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The significance of teleophthalmology during a pandemic and in general

Małgorzata Kowalik-Jagodzińska, Anna Turno-Kręcicka

Department of Ophthalmology, Wroclaw Medical University, Poland

ABSTRACT

The advent of the SARS-CoV2 coronavirus pandemic has significantly affected the quality of medical care delivery. Inefficiencies in the health care system and the fear of spreading the pathogen forced ophthalmologists to start using teleophthalmic methods if they had not done so already. However ophthalmology is an example of a medical specialty that had been benefiting from new technological solutions for many years before the pandemic, which makes it possible to correctly diagnose and treat eye disorders despite limited office visits. This publication aims to present the opportunities of teleophthalmology, which may provide advice for ophthalmologists on how to help patients at a distance without loss of quality. Attention was paid to teleophthalmology tools that may be useful in daily ophthalmic practice both in acute conditions and in the monitoring of patients with chronic conditions, for instance, age-related macular degeneration (AMD) or diabetic retinopathy. This publication presents, among other things, applications that are useful for assessing visual acuity, tonometers that can be used for self-measurement of intraocular pressure without leaving home. Moreover, this publication assesses the quality of photos taken with a smartphone for the evaluation of the anterior and posterior segments of the eye.

KEY WORDS: ophthalmology, telemedicine, COVID-19, pandemic.

INTRODUCTION

The emergence of a new highly infectious coronavirus that caused the 2020 pandemic has significantly impacted the frequency of patients presenting to physicians' offices. Both the specific nature of the eye physical examination and, in particular, the close contact with the patient increase the risk of infection for both the patient and the ophthalmologist. Despite the implementation of new epidemiologic standards, it seems safer to limit office visits to the minimum and provide teleconsultation in cases which do not require urgent surgical or therapeutic interventions. Ophthalmology is a field of medicine that benefits from the latest technological solutions, including those that enable remote consultations. Already in the past, in provincial areas where the availability of ophthalmologists was severely limited, the use of teleophthalmology tools greatly improved patient care. For example, in India, there is the SNTOP project in which a van that is properly equipped with diagnostic tools takes the role of a doctor's office in areas with a lack of access to medical care [1]. The tools are operated by an optometrist and sent to medical specialists for an assessment. Also in India, the EyeSmart EMR app is being tested to provide video consultations with specialists [2]. Teleophthalmology seems to be a satisfactory solution for providing emergency medical aid as well as ongoing follow-up of chronically ill patients.

Another example is Bourbon *et al.*'s study in Paris conducted on one hundred patients after the onset of lockdown. The aim of the study was to assess an algorithm which includes medical history and currently presenting symptoms to triage patients for groups with different urgency. Urgent ophthalmology intervention, delayed elective consultation or teleconsultation were the possibilities of giving ophthalmic healthcare [3]. The sensitivity of the algorithm was 96%, while its specificity was 97.5% in a correct assessment of the urgency of consultation. One patient who was referred to the ophthalmic emergency room could have been referred for an elective consultation after the physician's assessment, while two patients who were referred to a consultation at a later date should have attended an urgent appointment – neither patient, however, was harmed by the delayed intervention. The study results indicate that such algorithms can be used safely in reduced access to health care.

Another analysis, also conducted at the Paris centre, aimed to assess the accuracy of diagnoses and treatment using

CORRESPONDING AUTHOR
Dr. Małgorzata Kowalik-Jagodzińska, Ophthalmology Clinic of the Jan Mikulicz-Radecki University Teaching Hospital, 213 Borowska St., 50-556 Wroclaw, Poland, e-mail: mkowalik.jagodzinska612@gmail.com

teleophthalmology methods [4]. Sensitivity was estimated at 96%, specificity at 95%, and only 1% of cases received an incorrect diagnosis, resulting in a delay in appropriate treatment.

Based on the meta-analysis performed by Kawaguchi *et al.*, the time of detection of lesions typical of diabetic retinopathy or AMD by teleophthalmology methods was similar (or even slightly earlier but not statistically significant) to the detection of other lesions by standard physical examination [5].

There are many arguments from the points of view of both patients and physicians against the use of ICT (information and communications technology) methods. However, continued advances in technology create the opportunity to use telemedicine not only for screening visits but also for correct treatment at a distance.

TELECONSULTATION METHODS

To begin with, teleconsultations could be performed using different communicatory inventions. In the era of telemedicine, it is possible to use various online platforms, communicators or mobile applications that not only provide verbal contact but also give the possibility of real-time video consultation, which is relevant for ophthalmology. Photos taken by the patient and then sent to their physician via e-mail or mobile network also play a key role. The development of the 5G network has improved the use of online communication in many parts of the country, making such communications capabilities more widely available.

