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Review Article

Remote Imaging Opportunities, Innovations, and Considerations for Teleophthalmology

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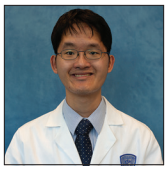

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ABSTRACT

Imaging has emerged as a key tool for ophthalmologists to quickly and accurately diagnose and help manage ophthalmic conditions. The importance of useful teleimaging technology will increase as remote appointments and surveillance becomes more widely utilized in ophthalmology. This review article describes the current state of remote imaging including the results of many "store and forward" studies. It also summarizes potential emerging teleimaging modalities such as home optical coherence tomography, remote slit lamps, and smartphone imaging. While published studies highlight many possible utilities for teleimaging, further clinical validation and technology improvement need to occur before teleimaging can become more ubiquitous.

Keywords: Fundus photography, Optical coherence tomography, Remote imaging, Smartphone imaging, Teleophthalmology

SEARCH TERMS AND DATABASES USED

The PubMed database of the National Center for Biotechnology Information (NCBI) was searched for peer-reviewed literature using the terms "remote imaging ophthalmology" AND "remote ophthalmology" yielding 240 results. Abstracts were reviewed and relevant articles were selected. From these articles, cited publications were also selected if related to the topic of this review.

INTRODUCTION

Imaging is critical to the diagnosis of ophthalmic conditions. Non-invasive imaging, including fundus photography and optical coherence tomography (OCT), has dramatically enhanced diagnostic accuracy in the clinic. However, imaging remains challenging when providing remote patient care. The most widespread modality of remote imaging is the "store and forward" method. A patient travels to a location where images are taken, stored, and shared remotely to the physician's location.[1] Real-time teleimaging for ophthalmic visits is rare and is at best limited to either screening purposes or management of acute conditions.[1] Benefits of improving remote imaging include diagnosis from a distance, improved screening, a wider range of conditions which can be addressed remotely, and improved access for more patients.

This review summarizes the current state of teleimaging approaches in ophthalmology, explores emerging technologies that may improve teleimaging capabilities in the future such as the use of smartphone imaging, and briefly comments on some challenges of these technologies to

consider. To explore the current state of teleimaging, this manuscript will address four questions: (1) Are current store and forward models expanding access? (2) Can providers use imaging to accurately screen for or diagnose disease? (3) Can imaging options be expanded beyond commercial imaging equipment to expand access? and (4) Can minimally trained individuals play a role in the future of teleimaging?

EXPANDING ACCESS WITH TELEIMAGING

The most common approach within clinical studies and medical practices currently is the "store and forward" approach.[1] Images are taken and stored on an imaging device and sent through a secure internet server to the provider at a remote location for diagnoses or referrals. This method is beneficial to patients because it saves patient's travel time and reduces appointment costs.[2-4]

Studies have shown that this approach improves access. Chilean ophthalmologists successfully expanded diabetic retinopathy (DR) screening with their TELMED platform for remote retina specialists to review.[5] The Atlanta Veterans Affairs hospital improved access time to rural veterans' appointments through remote screening.[2] The most vulnerable patients stand to benefit, as Owsley *et al*. found that approximately 21% of 1894 individuals had DR in at least one eye in a predominantly minority and uninsured patients sample.[6]

Although access may improve, it is a limited improvement. A major limitation of "store and forward" is that all patients have to go to a site where a trained health assistant or technician performs the imaging. A lack of adequate support staff in underprivileged locations and less developed countries can limit accessibility. Patients may also need to travel far distances depending on the availability of imaging locations.

