has already a long-standing history in the field of ophthalmology with wide applications in increasing the delivery and quality of care in various ocular diseases (1).

HISTORY OF TELEOPHTHALMOLOGY

Teleophthalmology combines the sharing of images and collaboration between specialists over geographic distance, and was first possible with the advent of the telegraph (2). It has become more vital now as a solution to accessing medical care in the COVID-19 pandemic. In order to understand the history of teleophthalmology, the history of ophthalmic imaging must be considered. In the 1800's, the retina of a living human was first photographed. The year 1961 marked the first use of fundus angiography (3). These images were stored on hard disks and first transmitted to remote computers by modem using standard dial-up telephone lines in 1987 (4). That same year, NASA transmitted retinal images from space using portable video fundoscopy allowing teleophthalmology to span over vast distances (5).

The ability to obtain ocular imaging without the need for expensive physical equipment allows for screening in remote sites. In 1975, Rose et al. documented the first use of phone and radio consultation between an ophthalmologist and a technician examining patients in an isolated location (6). Mobile medical units have since been used to deliver telemedical care to patients without easy access to specialists. Mobile units provided glaucoma healthcare services in Greece and Finland, for example (7). Over time, screening for ophthalmic pathology via telemedicine has expanded. One notable example is the Joslin Vision Network, established in 2000, which provides sites for diabetic retinopathy (DR) screening for veterans across 3 continents (5). Use of electronic mail (email) in patient and physician communication began appearing in the literature during the 1990's. Ophthalmic images can be shared via email in a store-and-forward fashion allowing for telediagnosis. Email further broadens the ability of specialists to provide care to underserved communities. A review found that secondary care providers and specialists make up the majority of reported medical services utilizing email, with image-based specialties having the greatest benefit (8). More recently, crowdsourcing is being explored as a method of remote image analysis and data processing in ophthalmology utilizing collective intelligence (9).

As technology advances, so does the ability to conduct teleophthalmology. Smart phones have become "portable exam instruments" changing how imaging is collected and interpreted (7). Smartphones can attach to slit lamps and record ocular biomicroscopic videography (10). Slit lamp smartphone attachments (considered Class 1 devices) allow physicians to screen for diseases, test visual acuity, and capture fundus images from their mobile devices (7, 11). Communication advancements enable ophthalmologists all over the world to collaborate in real-time – from computer screen sharing of images to real-time communication in the operating room (7, 10). Postoperative follow-up can also be achieved via telemedicine. In 1998, Shimmura et al. documented early use of video and audio transmission for post-operative consultation after keratoplasty (12). In Japan, post-operative follow-up was performed using a remote-controlled slit lamp, negating the need for a skilled operator at the site (7).

Digital advancements such as artificial Intelligence (AI), machine learning (ML), and deep learning (DL) have changed how teleophthalmology is practiced. Because these methods do not require interpretation by an ophthalmologist, they allow non-specialists to screen images for potentially devastating diseases. AI is the use of technology to mimic human behavior. ML describes a system that can learn from experience as opposed to human programming. DL is a subset of ML which further expands the capability of technology to learn and predict (13). There are two FDA approved AI screening algorithms for DR (14). The application of DL to ophthalmic images has been reported to achieve clinical screening and diagnostic accuracy (10). Google has conducted research exploring the use of DL as a tool for DR screening in Thailand (15).

Due to the relative lack of pediatric ophthalmologists, use of AI in screening and diagnosing pediatric ocular pathologies is increasingly important; an example of this can be found in screening for Retinopathy of Prematurity (ROP), a leading cause of blindness worldwide (16). The first automated ROP detection system using DL was established in 2016 using a convolutional neural network model (17). Now, ML programs DeepROP and iROP exist which can diagnose, monitor, and grade severity of ROP (16). Additionally, DL algorithms can screen for other pediatric pathologies including congenital cataracts, microphthalmia, aphakia, microcornea, lens dislocations and others using video clips of visual behaviors (18). AI has been used to screen for keratoconus, keratitis, and pterygium in the research setting, with diagnostic results comparable to that of ophthalmologists (7). Pre-op screening for corneal refractive disease using AI has been adopted, and AI has even been utilized in planning aspects of cataract surgery (7). For the post-op period, Long et al. created CC-guardian, an AI-based smartphone application that provides patients with specific follow-up plans (19).

