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Tele-Ophthalmology: Opportunities for Widespread Access to Eye Care

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ABSTRACT

Recently, tele-ophthalmology, the ability to deliver eye care though digital medical equipment and telecommunications technology, is revolutionizing the approach to diagnosing retinal and other ocular disorders, and expanding the concept of preventive eye health screening to include populations, regions and small countries. The digital acquisition, and electronic or wireless transmission of retinal images, is an assessment tool that is especially relevant for people with diabetes who have limited access to ocular health care. In this review, the experience of the Zimbabwe Diabetic Retinopathy Tele-medicine Project (ZRTP) in successfully implementing tele-ophthalmology for routine retinal screening for diabetic patients is summarized, and lessons learned are presented. From there, the future of tele-ophthalmology is considered. There is great promise moving forward including the introduction of miniaturized technology furthering the ease of taking and storing digital retinal images, the application of artificial intelligence to read digital retina photographs, and innovative research in the diagnosis of early onset Alzheimer's Disease. In order to systematize and enhance the research and innovation being accomplished, we introduce the concept of a global tele-ophthalmology network to create a platform for the sharing of ideas, and to advocate for the use of tele-ophthalmology in protecting the vision of patients who are not being reached by conventional ophthalmic services, along with a discussion of associated challenges in the areas of ethics and patient confidentially.

Keywords: Telemedicine; Tele-ophthalmology; Retina; Eye care; Fundus Imaging

Abbreviations: ZRTP-Zimbabwe Diabetic Retinopathy Tele-medicine Project; DR-Diabetic Retinopathy; DME-Diabetic Macular Edema; SMS-Short Message Service; FOP-Fundus on Phone; AD-Alzheimer's Disease; SD-OCT-Spectral Domain Optical Coherence Tomography; MCI-Mild Cognitive Impairment

INTRODUCTION

The eye is the body's window to the visual world, and since the invention of the ophthalmoscope in the mid nineteenth century the eye itself has been a window in the health of the human body. In the 1980s the ability to take fundus photographs and record the appearance of the retina heightened the ability of heath care professionals to detect retinal changes, diagnose disease both locally and systemically, and recommend treatment. Through technological advances, tele-ophthalmology is set to revolutionise eye care. Tele-ophthalmology involves the use of digital imaging equipment to capture retinal images followed by the electronic transmission of the images to a remote or distant site for interpretation and diagnosis by an expert reader or ophthalmologist. This emerging technology can provide convenient, routine, and cost effective screening tools for sight threatening eye conditions such as diabetic retinopathy (DR) [1–3]. Several tele-ophthalomology programmes for screening large numbers of patients for eye complications such as diabetic retinopathy have been clinically validated in USA and Europe and have a high level of accuracy [4]. Computers, smartphones or tablets enable uploading of high quality fundus images and subsequent transfer using Internet connectivity or telecommunications technology and access through online databases and shared folders. Tele-ophthalmology methods include real-time, store-and-forward mode, or hybrid techniques [5].

Combined with mobile fundus imaging equipment, tele-ophthalmology provides comparative services and wider demographic access for eye screening and preventive eye care using mobile health (mHealth) strategies. A key aspect of tele-ophthalmology, one that can help it realize its full potential, especially in underserved areas, is the use of non-mydriatic cameras by health care workers without specialized ophthalmic experience. For example, non-specialist photographers used the handheld, light weight non-mydriatic Volk Pictor imager to acquire gradeable retina photographs for diabetic retinopathy screening [6]. Other comparable models with features applicable for tele-ophthalmolgy include Nidek/JedMed, Zeiss VISUSCOUT 100 and Peek Vision (Table 1).

Table 1. Comparison of available technology with applications in tele-ophthlamology.