SCREENING AND DIAGNOSIS WITH TELEIMAGING

Standard of care for many ophthalmic conditions is considered both clinical examination and imaging. When the patient is remote, imaging becomes the ophthalmologist's primary tool. For this reason, teleimaging has been used for screening with critical cases referred to an ophthalmologist. However, teleimaging can play a more definitive role in diagnosis. A Brazilian ophthalmology emergency room successfully performed teleimaging with a smartphone with 85.0% overall accuracy relative to standard hospital diagnosis.[7] 12,634 of 50,384 patients (25.15%) in a Spanish study were referred to an ophthalmologist including 9.0% urgent visits based on remote imaging.[8] Remote evaluation has also been successful in identifying specific cornea findings commonly encountered by eye banks.[9] As these studies illustrate, the "store and forward" approach works for general ophthalmic complaints. It also has proven utility in several common conditions – DR, retinopathy of prematurity (ROP), age-related macular degeneration (AMD), and glaucoma.

DR

The utility of teleimaging for screening of DR has generally shown positive progress though image gradability remains a limiting factor. Joseph *et al*. in a cluster randomized clinical trial established that hospital attendance was proportionately higher with teleretinal screening (54 of 96 referred [56.3%]) compared with universal hospital referral (150 of 400 referred [37.5%]).[10] Although 10.8% of images in the teleretinal group patients could not be graded, this study establishes the utility of teleimaging to improve the likelihood of attendance.

In a study of 502 diabetic eyes, all remote non-mydriatic and mydriatic images were appropriately diagnosed based on dilated fundus examinations by ophthalmologists.[11] However, 10.1% of the photos used in the study were ungradable, highlighting a major limitation. Gradeability was also an issue in a study among six urban safety-net clinics, where remote graders determined that 4–13% of images taken were ungradable.[12] Furthermore, in a separate study examining DR screening differences, remote image graders only determined 82.4% and 85.7% of non-mydriatic fundus images in rural and urban clinics were good enough quality for evaluation.[13]

While non-mydriatic fundus imaging demonstrates potential utility for DR screening, alternatives such as ultrawidefield (UWF) imaging and OCT merit consideration. The initial Joslin Vision Network study demonstrates the utility of UWF compared with non-mydriatic fundus photography as the ungradable rate per patient was lower with UWF imaging for DR (2.9 vs. 9.9%, $P < 0.0001$) and diabetic macular edema (DME) (3.8 vs. 8.8%, $P < 0.0001$).[14] UWF reduced the ungradable rate by 71% (to <3%). In a separate Joslin Vision Network study of 35,052 eyes, the ungradable rate per patient for DR and DME was significantly lower with UWF imaging compared with non-mydriatic fundus photography (DR, 2.8% vs. 26.9% [$P < 0.0001$]; DME, 3.8% vs. 26.2% [$P < 0.0001$]) with improved DR identification rates with UWF.[15] Consequently, UWF teleimaging can be a reliable tool in DR screening.

A study by Manjunath *et al*. did not indicate positive results for OCT and fundus photography usage. The remote graders' ability to appropriately screen for DR based on widefield and OCT imaging only was compared to clinical examination only and gold standard combined clinical examination and imaging.[16] Remote image evaluation had a sensitivity of 73% and specificity of 96% for detecting proliferative DR. Although sensitivity was not extremely high, the study lends

potential for the utility of OCT in a screening setting as imaging alone found 35 more eyes with new vessels (19% of eyes with new vessels) than clinical examination alone.

ROP

Studies examining remote imaging for ROP have suggested teleimaging's value. About 93.6–97.3% of images obtained by neonatal nurses were judged to be useful by five remote graders, which indicate the utility of having non-ophthalmologists perform imaging.[17] There are a relatively high sensitivity and specificity in ROP detection by teleimaging. In the 6 years of screening for ROP with telemedicine (SUNDROP) study of 1216 eyes and 2169 examinations, remote interpretation of RetCam II/III images had a sensitivity of 100% and specificity of 99.8% for the detection of treatment-warranted ROP compared to bedside binocular ophthalmoscopy.[18] In the e-ROP study of 7905 images, the sensitivity of referral warranted ROP was 82.1% when all five retinal images of acceptable quality were taken.[19] The sensitivity decreased to 67.2% with four acceptable images, demonstrating the importance of having a complete quality set of images. In a multicentered study of 281 premature infants, ophthalmoscopy and telemedicine had similar sensitivity for type 2 ROP (86% vs. 79%; $P = 0.10$ [$n = 251$]), but ophthalmoscopy was more sensitive in identifying Stage 3 disease (85% vs. 73%; $P = 0.004$ [$n = 136$]).[20] These studies reinforce that remote imaging is non-inferior to ophthalmoscopy for identifying clinically significant ROP with the caveat that a quality image is obtained.