The invention of 5G internet has allowed physicians to view images and videos of patients in both a store-and-forward and live stream manner, with good image quality and essentially no network lags. 5G internet enables Ultra-High-Definition multimedia streaming with easily transferred high resolution images (10). Currently, screening for strabismus using live-streamed video captured with smart glasses is being developed (20). The use of 5G for teleconsultation and exams became especially important during the COVID-19 shutdown, when most healthcare visits transitioned to a digital platform. With the use of 5G, teleophthalmology has been adopted as a therapeutic modality. First reported in 2017, Kozak et al. remotely created offline photocoagulation treatment plans for diabetic macular edema patients (21). The year 2019 marked the first use of teleophthalmology as a real-time therapeutic modality for laser photocoagulation therapy, incorporating 5G high speed internet, navigated laser photocoagulation, and tele-photocoagulation, among others (22). Technological advancements increase the potential of teleophthalmology exponentially. 6G internet, Internet of Things, and AI, DL, and ML can allow for disease prediction and forecasting. Augmented reality and virtual reality can help patients monitor chronic disease progression from home and detect vision changes before they are clinically significant (10). This chapter further explores the vast possibilities and future directions of teleophthalmology.

DIABETIC RETINOPATHY

Over one third of diabetic patients experience DR, the fifth leading cause of blindness in adults aged 50 years and older (23, 24). While age-standardized prevalence for more common causes of vision loss have decreased between 1990 and 2020, DR was the only cause found to have increased with an estimated global prevalence of 103 million in 2020, expecting to increase to 160 million by 2045 (23, 24).

Traditionally, DR is diagnosed by an "eye-care provider" (for example, an ophthalmologist or an optometrist) examining the fundus, with screenings recommended annually for early diagnosis and treatment. However, the increasing DR prevalence can outpace eye-care providers' screening abilities, especially in geographically remote areas (23). Telehealth can provide a solution by improving screening efficiency and accessibility with color fundus photography (CFP) that trained image graders can interpret remotely. Reallocating screening from providers to photo technicians and graders can streamline the patient-provider relationship, increasing eye care both in quantity and in geographic coverage.

Asynchronous modalities

CFP has been most commonly conducted via tabletop fundus cameras capable of capturing retinal pathologies with seven standard field (30°) images, with graders evaluating each field before providing overall DR severity scores. A newer imaging modality that could be the future gold standard is ultra-wide fundus (UWF) imaging, with wide-angle lens (100–200°) more than doubling the total retinal surface area captured to allow simultaneous evaluation of the peripheral and central retina (25). Numerous studies have demonstrated tabletop cameras' effectiveness in detecting DR, with pooled sensitivity and specificity of 95.0% and 86.0%, respectively, highest with mydriasis and wide-angle lens (26). In fact, UWF imaging has demonstrated an impressive sensitivity and specificity of 99% and 100%, respectively, with a lower proportion of ungradable images (27). Given the accuracy of tabletop cameras, multiple countries have implemented them in DR telescreening programs to better triage patients for ophthalmic care (10). Results from these large-scale programs have shown these cameras to be a valid screening method, though expensive in equipment and technicians especially for UWF imaging.

Technological advances have also allowed CFP via smaller handheld devices, a cheaper, more portable, and more accessible alternative for under-resourced communities unable to supply high-cost tabletop cameras with trained personnel (25). Newer models for mydriasis have promising sensitivity and specificity >88% and strong agreement with tabletop cameras (28, 29). Smartphone-based apparatuses have also shown potential in detecting DR with pooled sensitivity and specificity 87% and 94% (30). Though tabletop cameras are still the preferred screening method, portable systems can provide an innovative solution in resource-limited rural settings.

If countries across the world were to implement DR telescreening programs, there would be close to one billion fundus images taken annually, an unsustainable workload for graders (10). Automated AI has the potential to efficiently assist in DR image interpretation. The deep-learning system EyeArt v2.0 was able to process 100,000 encounters in less than 45 hours with sensitivity and specificity >90%, accuracies consistent with other DR AI systems (31, 32). One algorithm was even able to predict future worsening of DR for up to two years, suggesting that AI could have the potential to risk stratify patients based on calculated prognosis (33). Depending on AI's generalizability with real-world diverse and non-ideal image qualities, it can serve as a powerful tool in CFP interpretation.

While most applications of CFP have focused on DR telescreening, CFP also has the potential for tele-treatment. One study successfully conducted laser photocoagulation on ten patients with diabetic macular edema in Saudi Arabia using image-based treatment plans created by retinal specialists in the U.S. (21). Telehealth's ability to asynchronously transfer retinal images allows for international provider-provider collaboration, where specialists can design treatment plans for local providers in remote areas.