Model	Features	Advantages	Limitations	Cost
Volk Pictor	Hand held -20 to +20 D WiFi functionality	45 degree field of view	Smaller viewing screen for user	+
Zeiss Visuscout 100	Hand held -20D to +20D WiFi functionality	40 degree field of view Optional viewing software allows connection to Zeiss patient management system	More fragile than non-hand held systems	++
Nidek	Fully automated Measuring capabilities	Stereo and panoramic views	Larger size -less portable	++++
PEEK	Smart phone attachment	Extreme portability	Under development	-

The Opportunity for Tele-Ophthalmology

All the above emphasise the need to explore opportunities for the application of tele-ophthalmology for improved eye care services. The growing availability of tele-communication technologies especially in low and middle income countries will support tele-ophthalmology. The increasing incidences of chronic non-communicable diseases such as diabetes, which require routine monitoring of eye complications, also indicates an opportunity for tele-ophthalmology applications. The greatest immediate impact and immediate utility for tele-ophthalmology is demonstrated in low and middle income countries including the Sub-Saharan African region where diabetes eye care services and eye screening facilities are limited, and often restricted to larger urban areas which are inaccessible for the majority of patients living in the remote areas.

The Challenge

Despite the obvious advantages of tele-medicine and tele-ophthalmology and the anticipated impact in reaching out to the wider community, there is still limited implementation and uptake. This is possibly due to lack of coordinated efforts, economic constraints, competing health priorities and, limited evidence of the impact of tele-ophthalmology. More research is required to demonstrate its utility to relieve the growing public health burden due to eye diseases in order to entice health institutions and national health services to invest in tele-ophthalmology.

Tele-Opthalmology for Diabetic Retinopathy

Using diabetes as a candidate disease area for tele-ophthalmology application, there is growing evidence of its potential utility to screen for diabetic retinopathy, glaucoma and cataract in Sub-Saharan Africa [7–9]. The overall prevalence rates of any retinopathy, sight-threatening diabetic retinopathy and proliferative retinopathy was 50.1% among patients at a diabetic clinic in Malawi [7]. This suggests an urgent need to address the growing burden of diabetes eye complications. Development and coordination of multi-disciplinary teams, consisting of scientists, healthcare practitioners and policymakers is a sure way of integrating tele-ophthalmology applications into national healthcare systems. For example, Matimba et al. [10] recently piloted a tele-ophthalmology project in Zimbabwe, and the study is summarized below.

The Zimbabwe Retinopathy Telemedicine Project (ZRTP) Pilot Study

In sub-Saharan African countries such as Zimbabwe where diabetes healthcare services are limited, the low numbers of ophthalmologists and eye centers in the public health system, as well as high cost of care for diabetic patients, impacts negatively against timely diagnosis and management of eye diseases primarily diabetic retinopathy (DR) [11–13]. While the International Council of Ophthalmology and the World Health Organization recommend annual retinopathy screening for diabetic patients, this remains a challenge for most diabetic patients. In some cases diabetic patients who need retinal screening are subjected to waiting periods of six months or longer due to limited public health facilities able to detect DR [10]. Therefore tele-ophthalmology applications may provide a convenient, routine, and cost-effective screening tool for eye conditions such as DR, glaucoma and cataract where eye care services for diabetic patients are not available. Therefore a team of scientists, nurses and ophthalmologists, with the support from the Ministry of Health and Child Care initiated the Zimbabwe Retinopathy Telemedicine Project (ZRTP) in the capital city, Harare as a start. A pilot project was conducted to demonstrate the applicability and need for tele-ophthalmology for eye screening for diabetic patients. The objectives were (i) to provide mobile handheld fundus cameras and core facilities for routine eye screening at a diabetic clinic (ii) train and educate nurses and other health professionals on the use of fundus cameras (iii) provide educational materials for diabetic patients and (iv) to provide a framework to broaden the use of tele-ophthalmology in Zimbabwe in the future.