Glaucoma

Among the major causes of blindness in the developed world, glaucoma has arguably seen the least amount of teleimaging advances. This is most likely attributable to the need for the detection of both structural and functional changes for diagnosis. Pasquale *et al*. found that 103 of 175 (59%) individuals who were labeled as glaucoma suspects based on the initial imaging had glaucoma suspicious optic discs based on clinical data obtained after imaging.[21] In the Muranga teleophthalmology study of 309 diabetic patients, 74 (24%) had remote imaging deemed unreadable due to media opacities, patient cooperation challenges, and unsatisfactory imaging techniques.[22] The positive predictive value for teleimaging was 77.5% and negative predictive value 82.2% relative to clinical slit-lamp examination. Both studies demonstrate the potential for a teleglaucoma detection model, however, high-quality teleimaging technology serves as a major barrier to successfully implement this diagnostic approach.

Another area of remote monitoring in glaucoma is intraocular pressure (IOP). Sensimed Triggerfish® (Sensimed S.A., Lausanne, Switzerland) is a contact lens sensor that received FDA marketing approval in 2016, but its utility has remained controversial as it is limited in its capabilities, particularly in terms of measuring absolute IOP. Vitish-Sharma *et al.* found SENSIMED Triggerfish measured IOP to be weakly correlated with measurements taken with a Tono-Pen® XL (Reichert Technologies, Depew, NY) applanation tonometer.[23] iCare® Home (ICare USA Inc., Raleigh, NC) rebound self-tonometer has shown feasibility in self-monitoring of IOP, but it tends to overestimate IOP compared to Goldman applanation tonometer (mean IOP difference 0.70 mmHg, $P < 0.001$).[24] Furthermore, other technologies such as EyeMate® (Implandata Ophthalmic Products GmbH, Hannover, Germany) are in development.

AMD

Using OCT and visual acuity data, Adonegui *et al.* were able to detect AMD with 96% sensitivity and 87% specificity with 16 false positives and 3 false negatives compared to office examination.[25] The study demonstrated a reduction in examination time. Remote evaluation on average took 1 minute and 21 seconds (s) while in office examination took 10 minutes (min).[25] Hadziahmetovic *et al.* found that remote diagnosis image interpretability was better when OCT was used compared with color fundus photography (241 [96.4%] vs. 164 [65.6%]).[26] A patient satisfaction survey within the study revealed that 122 participants (76.7%) preferred remote imaging over the standard care examination, indicating that remote imaging can have a positive impact on many patients. AMD can be a viable condition monitored through teleimaging if remote OCT monitoring options continue to improve and reduced treatment burden minimizes the need for in-person injections.

CURRENT AND FUTURE DEVELOPMENTS IN TELEIMAGING

Expanded imaging options beyond current "store and forward" techniques may improve disease detection and reduce travel and time burden of provider-based appointments for disease monitoring. Smartphone and home monitoring technology are poised to supplant current teleimaging equipment. Smartphones are ubiquitous and when the appropriate accessory is used, can double as an inexpensive ocular imaging tool in the patient's pocket. This section considers the ease of operation, image quality, and development of smartphone imaging technology. In addition, it touches on other remote technologies including portable OCT and remote slit-lamp technology.

Anterior segment portable imaging

Various adapters compatible with smartphone cameras have been developed for anterior segment imaging.[27-29] [Table 1] summarizes the developments in anterior segment portable

Table 1: Summary of studies utilizing a portable imaging modality for anterior segment of the eye.