Synchronous modalities

Though there are numerous asynchronous DR screening programs, synchronous screenings are less established. One example in the U.S. evaluated the ability of nonphysician imagers to also be trained in grading, allowing for real-time UWF interpretation (34). Trained imagers in this study were able to provide immediate results with a referable DR false negative rate of 1% and faster turnaround time compared to asynchronous grading. Reviewing retinal imaging results in these primary care settings is suggested to improve patient adherence to glucose control (35). Therefore, conducting CFP with real-time results in primary care settings could reduce the workload of reading centers and improve patient compliance.

An exciting future of DR telehealth is its ability to provide synchronous treatment through laser photocoagulation. In a 2021 study, a retinal specialist in Beijing, China, safely performed online real-time laser photocoagulation on nine eyes with DR in Huzhou, China, 1,200 km away (22). The specialist first videoconferenced with participants and local ophthalmologists to design image-based treatment plans, then remotely controlled the laser device using real-time fundus video without any noticeable delay or safety issues. While this is the first study of synchronous DR tele-treatment, it demonstrates telehealth's potential in improving access to quality care for areas with retinal specialist shortages.

AGE-RELATED MACULAR DEGENERATION

Age-related macular degeneration (AMD), one of the leading causes of vision loss in people 50 years and older, has strong potential of vision retainment after anti-vascular endothelial growth factor intravitreal injection treatment with patients recommended to be screened every 1–2 years (24). This clinical burden to frequently screen an aging population can be alleviated with asynchronous telescreenings, since decision for treatment is heavily dependent on visual acuity (VA), CFP, and optical coherence tomography (OCT) findings, all capable remotely.

The combination of OCT and CFP findings have been shown to effectively identify patients requiring AMD referral with sensitivity and specificity >90% (36). When compared to in-person examinations, telescreenings have shown no significant difference in referral times or patient satisfaction, with one study even showing that a majority of AMD patients surveyed preferred telehealth (36, 37). Once diagnosed by a retinal specialist, patients with AMD can have follow-up care at "virtual" clinics that utilize imaging in place of an in-person retinal specialist. In the UK, these clinics have shown to be more time-efficient with shorter visits and sooner follow-up appointments (38). Another model had AMD patients receive follow-up care by local ophthalmologists, with retinal specialists at the Mayo Clinic making recommendations remotely using the ophthalmologists' clinic observations, VA, intraocular pressure (IOP), and imaging (39). With these patients living a mean distance of 112 km away from the specialists and only 2.5% of e-consults recommended for in-person specialist care, this model shows that asynchronous physician-to-physician collaboration could be an effective use of resources when in-person retinal specialists are not readily available.

Once disease stability has been achieved, patients can be monitored for AMD progression at home in order to minimize unnecessary in-person visits. AMD home-monitoring began in 1947 with the Amsler grid, where deviations in grid paper lines indicated macular dysfunction. A modern alternative with higher accuracy is ForeseeHome, a system that uses preferential hyperacuity perimetry technology where patients click on a screen of dotted lines in areas they see distortions. This has the ability to detect AMD-associated vision changes even prior to symptomatic VA loss, automatically alerting clinics to recall patients for in-person exams resulting in a higher detection rate of neovascular AMD and less visual loss compared to standard in-person monitoring (40).

An exciting future is AI's role in AMD detection and management. DL systems have shown strong accuracy in detecting AMD from CFP, with sensitivity and specificity >96% (37). In addition, AI has the ability to assist in disease management by measuring retinal fluid, drusen, hyperreflective foci, and pigment epithelial detachment on OCT, all key biomarkers of AMD (41). Being able to quantify these variables rather than solely using a clinician's qualitative evaluation can help assess anti-VEGF treatment response. Areas in need of further development for AMD include using AI to predict disease progression, with existing systems having limited accuracy, along with ways to integrate telehealth synchronously, as no real-time methods exist (41).

GLAUCOMA

Glaucoma is the second leading cause of blindness worldwide with an estimated prevalence of 76 million in 2020, only expected to rise with an aging global population (42). This increase can be difficult for eye-care providers to efficiently screen and care for patients given that glaucoma assessments are multifaceted with ophthalmic exams, visual field (VF) testing, tonometry, central corneal thickness, and OCT. However, with many of these tests able to be translated remotely, telehealth can effectively address this need.