The overall 'store and forward' procedure is shown in Figure 1 and included image acquisition, transfer of fundus images to an Internet based shared folder, access and reading by a qualified reader ophthalmologist in USA, provision of diagnosis and email of results to doctor or nurse who used the Short Message Service (SMS) to alert the patients to return to the clinic and collect their results. Referral was made for patients in need of treatment. Diagnosis was provided for 203 diabetic patients over a 10 month period consisting of 68% females, 32% males with 62% with 40 years or older [10]. Non-macular DR and DME was detected in approximately 11% and 5%, respectively. Other eye diseases were also detected including glaucoma and cataract (Table 2). Other conditions included arteriolar narrowing/hypertensive changes; branch retinal vein occlusion, drusen, cotton wool spots, arteriolar narrowing and macular (Table 2). Urgent referrals were made for DME cases while other cases were advised to visit an ophthalmologist within 3 months. It was also possible to diagnose poorly controlled hypertension as evidenced by arteriolar narrowing and cotton wool spots and these patients (7%) were referred to a medical doctor. The use of tele-ophthalmology is now embedded in the system at the diabetic clinic and eye screening is provided as routine care for diabetic patients. The anticipated impact of retinal screening includes reduction of visual impairment when patients found to have DR are referred for treatment. ZRTP provided the first step in understanding the needs for ophthalmic care and treatment requirements for diabetic patients in Zimbabwe. This will assist in healthcare planning by health institutions and the health ministry. The lessons learnt from ZRTP are highlighted in Box 1.

Table 2: Prevalence of eye conditions among diabetic patients.

Diagnosis	Percentage % (n = 203)
No evidence eye disease	62
Non-macular Diabetic Retinopathy	11
Diabetic Macular Edema	5
Retinal detachment	<1
Lens or media opacity	5
Nerve related disease (glaucoma)	6
Macular scar	1
Other*	9

*Other includes Arteriolar narrowing/Hypertensive changes; Branch Retinal Vein Occlusion; Drusen; Cotton Wool Spots

Box 1. Lessons learnt from ZRTP and future plans.

- ZRTP demonstrated the utility of tele-ophthalmology in sub-Saharan Africa
- Tele-ophthalmology can be an efficient method for diabetes eye screening in a resource limited setting
- There is need to strengthen prevention strategies by increasing knowledge and awareness of diabetic complications and how to prevent them though education provided at screening clinics.
- There is an urgent need to build local capacity for reading fundus images and to increase capacity for treatment at public healthcare centres.