Study authors (and reference)	Imaging modality used	Add-ons or setting modifications	# of eyes and disease conditions studied	Study results summary
*Chiong *et al.*[27]	iPhone 6 ©	Smartphone adaptor with biconvex lens and cobalt blue and red-free filters	N/A	• Adapter takes 25 min to print through 3D printing
*Myung *et al.*[28]	Smartphone (e.g., iPhone 4s ©)	Adaptor with LED external light source	N/A	• Successful imaging of eyelids, conjunctiva, cornea, iris, and lens
*Mohammadpour *et al.*[29]	iPhone 6 ©	90 Diopter Volk non-contact slit-lamp double aspheric lens	N/A	• Successful imaging of ocular surface, cornea, iris, and lens
Sanguansak *et al.*[30]	iPhone 6 ©	Macro lens only; macro lens with augmented light-emitting diode; slit-lamp adapter; no adapter	190 eyes; post-operative cataract	• No adapter: 100% acceptable image quality • Macro lens with LED: 93.7% acceptable image quality • Slit-lamp adapter: 86.3% acceptable image quality • Macro lens: 61.1% acceptable image quality
Otero *et al.*[31]	Nexus 6P Huawei©, BQ Aquaris U Lite ©, and iPhone 6s ©	Two lighting levels and two magnification levels	192 pictures of four subjects; conjunctival hyperemia	• No subjective differences in evaluation of disease with three smartphone cameras • Calibration settings were important for extracting objective data from imaging
Ludwig *et al.*[32]	iPhone 5s © compared against BX 900 slit lamp with a Canon EOS 40D digital camera™ and an FF 450 plus Fundus Camera™	Paxos Scope™; macro lens and indirect ophthalmoscopy with an iPhone 5s ©	229 patients with 719 useable images	• High level of agreement between Paxos Scope and existing clinical cameras (92.6% anterior, 84.4% posterior) was found
Chen and Tan CW[33]	iPhone 5 © and commercial Canon EOS 10D™ anterior segment camera ©	Telescopic mount for iPhone 5 ©	440 anterior segment images; healthy eyes	• There was no difference in grader impression of confidence and usability between both cameras of anterior segment slit-lamp and retroiluminated images of the cortex and posterior subcortex (iPhone 5, P=0.66; Canon, P=0.58)
Woodward *et al.*[34]	Portable Pictor Plus™ Camera	None	24 eyes of 15 patients for anterior segment photographs and 39 eyes of 20 patients for posterior segment photographs	• Anterior segment images had 62–81% sensitivity, increasing to 87–88% with chief complaint • Posterior segment images had 79–86% sensitivity, increasing to 100% with chief complaint
Oliphant *et al.*[35]	Digital compact camera with slit-lamp adaptor versus slit-lamp mounted anterior segment camera	Slit-lamp adaptor on digital compact camera	72 eyes; posterior capsule opacification	• Digital contact camera with adaptor was determined to be comparable to a slit-lamp camera (coefficient of repeatability of 0.58)
Woodward *et al.*[36]	iTouch 5s © and Nidek VersaCam™	None	198 eyes (110 subjects); corneal conditions such as ulcers, scars, and abrasions	• iTouch 5s sensitivity: 54–71% • iTouch 5s specificity: 82–96% • VersaCam sensitivity: 66–75% • VersaCam specificity: 91–98%

*Denotes published descriptions of technology and involve minimal human imaging. N/A: Not applicable

imaging. The quality of smartphone-based images has also been evaluated with mixed results. Sanguansak *et al.* determined that a smartphone with only autofocus and flash illumination at 30 cm from the eye had the highest acceptable image quality compared to phones with adapters.[30] Otero *et al.* in a study of conjunctival hyperemia found no subjective differences in evaluating disease with three smartphone cameras, but camera settings were important for extracting objective data from imaging.[31] A study of the Paxos Scope™ (Digisight Technologies Inc., San Francisco, CA, USA) found that there was a high level of agreement between Paxos Scope™ and existing clinic cameras (92.6% agreement anterior images and 84.4% posterior).[32] Chen *et al.* observed no difference in grader impression of image usability between an iPhone 5 © ($P = 0.66$) and a traditional Canon EOS™ (Canon Inc., Tokyo, Japan) anterior segment camera ($P = 0.58$).[33]