Asynchronous modalities

Glaucoma telescreening uses anterior segment photographs, CFP, VA, and IOP to identify patients and expedite care. These programs have been effective in screening high-risk populations, with a study on first-degree glaucoma relatives finding 27% screened with glaucoma or requiring a referral and another study with a predominantly African American cohort, a high-risk population, finding over one-third of subjects with glaucoma-suspicious images (43, 44). These programs have also been implemented in rural settings, such as in China with an established system screening elderly in remote villages (45). A Uganda study also found that smartphone-based ophthalmic imaging has a strong correlation with the standard spectral domain OCT, potentially useful in screening remote or under-resourced communities (46).

With telescreenings increasing the quantity of glaucoma images, AI can assist with image interpretation. Models have been developed to detect glaucoma from CFP and OCT with an impressive AUC of 0.98 and 0.99, respectively, with some models having a higher sensitivity in detecting early glaucoma than with standard OCT and VF (47–49). Some models are also able to predict the severity of VF loss based on OCT imaging, possibly allowing clinicians to individualize the frequency of VF testing (50). Further studies on AI's consistency with various optic disc appearances especially in myopic patients will determine its generalizability.

After a glaucoma diagnosis has been made, remote management can be done utilizing telehealth. "Virtual" clinics, composed of optometrists consulting remote glaucoma specialists, have been successfully implemented in several countries, with a UK study showing an 87% level of agreement between optometrists and specialists and a Singapore study finding these clinics to be more time-efficient and cost-effective (51, 52). Glaucoma monitoring can also be done at home with smartphone VA testing and home tonometers that do not require topical anesthetics. Since IOP fluctuates throughout the day, home-monitoring could potentially provide a more comprehensive depiction of IOP rather than a one-time measurement in the clinic. This can prove useful in monitoring treatment response and complications, tracking decreases in IOP after selective laser trabeculoplasty in adults and even detecting 92.3% of spontaneous tube openings in pediatric glaucoma patients (53, 54). VF can also be assessed at home with virtual reality headsets and smartphones, showing a strong correlation to the standard automated perimetry with fewer fixation losses (55, 56). However, further research with larger sample sizes and on its cost-effectiveness is needed.

Synchronous modalities

Glaucoma visits can be conducted synchronously with video slit lamps, fundus cameras, and videoconferencing. One rural healthcare center provided real-time exams with a university glaucoma clinic, showing high patient satisfaction with

96% of patients preferring telemedicine over traveling to the university (57). Real-time video imaging has also shown potential in remotely examining glaucomatous eyes after trabeculectomies, with all bleb leak cases identified by slit lamp also successfully detected by ophthalmologists via telemedicine in one study (58).

ANTERIOR SEGMENT AND EXTERNAL DISEASES

Anterior segment diseases involving the conjunctiva, cornea, anterior chamber, and lens are responsible for some of the leading causes of visual impairment worldwide. Cataract alone is the leading cause of blindness in people 50 years and older with approximately 36 million cases globally, with corneal opacity and trachoma as the fifth and sixth (59). Therefore, telehealth for anterior segment and external pathology can increase screenings and treatment.

Asynchronous modalities

For corneal diseases, single-lens reflex photography and smartphones with magnifying attachments are more portable than slit lamps while still being able to detect corneal ulcers, abrasions, and trachomatous follicular inflammation, though with lower accuracy for smaller corneal opacities and fainter scars (60, 61). To assist with image interpretation, AI can distinguish several corneal diseases including keratoconus, keratitis, and pterygium based on corneal topography, anterior segment OCT, and slit lamp images (62). Some systems are even able to detect high-risk corneas or graft detachment after Descemet membrane endothelial keratoplasty (63, 64). A unique telehealth application in corneal disease is evaluating donor corneal tissues remotely via digital images from slit lamps, OCT, and specular microscopes (65). For cases with common corneal findings, the remote evaluators, eye bank staff, and in-person evaluator had a 100% rate of agreement in one study. However, more research is needed to determine its reliability given the lower rate of agreement (80%) for ambiguous cases.