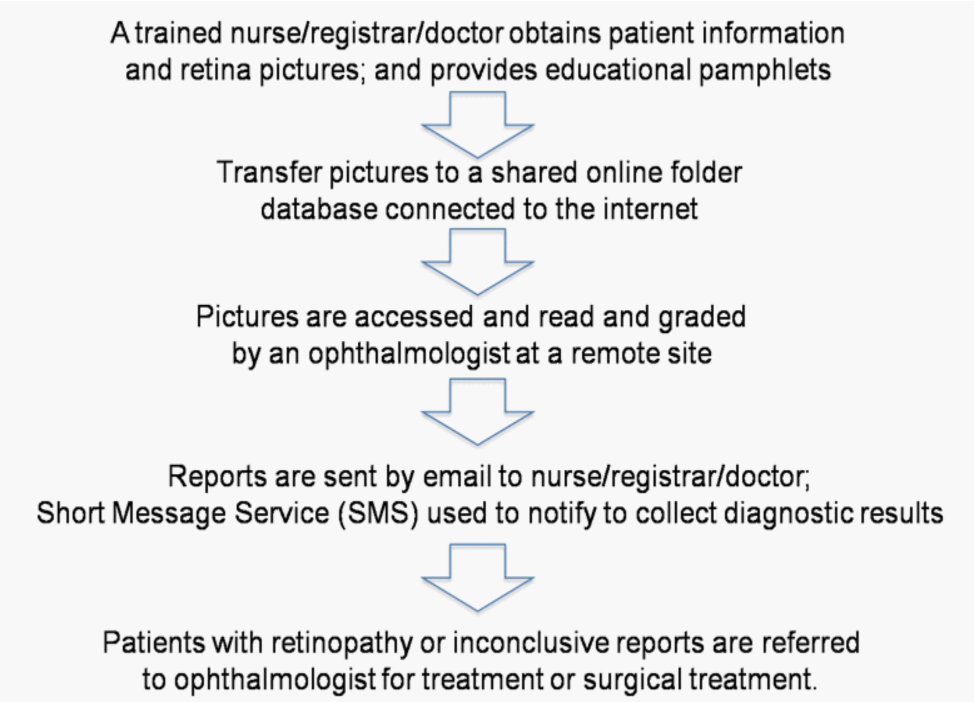

Figure 1: Store and forward method [10].

Other Recent Tele-Ophthalmology Programmes

The opportunity for remote consultation means that tele-ophthalmology provides alternative and cheaper solutions for routine eye care and could address limitations of eye care services in low and middle income countries. In India, tele-ophthalmology using real-time virtual visit software assisted in specialist care provision illustrated a novel tele-health solution for low resource population [14]. Tele-ophthalmology was also shown to be an effective tool for improving eye care delivery system in rural and underserved areas of India [15]. In addition retinal photography using 'fundus on phone' (FOP) smartphone based camera was shown to be effective for screening and diagnosis of DR and sight threatening DR with high sensitivity and specificity and has substantial agreement with conventional retinal photography [16]. Teleophthalmology for diabetic retinopathy has also been demonstrated in Sub-Saharan African countries including Cameroon and Kenya [17,18]. Diabetic retinopathy was detected at 20.6% of patients in a mobile tele-ophthalmology programme in North West Cameroon. Tele-opthalmology was conducted in South Africa, Ghana and The Gambia with a UK based eye hospital [19]. However further work on the use of tele-ophthalmology in these countries is not well reported.

In developed countries, tele-ophthalmology supports exisiting screening care programmes by increasing access to regular, comprehensive eye care services. With the extension of tele-ophthalmology services into primary care offices, the advent of new technology, and the inclusion of disease other than diabetic retinopathy that can be screened for, the arc of telemedicine to help the previously unreachable is increasing. In the area of diabetic retinopathy tele-ophthalmology is extending eye care to people living in rural and remote areas in the United States who otherwise might not have retina exams done timely enough to detect changes needed treatment. Offering tele-ophthalmology retinal exams could increase screening compliance over time, according to a recent study [20]. Diabetic patients were randomly assigned to receive either traditional surveillance by an eye-care professional or tele-health screening in a primary care clinic for two years. Those in the telemedicine group were about twice as likely to be screened for DR. In Canada, aboriginal communities were offered tele-ophthalomology for identification of high-risk individuals who can then be monitored and receive treatment related to their diabetes or other health issues [21]. The programme also demonstrated cost savings largely due to elimination of transport costs.

The above-mentioned tele-ophthalmology programmes in Sub-Saharan Africa indicate that the reading was conducted by ophthalmologists in USA, Canada or United Kingdom [10,17,19]. Therefore, in anticipation of expanding tele-ophthalmology use in diabetic retinopathy, capacity for reading within the local environment could enhance the process, and limit dependence on outsourcing to international experts. This capacity could include non-specialists who would receive an intensive training course in reading retinal images. A recent prospective study to determine the ability of individuals without prior health care training, who received an intensive three day training course in reading retinal images, to accurately detect American Telemedicine Association Category 2 (presence vs. absence of sight threatening DR) and identify unreadable images showed that this could be done with a high degree of sensitivity and specificity [22]. A retina reading center with imagers receiving a validated standardized method of certification and training can then be established in a specialist limited area to identify which patients, based on their retinal images, need future ophthalmic care. In addition to having all images being primary graded, 1 in 10 negative screens would be secondarily graded by an ophthalmologist as a form of quality control. Readers would also need to be trained to recognize signs of glaucoma and suspected cataract, and hypertensive changes. Any patients with sight threatening retinopathy or other eye disease would be referred to an ophthalmologist or appropriate medical specialist. As part of the operating procedure, it is proposed that certified imagers would be required to attend an annual refresher training course and have biannual testing against known images in order to remain certified.