More importantly are studies commenting on diagnostic capacity. In a study with a 5-megapixel portable camera, anterior segment diagnoses had 62–81% sensitivity, increasing to 87–88% with chief complaint information.[34] Posterior segment images had 79–86% sensitivity, increasing to 100% with chief complaint information. Another study with a digital compact camera and slit-lamp adaptor suggested that imaging with a digital compact camera and adaptor had comparable gradeability to a slit-lamp camera in 72 eyes with posterior capsule opacification.[35] Despite these positive results, not all studies examining imaging in disease states displayed supportive findings of portable imaging. For example, the sensitivity to detect corneal pathology was 54–71% for the iTouch 5s © (Apple Inc., Cupertino, CA, USA) camera and 66–75% sensitivity for the Nidek VersaCam™ (Nidek Co. Ltd., Tokyo, Japan) in a study of 198 eyes.[36]

These studies indicate the potential of smartphone imaging to obtain high-quality images and detect pathologies of the anterior segment. The emerging technology is promising though currently hindered by accuracy and reliance on well-trained operators.

Posterior segment portable imaging

Posterior segment imaging is limited in teleophthalmic settings and can greatly improve a clinician's diagnostic and monitoring capabilities. [Table 2] summarizes the developments of retinal portable imaging. A number of smartphone adaptors have been developed.[37,38] A D-Eye adapted smartphone (D-Eye S.r.l., Padova, Italy) had shorter mean ocular fundus examination duration (74 ± 31 s) compared to traditional ophthalmoscopy (130 ± 39 s).[39] Day *et al.* utilized the Welch Allyn Pan Optic iExaminer (Welch Allyn Inc., Skaneateles Falls, NY, USA) to obtain clinically adequate images in 91.06% of children presenting to a pediatric emergency department.[40] Device median examination time was 3 min 24 s.

In a pilot test for the evaluation of DR with CellScope Retina, DR grade matched perfectly with dilated clinical examination in 55.1% of eyes and within one severity level for 85.2% of eyes.[41] Russo *et al.* observed that smartphone ophthalmoscopy with a D-Eye device had exact DR grade agreement for 204 out of 240 (85%) of eyes with slit-lamp examination.[42] About 5% of eyes were unable to be visualized with smartphone ophthalmoscopy due to cataract or small pupil diameter.

Portable widefield imaging has seen improvements. The Ocular CellScope successfully widefield imaged patients with DR and cytomegalovirus retinitis.[43] The study team renamed the Ocular CellScope as the RetinaScope and image quality was determined to be acceptable in 95–98% of images in an ROP study of 54 eyes.[44] In a separate study of 43 pediatric patients, the RetinaScope was utilized to acquire five standard photographs in an average of 2.3 ± 1.1 minutes and 96% agreement occurred between image-based diagnosis and clinical diagnosis.[45]

In a single-center retrospective study, good quality images of the retina were captured in 33 (78.57%) ROP infants with the Make in India Retinal Camera (MII RetCam) (MIIRetCam Inc., Coimbatore, TN, India).[46] Goyal *et al.* found that image quality was good in 25 out of 28 (89.2%) of eyes that underwent MII RetCam imaging.[47] While the image quality is generally high, more studies need to evaluate the detectability of disease with this technology.