A study conducted at a government facility in northern India found that WhatsApp was the most popular communicator among ophthalmologists while e-mail correspondence was the least frequently used [6]. Since the most common complaints included eye redness and foreign body sensation as a consequence of prolonged computer work causing conjunctivitis, as many as nearly 60% of patients did not require any office visit.

VISUAL ACUITY TESTING

Visual acuity assessment is the primary component of the eye examination that best determines visual function. Due to specific conditions that must be met during the visual acuity testing, i.e. charts with correct angular sizes of optotypes and a matched distance between the patient and charts, this assessment is difficult to control objectively in a home setting.

Actually, there are a lot of mobile applications for visual acuity testing available. For instance, Peek Acuity is an application dedicated for Android that evaluates visual acuity. This application uses a scheme that is consistent with the Early Treatment Diabetic Retinopathy Study (ETDRS) chart, in which the letters “E” pointing with their arms in different directions (so-called hooks) are the optotypes. Peek Acuity enforces the appropriate brightness of the screen, resulting in the elimination of the lighting factor that can negatively interfere with the quality of the results obtained. A study was conducted to validate this application by comparing the results of visual acuity measured via this application in clinical and home settings with the results determined with the ETDRS and Snellen charts [7]. The above-mentioned study proved that the results obtained using The Peek Acuity app were not significantly different compared to the standard methods, and it was even proven that the difference between this application and the ETDRS chart was smaller than that between Snellen and ETDRS charts. Moreover, paying attention to the settings in which the assessment using Peek Acuity app was performed (clinical or home settings), the differences between its results and those obtained using the ETDRS chart were smaller (difference of 3 optotypes) or larger (5 optotypes = 1 line). It is not the only mobile tool for visual acuity assessment that has been described in publications to date. For instance, a similar validated application is the Vision@Home app [8].

Another study assessed a larger number of mobile applications, and it was conducted after the COVID-19 pandemic had already broken out, which would indicate a strong need to resort to alternative methods with the highest possible quality of examination. In addition to PeekAcuity, the SmartOptometry app was compared [9]. The study consisted of three stages. The first stage involved evaluation of the ease of application download onto a smartphone. The second stage compared the results obtained through the COMPlog test chart, the reduced Snellen chart for near vision testing, Peek Acuity (for assessing distant visual acuity) and SmartOptometry (for near vision testing). The third stage paid attention to the reproducibility of the results obtained through all the above-mentioned methods. It was found that these applications are easy to download and they are suitable for self-assessment by patients. Although the SmartOptometry app produced different results compared to the reduced Snellen chart for near vision testing, the PeekAcuity app produced results comparable to COMPlog, and all four methods had a high degree of reproducibility.

The quality of the GoCheck Kids app was assessed for the paediatric population. The assessment revealed that the application had a medium correlation with the results obtained using the charts and a low correlation compared to the HOTV-ATS (Amblyopia Treatment Study Visual Acuity Testing) protocol [10].

To summarise the possibility to use applications to assess visual acuity, emphasis should be put on the importance of lighting conditions that affect adequate optotype contrast and the need for consistent use of one application to minimise errors due to differences in the accuracy of individual applications. Another aspect is the multitude of applications. Therefore, it is worth making sure which one is used by the patient for correct assessment of visual function because not all of them have been validated by specialists.

GLAUCOMA

Glaucoma is another chronic disease that requires ongoing monitoring and treatment to prevent its progression. The only effective method to do it is to reduce intraocular pressure. This method is used even in those variants of glaucoma in which intraocular pressure (IOP) is within the population norm.

Although methods that provide 24/7 IOP measurements, such as intraocular lens implants and Triggerfish contact lenses with a pressure sensor, are those that accurately reflect the actual pressure value, their use carries an increased risk of inflammation and infection, and it is associated with excessive costs for the patient. The home version of the iCare tonometer can be a suitable alternative to in-office measurements because it is easy to use and gives reliable results, however, it is also expensive [11].

In terms of inexpensive methods that are available to all patients, palpation measurement of intraocular pressure is advised. This method requires an online course or a prior office visit of the patient to familiarise them with this method. Measurements are only indicative, which means that they cannot replace objective measurements. Nevertheless, this method can be a valuable tool in emergencies, such as sudden pressure increase in the course of glaucoma (e.g. during the closure of the iridocorneal angle) or hypotonia after surgical treatment of glaucoma.