Regarding cataracts, a Beijing project screening elderly in rural areas had patients with visual acuity less than 0.30 referred to a primary care center for photographs of the anterior segment and fundus (45). Among 37,281 individuals, 19,163 were graded as cataracts and 5,853 as advanced cataracts requiring surgery, all referred to local ophthalmologists. AI has also been developed to diagnose the presence of cataracts (AUC ≥99.8%) and cataracts requiring referral (AUC >91%) via slit lamp imaging (66). Wu et al. integrated these methods into a three-tiered screening system beginning with home self-monitoring via smartphone applications assessing VA and taking eye photos, followed by community-based assessments with AI-interpreted slit lamp photos, and finally tertiary referrals to ophthalmologists if visually significant cataracts is deemed by the AI system. This model increased the ratio of ophthalmologists to population-served by ten-fold, with an ophthalmologist in theory able to serve over 40,000 patients screened for cataracts every year.

Telehealth can also be used to evaluate red-eye, the most common eye complaint to primary care physicians with a wide range of etiologies including subconjunctival hemorrhage and pterygium. Sink et al. found a 92% rate of agreement for red-eye etiology between corneal ophthalmologists in-person and remotely from smartphone photos taken by patients' companions (67). Similarly, the study also found that oculoplastic ophthalmologists were able to interpret patients' smartphone photos of post-eyelid surgery complications with perfect agreement. This demonstrates how oculoplastic and external eye diseases are well-suited for telehealth, with diagnoses made possible via phone cameras without the need for slit lamps or additional imaging.

Synchronous modalities

Telehealth can be used to provide real-time consultations for anterior segment and external diseases. One notable model is Brazil's TeleOfthalmo, a primary care network where ophthalmologists examine patients' eyes in real-time using videoconferencing with remotely-operated robotic cameras, examining the external eye and supplementing the data with slit lamp images of the anterior segment taken by technicians (68). Using remote ophthalmologists, two-thirds of eye complaints were able to be managed at the primary care level, potentially allowing a more effective use of specialty centers in the future. For oculoplastics, patients in the UK were able to see specialists at home in real-time using their cellphones, capturing a wide range of diseases including basal cell carcinoma and orbital inflammation (69).

Synchronous treatment for anterior segment and external diseases are less established. Camara et al. described the successful surgical removal of an orbital tumor in a 15-year-old girl in Hawaii by a general ophthalmologist under the guidance of an orbital specialist videoconferencing 338 km away from another island (70). In Australia, a Sydney hospital was able to guide general practitioners in two cases of corneal foreign body removal in a rural hospital 788 km away via videoconferencing and slit lamp imaging (71). These cases demonstrate the effectiveness of telehealth in providing real-time collaborative specialty care in extreme situations with geographic barriers.

NEURO-OPHTHALMOLOGY

The subspeciality of neuro-ophthalmology, caring for eye manifestations of multi-organ pathology like thyroid eye disease and life-threatening neurological conditions like papilledema, has been increasingly implementing telehealth especially since the COVID-19 pandemic. In 2020, video visits increased from 3.9% to 68.3%, with 87% of surveyed U.S. neuro-ophthalmologists able to complete a remote examination enough for medical decision-making (72, 73).

One important neuro-ophthalmology pathology that can potentially be diagnosed with asynchronous imaging of blurred optic discs is papilledema, a sign of increased intracranial pressure. In a study with 133 patients at a blurred disc clinic, neuro-ophthalmologists were able to correctly identify all six cases of true papilledema confirmed via direct ophthalmoscope by remotely grading CFP (74). Additionally, CFP could prove to be a better modality than direct ophthalmoscopes for non-ophthalmologists. In a study of patients with neurological findings warranting a fundus exam, emergency physicians did not detect any of the patients who had a course-altering eye finding via direct ophthalmoscopy, yet were able to identify 82% of relevant findings via CFP (75). However, the reliability is questionable with further studies showing low accuracy with little improvement after brief trainings (76).

Teleconsultations are also useful in extreme circumstances where neuro-ophthalmologists are not readily available. For instance, a previously healthy service member deployed in the Middle East presented with acute diplopia and recorded a sensorimotor examination for an ophthalmologist in the U.S. (77). After ruling out any urgent neurologic etiology, the ophthalmologist deemed it safe for the patient to remain at his duty station, later receiving a diagnosis of thyroid eye disease in the U.S. The use of asynchronous telehealth helped triage the patient's acuity and ultimately avoided an unnecessary evacuation.

PEDIATRIC OPHTHALMOLOGY

It is estimated that 19 million children worldwide aged 14 and under are blind or visually impaired, with a majority likely from preventable or treatable diseases (78). While childhood blindness heavily impacts middle-to-low-income countries, even high-income countries are in need of increased resources because of shortages of pediatric ophthalmologists (79). Telehealth can help by increasing capacity for screenings and treatment.