Technologies have also been utilized for portable imaging of glaucoma. In a screening examination in Cameroon, 39 (9.87%) were screened positively for glaucoma based on photos by an iPhone 5s © camera coupled with the MIIRetCam.[48] Out of the 14 patients who underwent clinical examination (64.1% lost to follow-up), 8 patients were true positives and 6 were false positives. Bastawrous *et al.* found excellent agreement (k = 0.69) between vertical cup-to-disc ratio (VCDR) measurements by a desktop fundus camera and retinal adapter Peek Retina (Peek Vision Ltd., Hertfordshire, England).[49] Wintergest *et al.* established that VCDR measurements appeared to better correlate with conventional fundus photography when eyes were dilated (r = 0.91) compared to not dilated (r = 0.70, $P < 0.001$).[50] Russo *et al.* found that smartphone ophthalmoscope yielded no mean differences in vertical cup-to-disk ratio relative to slit-lamp biomicroscopy with exact agreement occurring in 21 of 29 glaucoma eyes (72.4%).[51] Miller *et al.* established that there was no significant difference in cup-to-disk ratio between a portable 45-degree non-mydriatic fundus camera (Pictor, Volk Optical Inc., Mentor, OH, USA) and a traditional tabletop mydriatic fundus camera (Topcon TRC 50 DX, Topcon Medical Inc., Oakland, NJ, USA) (estimate = 0.004, $P = 0.24$).[52]

A study of 103 eyes with and without optic disc edema using Pictor Plus™ (Volk Optical Inc., Mentor, OH) portable imaging suggested that the sensitivity and specificity for

Table 2: Summary of studies utilizing a portable imaging modality for retina.

Study authors (and reference)	Imaging modality used	Add-ons or setting modifications	# of images taken	Study results summary
*Livingstone *et al.*[37]	Samsung Galaxy S3 ©	3D-printed adaptor	N/A	• Retina images were of sufficient quality for clinical examination
*Myung *et al.*[38]	iPhone 5 ©	Adaptor with Volk Optical Inc. Pan Retinal 2.2 lens	N/A	• Successful retinal imaging of branch retinal vein occlusion, diabetic macular edema, and RPE hypertrophy was demonstrated
Muiesan *et al.*[39]	iPhone 6 ©	D-Eye Adaptor	52 patients in emergency department with intense increase in blood pressure (SBP> 180 and/or DBP >100); Examined for hypertensive ocular damage	• Mean duration time of ocular fundus examination was 74±31 s and 130±39 s for D-eye smartphone fundus imaging versus traditional ophthalmoscopy, respectively • High concordance for D-eye smartphone by two users existed for papilledema presence (K: 0.89–0.90) and good concordance for the assessment of hemorrhage and exudates (K: 0.66–0.77)
Day *et al.*[40]	Pan Optic iExaminer®	None	184 pediatric patients; variety of emergency department-based ophthalmic conditions	• Clinically adequate images in 91.06% of children • Median examination time: 3 min 24 s
Kim *et al.*[41]	Cellscope Retina	None	142 eyes; diabetic retinopathy	• 100-degree photomontage images successfully obtained • DR grade matched perfectly with dilated clinical examination in 55.1% of eyes and within one severity level of 85.2% of eyes • For referral warranted DR, average sensitivity was 93.3% and specificity 56.8%
Russo *et al.*[42]	iPhone 5 © versus slit-lamp examination	iPhone had D-Eye adapter	240 eyes with type 1 or 2 diabetes mellitus	• Diabetic retinopathy grade between modalities had exact agreement in 204/240 (85%) of eyes • About 5% of eyes could not be visualized with smartphone
*Maamari *et al.*[43]	iPhone 4s ©	Ocular Cellscope	N/A	• Successful widefield imaging in healthy retina, diabetic retinopathy, and cytomegalovirus described
Patel *et al.*[44]	iPhone 5s ©	RetinaScope	54 eyes; retinopathy of prematurity	• Acceptable image quality in 95 and 98% of images by two masked graders • Excellent agreement between gold standard and image assessment for the presence or absence of plus disease (K=0.85)
Patel *et al.*[45]	iPhone 5s ©	RetinaScope	43 pediatric patients; variety of childhood retinal conditions such as retinoblastoma, Coat's disease, and optic nerve hypoplasia	• Average acquisition time was 2.3±1.1 min • 96% agreement occurred between image-based diagnosis and clinical diagnosis
Lekha *et al.*[46]	iPhone 4s © + 20 diopter lens	MIIRetCam	42 babies; retinopathy of prematurity	• Central and peripheral retina could be imaged of adequate quality in 33 (78.57%) of babies
Goyal *et al.*[47]	iPhone 5s © + 20D, 28D, or 40D lens	MIIRetCam	28 eyes imaged for retinopathy of prematurity	• 89.28% of eyes were deem to have good quality imaging