Another crucial element in terms of care and evaluation of glaucoma patients is constant visual field checks. This examination is also possible to perform online via the Peristat Online Perimetry platform [12]. The comparison of the standard examination using the Humphrey perimeter in the Swedish Interactive Threshold Algorithm (SITA)-Standard with its online version without specialist instrumentation revealed a high correlation of results. The online version of the examination took place in a clinical setting with the assistance of qualified personnel. However, the program is available for home use to everyone at http://www.keepyoursight.org. The examination takes only 5 minutes per eye and analyses a horizontal field range of 24 degrees and a vertical field range of 20 degrees [13].

ANTERIOR SEGMENT OF THE EYEBALL

Taking photos of the anterior segment of the eye with a smartphone or digital camera often provides a reliable picture of the eye's status and may be sufficient to make a correct diagnosis without an in-office visit. Especially assessing the status of ocular adnexae, diagnosing strabismus and checking the results of palpebral or strabismus surgery using high quality images may limit the need for ambulatory visits [14].

Due to the technical limitations of this type of camera, however, not every pathological lesion may be visible on such photos. Visualisation of the anterior segment of the eyeball without the use of a microscope is a very difficult task, as the capabilities of slit lamps cannot be underestimated. Especially their much higher magnification, abilities to focus on a specific eyeball structure, capability to change the angle of illumination or use several types of filters make the slit lamp irreplaceable. In particular, while using digital photos the inability to illuminate the eyeball with a slit limits the assessment of the corneal wall structure, its thickness and shape, and assessment of the tyndallisation of fluid in the anterior chamber. This is the reason why photos cannot always completely replace the standard examination. Nevertheless, this type of imaging may be considered in areas with poorer access to specialist eye consultation and such images are often sufficient for a correct diagnosis.

OPHTHALMOSCOPY

Monitoring of diabetic retinopathy, AMD and other retinal conditions cannot be done without a complete eye examination, of which funduscopic examination is an integral component. Visualisation of the fundus of the eye can be done by means of mobile apps and specific tools for slit lamps or mobile phones. Such findings can be easily stored and spread in digital format.

Diabetic retinopathy is the leading cause of blindness among working-age population; hence it is important from the state's perspective to provide easy access to regular check-ups [15]. Teleophthalmology methods such as fundus cameras that do not require pharmacological mydriasis and are available in primary care facilities may successfully decrease a prevalence of diabetic ophthalmic complications. This is the case in, for example, the United Kingdom. Based on the example of the USA, however, it is known that these methods are very expensive and thus the access to them is not satisfactory.

In 2017 Jin *et al.* presented a prototype of a portable handheld fundus camera that enables visualisation of the retina without mydriasis [16]. This device was designed and developed by Medimaging Integrated Solution Inc. The camera consists of an optical part with an overlay on the patient's eye, which contains a 20 D lens that enables visualisation in the range of 60 degrees and from the LCD screen. The operating principle of the camera is based on an indirect ophthalmoscopy technique. This publication includes an assessment of the quality of taken photos compared to images made by a stationary Topcon fundus camera. The portable device fared favorably in this comparison. Furthermore, compared to other devices of this type, it provides a larger imaging area, even though the examination is performed at a narrow pupil. Another positive aspect of this camera is the ability to send images via Wi-Fi to vitreoretinal specialists, who interpret the images received and then they send back the results. Finally, the image is printed and it is provided together with the impression and diagnosis to the patient.

Another alternative to retinal imaging includes special smartphone applications, for instance, iExaminer (Welch Allyn, USA) designed for iPhone [17].

Fundus photography gives an objective picture of the status of the retina. A fundus photo taken with a smartphone using a special attachment for a slit lamp (e.g. in optometrists' offices) can be a convenient tool to enable a specialist consultation despite the unavailability of an ophthalmologist in the office.

AGE-RELATED MACULAR DEGENERATION

Patients with exudative or non-exudative age-related macular degeneration (AMD) need to be familiar with self-monitoring methods. Usually, patients are given the Amsler test for home use when provided with prior training on how to use it properly. Because of free and widely available mobile applications, the Amsler test, as well as reliable visual acuity testing, can also be available without an office visit to even elderly patients. These types of aids will help the patient become aware of retinal deterioration in advance.

ForeSee Home (Notal Vision) is an example of a more modern self-monitoring system. It is available in the United States and may be free or partially reimbursable depending on the patient's insurance [18]. This device is small and similar to most ophthalmology cameras. The patient can examine their field of vision on their own; the results are recorded by the device. As soon as new abnormalities such as image distortion or scotomata appear, the device automatically informs the physician of the results, which prevents delayed intervention.

A study comparing neovascular AMD patients who attended scheduled in-office appointments with a group of patients who were regularly monitored using ForeSee Home and visited an ophthalmologist when lesions had been observed revealed that regular home monitoring is associated with higher detection of neovascularisation and less advanced visual acuity impairment [19].