While the ability of tele-ophthalmology programs to detect DR is established, minimal information exists on the subsequent effect of telemedicine activities on eye care resources and what the expected burden to a health care system would be when more individuals are found to have eye disease [23]. An analysis of the impact of a tele-retinal screening for diabetic retinopathy within community based clinics in the USA found the mean two-year cost in Medicare reimbursement fees to care for a patient with an abnormal tele-retinal screening result was approximately $1000, not including the cost of medication and spectacles [24]. This monetary sum does not include the initial cost of establishing specialist and hospital services, including investment in purchasing and maintaining expensive equipment and in training ancillary personal to assist in using it. The issue of tele-ophthalmology programs generating more demand for medical services is even more urgent in low resource areas such as sub-Saharan Africa where, in order to realize a program's potential in reducing vision loss, patients must have access to already scarce specialist care and modern equipment for treatment.

Expansion of Utility and Continual Innovation

There are growing opportunities for tele-ophthalmology to be expanded to screen for other eye diseases and medical conditions. Similar to diabetes, glaucoma is a leading cause of irreversible visual impairment throughout the world, and the numbers of affected individuals is expected to increase over time. Thus, glaucoma screening is important to detect, diagnose, and treat patients at the earlier stages to prevent disease progression and vision loss. Glaucoma management increasingly involves use of devices that are perceived to be 'telemedicine-friendly. Automated perimetry, tonometry, corneal pachymetry, imaging of the optic disc, nerve fibre layer and anterior segment, may all generate digital outputs that can be transferred electronically and viewed remotely [25]. However, of these telemedicine friendly tools, tele-glaucoma using stereoscopic digital imaging to take ocular images, which are transmitted electronically to an ocular specialist for reading may hold promise as a tool to detect of glaucoma among populations that do not have access to eye care. A recent systematic review and meta-analysis of the literature highlighted that tele-glaucoma using fundus photographs have the potential as a screening device to detect a greater amount of cases than in-person examination [26].

While many tele-ophthalmology clinics rely on free standing or hand held portable imagers andnon-mydryiatic cameras can serve patients who are able to come to the clinic, new technology is making it easier to take quality retinal images using a smart phone, thereby extending the reach of telemedicine. The D-Eye Portable Retinal Imaging System (https://www.d-eyecare.com) is a recent innovation attached to the camera aperture of a smart phone and uses the LED light source from the phone to capture high-definition still images of the retina. These images can be transmitted wirelessly and stored in an image vault for later reading. The D-eye offers a low cost extremely portable retinal imaging device, with the potential to be used by visiting nurses or community health care workers making home visits or screening patients with medical conditions such as diabetes in villages or other remote areas.

Developments in tele-ophthalmology are progressing quickly, and the tele-ophthalmology of the future may look very different than it does now. The initiatives using tele-ophthalmology to improve access to recommended eye screening will most certainly be supported and integrated more and more into primary care settings in the area of diabetic retinopathy and as the various parts tele-glaucoma fall into place. In general, patients are not always likely to get to an eye doctor, even though they may see their primary care doctor for treatment. This makes a more compelling argument for the widespread adoption of tele- ophthalmology for screening for eye complications such as for diabetic retinopathy in primary care diabetic clinics.