(Contd...)

Table 2: ***(Continued)***

Study authors (and reference)	Imaging modality used	Add-ons or setting modifications	# of images taken	Study results summary
Bilong *et al.*[48]	iPhone 5s ©	MIIRetCam	395 patients, glaucoma screening	• 39 were found to be suspicious for glaucoma (9.87%) • Out of 14 patients who followed up for clinical examination, 8 were true positives for chronic open-angle glaucoma, and 6 were false positives
Bastawrous *et al.*[49]	Peek smartphone adaptor versus desktop fundus camera	None	2920 eyes; vertical optic cup-to-disk ratio	• Excellent agreement between measurements (Kappa coefficient 0.69) • No observable difference in image quality between lay photographer and experienced retinal photographer
Wintergerst *et al.*[50]	Samsung Galaxy S4 ©	D-Eye adaptor	54 eyes (27 patients); glaucoma or suspected glaucoma	• Vertical cup-to-disc measurements of D-Eye adaptor better correlated with conventional fundus photography when eyes were dilated (r=0.91, P<0.001) than without dilation (r=0.70, P<0.001) • More optic disc rims were visible with dilation (94%) than without (46%)
Russo *et al.*[51]	Smartphone ophthalmoscope versus slit-lamp biomicroscopy	None	110 patients; ocular hypertension or primary open-angle glaucoma	• Exact agreement between smartphone and slit lamp was found in 21 of 29 (72.4%) glaucoma eyes • Exact agreement was 52 of 78 (66.7%) in ocular hypertension • No mean differences in vertical cup-to-disk ratio
Miller *et al.* [52]	Pictor 45-degree portable non-mydriatic fundus camera versus Topcon mydriatic camera	None	422 eyes; glaucoma and cup-to-disk ratio	• No significant difference in cup-to-disk ratio measured (estimate = 0.004, 95% CI, 0.003–0.011, P=0.24) • Moderate interobserver reliability for diagnosis of glaucoma (Pictor (k=0.54, CI, 0.46–0.61); Topcon (k=0.63, CI, 0.55–0.70))
Bursztyn *et al.*[53]	Pictor Plus non-mydriatic fundus camera versus clinical examination	None	103 eyes; optic disc edema	• Sensitivity for detecting optic disc edema: 71.7–02.2% • Specificity: 81.6–95.2% • 0–8.3% photos ungradable

*Denotes published descriptions of technology and involve minimal human imaging. N/A: Not applicable

detecting optic disc edema were 71.8–92.2% and 81.6–95.2%, respectively, compared to clinical examination.[53] Unreadability was relatively low with graders finding 0–8.3% of photos ungradable.

A major limitation of many studies is that the developed technology is dependent on mydriatic imaging.[37,42,44-50] Access to mydriatic drops may be a limiting factor to successful remote imaging in many settings such as a patient's home. If these technologies could support non-mydriatic imaging, then a greater number of photographers and patients could comfortably acquire images. Notwithstanding, portable mydriatic retinal imaging technology can still be a highly useful and more accessible technology than what is currently available if photographers appropriately plan for the need to dilate the patient.