Asynchronous modalities

The variety of pediatric ocular diseases ranging from eyelid pathology to retinal diseases requires unique technologies best suited for each component of the eye. For the anterior segment, asynchronous digital slit lamp videos have been shown to have high sensitivity for detecting pathology in the cornea, anterior chamber, iris, and lens (89–96%), with 87% or greater agreement with in-person examination (80). For strabismus detection, wireless smart glasses can record defects in ocular alignment and motility, with graded store-and-forward videos having perfect agreement (k=1.0) on detection of horizontal and vertical deviations and almost perfect agreement (k=0.99) on degree manifest with in-person examinations (20). These glasses were also successfully used for detecting blepharoptosis surgical candidates after same-day video review (sensitivity 100%, specificity 94.1%) (81). A major advantage of these glasses is easier assessments of pediatric patients, with its hands-free capability allowing examiners to hold toys to maintain children's attention and the video functionality able to capture footage in children unable to sit still.

For ROP detection, retinal pathology in newborns is possible remotely through grading of wide-field CFP images, with multiple studies showing strong diagnostic accuracy. One well-established ROP U.S. screening program (SUNDROP) found images interpreted by ROP specialists to have a high accuracy in detecting treatment-warranted ROP compared to BIO examination (sensitivity 100%, specificity 99.8%) (82). Another study (e-ROP) had trained non-physician image graders detect ROP requiring referral with a sensitivity and specificity of 90.0% and 87.0%, respectively, demonstrating that trained personnel could lessen physician workload with ROP screenings (83). More recently, ML programs such as DeepROP and iROP have been developed which can diagnose, monitor, and grade severity of ROP (16).

Synchronous modalities

Real-time telehealth via video streaming has shown to be effective in a wide range of pediatric ocular diseases. In one study, the use of live digital slit lamp videos had 88–96% sensitivity in detecting pathology in the cornea, anterior chamber, iris, and lens (80). For strabismus, real-time assessments via Pivothead video glasses showed perfect agreement (k=1.0) for detection of horizontal and vertical deviations and almost perfect agreement for degree manifest (k=0.94) (20).

One study used a combination of these technologies (digital slit lamp, smart glasses, digital indirect ophthalmoscope), with an optometrist live-streaming to a pediatric ophthalmologist for real-time assessments, finding no discrepancy in primary diagnoses or management plans compared to in-person examination later that day by the same ophthalmologist (84). Most notably, 98.2% of patients that consented for surgery did so over telehealth with 98.5% of families feeling comfortable with the quality of the telehealth exam and 97.1% willing to participate again in the future. This demonstrates the reliability of real-time remote assessments, potentially increasing efficiency and geographic coverage in situations where pediatric ophthalmologists would have been inaccessible otherwise.

Telehealth can also assist with physician-to-physician collaboration and education in pediatric eye care. In a unique Ethiopian program, ophthalmology residents were trained remotely by Canadian pediatric ophthalmologists, developing the first pediatric ophthalmology fellowship in East Africa (85). With Canadian physicians providing synchronous videoconference didactics including review of cases and images throughout the year as well as visiting in-person for concentrated surgical supervision, this program had residents complete over 14,000 medical and over 600 pediatric surgical cases. This demonstrates telehealth's ability to provide academic partnership, with high-income countries sharing educational resources to increase training and accessibility in low-to-middle income countries.

CONCLUSION

Overall, ophthalmology remains an ideal specialty for telehealth integration, with diagnoses and disease management able to be made with digitally transmissible images and videos. Teleophthalmology has rapidly evolved over the past century and will continue progressing even further with technological advancements like 5G and 6G internet and AI. While the high prevalence of ocular diseases pose a challenge for ophthalmologists to frequently screen and treat, telehealth provides a solution in increasing the quantity and geographic coverage of care. This has been demonstrated in both low and high-income countries, increasing care in underserved high-risk populations as well as reaching rural and remote communities.

Teleophthalmology has not only impacted patient-physician interactions with increased convenience and time efficiency, but also collaborations between physicians, allowing general eye-care providers to consult remote specialists even across continents. While integrations of teleophthalmology still require further research on its generalizability and accuracy in larger real-world settings, its increasing patient satisfaction and clinical efficacy foreshadows its important role in delivering quality eye care long into the future.

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