While this is a way to reduce vision loss from diabetes, it also means that telemedicine programs will need to read many more digital images. What is anticipated is with the advent of computer algorithms that can read clinical images of the retina, the detection of DR may soon be automated. Researchers are taking advantage of the ability of computers to increasingly possess the pattern-recognition skills that have previously been thought to be unique to humans and other living species. Recently, the organization Kaggle (www.kaggle.com), a competition platform for predictive modeling and analytics, partnering with the California Health Care Foundation, uploaded a data base of over 30,000 retinal images obtained from patients and challenged teams of computer and artificial intelligence experts to train computer algorithms to notice the often subtle changes such as microanuerysms associated with diabetic retinopathy and assign a retinopathy score on a scale of 0 to 4 (with 0 being no retinopathy). After a five-month period, the contest's winner developed an algorithm that agreed with a doctor's opinion 85% of the time. If a computer application is realized to read retina images, this itself may catalyze the even more widespread adoption of tele-ophthalmology, as patients in primary care settings can then immediately be given recommendation on further steps they need to take, or if the images are inadequate and need to be re-acquired. This is open to study, although, a more seamless connection between taking the retinal image and the results, with the potential for immediate feedback may improve patient compliance with screening. The quality of the Internet connection between patient and reader of the retinal image, and the need for an "on call" reader may be a limitation to the reading of images in real-time and establishing the seamless connection. However, this is bypassed when clinics only need the algorithm for obtaining results and an inexpensive retinal camera, making it more likely that people at risk for retinal or other eye disease in remote or rural areas, can receive vision-saving screening services

Other innovations in the preliminary stages hold promise for broadening the reach of tele-ophthalmology to include the early diagnosis of other medical conditions. Physician scientists at Duke University are collaborating to study the connection between the eye and Alzheimer's disease (AD) in particular the potential for eye imaging to diagnosis early AD. Retinal findings have been detected in early onset AD that parallels the neurodegenerative changes in the brain [27]. Biomarkers in the retina include twists and turns in blood vessels, presence of extracellular deposits, and thinning nerve fiber layers. Spectral domain optical coherence tomography (SD-OCT) together with a proprietary software program is being used to visualise and measure layers of the retina. These patterns are associated with the clinical conditions of mild cognitive impairment (MCI) and early onset AD, and can potentially be used to as a tool to provide early identification and distinguish between the two conditions. The digital transmission of SD-OCT images has been used in a community setting to evaluate suspected macular conditions [28]. and could be applied for screening of neurological disease such as MCI and early onset AD in remote areas.

Broader Issues

The rapid pace of advances in tele-opthalmology calls for a platform for global networking among institutions, researchers, and scientists involved in developing and applying tele-ophthalmology. This will create a community of researchers, physicians, developers and policymakers, who can build collaborations, develop documents, share resources and exchange information. Tele-ophthalmology will be most effective if it is integrated into referral and treatment networks.

With the ability to send images and clinical data and in order to have them read and analyzed comes the question of how to address the potential risk to patients' privacy and confidentiality. Ethical issues involving consent, photographic ownership, and photographs as personal heath information and physician responsibility to uphold patient confidentially are complicated the security concerns associated with mobile devices. It can be debated, whether there is enough potential risk to patients' privacy and confidentiality to warrant obtaining written informed consent for routine telemedicine applications. These are issues that can be addressed as tele-ophthalmology moves forward.

CONCLUSION

Though tele-ophthalmology, technology is connecting those who are at risk for preventable blindness to specialist ophthalmologists with the goal of preventing vision loss. Whether it is a need due to remote location, a matter of convenience or time, or paucity of eye health services, tele-ophthalmology is playing an ever more important role in reaching the unreachable. Perhaps the most vital and important aspect of tele-ophthalmology is its ability to reach across communities, borders and boundaries to bring patient and specialist together. Even with the advent of real time results, and if and when computerized algorithms to read retinal images become a reality, the role of the ophthalmologist is heightened rather than diminished by tele-ophthalmology; the increasing number of people who will be diagnosed with eye disease in the early stages will still need ophthalmic care to achieve the ultimate goal of preventing vision loss and blindness. It is hoped that now and in the future, networking among those bringing tele-ophthalmology to the medically underserved, along with the creation of new platforms for research, can keep tele-ophthalmology moving forward.

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