Development of portable OCT

Several groups have published on portable OCT technology. Mehta *et al.* described the creation of a control system of OCT devices through a mobile device.[54] Lu *et al.* developed a handheld swept-source OCT (SS-OCT) instrument using 2D microelectromechanical system mirrors.[55] Other design teams have described various iterations of spectral-domain and swept-source OCT.[56-58] The aforementioned systems are yet to be

validated in human patients and across many ocular conditions. Notwithstanding, their emergence not only indicates a bright future for remote OCT monitoring but also highlights the demand for remote monitoring of posterior segment conditions.

Remote slit-lamp monitoring

Even the mainstay of the ocular examination, the slit lamp, is being redesigned for remote visits. Tanabe *et al.* described the development of an internet-based remotely operated slit-lamp system that had similar diagnostic ability to conventional slit lamp.[59] Nankivil *et al.* remote slit-lamp system permitted for real-time slit-lamp video with a WiFi latency of 483 ± 64 milliseconds with patients and providers within the same continent.[60] These tools have proven success. Kumar *et al.* established that remote slit-lamp images of 392 eyes had moderate to good agreement with clinical gold standard grading (unweighted κ 0.43–0.65).[61] Meanwhile, the TeleOftalmo virtual visits program successfully implemented remote slit lamps with 70% of ophthalmic cases virtually resolved.[62]

TeleOftalmo utilized a telepresence system where remote ophthalmologists were able to visualize fine details such as eye movements when testing for extraocular motor function and pupil size when testing for pupillary reflexes. Notwithstanding, there are several notable limitations. First, only select cases were seen including a complaint of diminished vision, known or suspected refractive errors, strabismus, disorders of the eyelids, conjunctival disorders, cataract without previous indication for surgery, or need for DR screening. Second, as with many of the other studies discussed, this study relied on a certain level of technological infrastructure capable of supporting real-time image delivery. The limitations of this study are illustrative of a wider concern: Teleimaging demands robust technological infrastructure and since these are nascent technologies, further testing must be implemented to make full use of their potential.

EXPLORING THE POTENTIAL FOR EXPANDED IMAGING PERSONNEL IN TELEIMAGING

Current teleimaging modalities rely on patients making a trip to a medical center where trained technicians can dilate the patient and operate commercial equipment to obtain an image. To truly broaden access, technology must first be improved to function under non-mydriatic conditions as this eliminates the complicating factor of dilation. Armed with this advancement, these technologies can be employed by minimally trained healthcare professionals to obtain images. Although more verification will need to occur, studies have already established the ability of non-expert photographers.[17,49,63,64] The greatest enabler of expanded teleimaging may already be in our pockets. Smartphone image quality in many cases is non-inferior to clinical images and with the appropriate accessory and navigable interface, the casual smartphone user could conceivably be guided through the imaging process.

POTENTIAL CHALLENGES AND LIMITATIONS TO TELEIMAGING

Teleimaging has appeal to all stakeholders for the promise of time saved, expense spared, and streamlined visits. As with any new technology, teleimaging is not free from complications. Teleimaging technology for the purpose of screening will generally be conservative in terms of its screening recommendations, erring on the side of caution to refer to a specialist. As a result, providers, patients, and payors may face increase costs associated with false-positive referrals. Moreover, false positives can stem from artifacts that the teleimaging technology is unable to correct or appropriately consider, adding an additional possible source of error that may lead to unnecessary visits. Furthermore, additional challenges that may merit consideration include patient willingness to embrace this technology and integration of this technology into provider practices and reimbursement for these technologies.

CONCLUSION

While the "store and forward" model is a viable approach to remote imaging and has expanded the scope of practice, it depends on trained individuals operating machinery in brick-and-mortar establishments. Consequently, the "store and forward" model remains grounded in an older model of practice. With an increased demand for a truly remote or home-based visit, a wide array of developing ophthalmic teleimaging technologies is poised to meet this demand and shift the paradigm.

Declaration of patient consent

Patient's consent not required as patient identity is not disclosed or compromised.

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Conflicts of interest

Dr. Rishi P. Singh is on the Editorial Board of the Journal.

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