A 2018 Australian study assessed the use of a tablet application that enables microperimetry in central 2 degrees of the visual field [20]. Patients were to use the application once a week. The aforementioned study revealed comparable perimetry results with standard perimetry in stationary conditions. The use of this type of aid would make for more regular check-ups; however, the use of the application presents many difficulties in elderly patients, which limited the eligibility of patients. On the other hand, another smartphone application, mVT (myVisionTrack), operating by shape recognition using hyperacuity was assessed very positively – nearly 99% of the study participants performed the test at least once a week [21].

RETINOPATHY OF PREMATURITY

Retinopathy of prematurity (ROP) is a condition that requires regular ophthalmologic follow-up and prompt decisions regarding intervention to prevent serious complications that threaten normal visual development. Due to the specificity of the examination of preterm infants and the lack of availability of specialists in this field in many regions of the world, telemedicine methods have been used for many years. In spite of the increasing survival of premature infants the knowledge about existing screening programmes for ROP is still not sufficient [22]. Using specific tools and qualifying preterm infants for the programmes is important to improve the visual outcomes, especially in countries with poorer availability of specialists. Stanford University Network for Diagnosis of Retinopathy of Prematurity (SUNDROP) is an example of a well-working screening telemedical programme with sensitivity and specificity of 100% and 99.8% respectively [23].

A 2014 study conducted by Quinn *et al.* found that both the sensitivity and specificity of teleophthalmology methods for acute phases of ROP that require urgent intervention are comparable to standard indirect biomicroscopy assessment [24]. The study consisted of assessing the severity of ROP during an eye examination and using a digital camera (RetCam) operated by a trained non-medical professional, and it was sent electronically for an assessment made by two masked non-medical professionals. Because of huge costs of the invention another study compared this method with smartphone wide-field imaging accompanied by different indirect condensing lenses [25]. The quality of the images was positively judged and the method was easy and widely available.

In 2015, a group of experts developed a protocol for the assessment of ROP grading by non-medical professionals based on digital images [26]. Trained readers under the supervision of specialists screened infants for referral warranted ROP (RW-ROP) by using digital grading system. Then, the computer algorithm decided if RW-ROP was present.

Images could also be obtained by smartphone-based specific devices such as RetinaScope. The device was assessed in a study where two independent graders used photographs to find cases of plus disease. The method had similar sensitivity to the standard indirect ophthalmoscopy. Moreover the quality of the images was judged as acceptable (in 98%) or excellent (in 95%) [27].

Plus disease could also be found by artificial intelligence. The study conducted by Brown *et al*. revealed that the effectiveness of the algorithms was similar or even higher than standard assessment made by experienced ophthalmologist [28].

Deep neural networks are the promising tool for future management in ROP. Computer networks are tought to scale the abnormal image of the retina by assessing especially the dilation and/or tortuosity of the vessels [29].

ARTIFICIAL INTELLIGENCE AND DEEP LEARNING

It is well known that correct interpretation of retinal images, OCT images and other ophthalmic findings needs years of education and practice. Even truly experienced specialists meet some diagnostic challenges and make mistakes. Using Artificial Intelligence (AI) to accelarate the process of gaining experience can be a big step for improving accuracy of diagnoses.

The development of screening for diabetic retinopathy is exemplified by the tremendous progress in the quality and effectiveness of its detection [30]. The quality of imaging, including its scope as well as resolution, enables increasingly early detection of complications and risk assessment of future threats. Initially, specialists assessed the images. Currently, there is an opportunity for correct quantitative and qualitative assessment of lesions typical of diabetic retinopathy without the participation of an ophthalmologist – using AI and programmes that are specially "trained" for this purpose.

Artificial Intelligence in medicine is used for the evaluation of X-ray images, photos showing skin lesions, or pathomorphological specimens [31]. In ophthalmology, in addition to the aforementioned diabetic retinopathy, there are systems to detect AMD, retinopathy of prematurity, optic nerve disc damage indicating glaucomatous neuropathy. Machines are able to learn image patterns corresponding to individual pathologies based on repeated presentations. These systems often make fewer diagnostic errors than humans. Based on the meta-analysis performed by Kawaguchi *et al.*, the time of detection of lesions typical of diabetic retinopathy or AMD by teleophthalmology methods was similar (or even slightly earlier but not statistically significant) to the detection of other lesions by standard physical examination [5].

Deep learning (DL) is a more advanced method compared to traditional machine learning, where the „teacher" was a specialist, as it completely bypasses the need for human presence. The machine „independently" analyses images previously described and identified by ophthalmologists.

Diagnostic and staging systems using DL have been developed. These conditions include diabetic retinopathy, retinopathy of prematurity, glaucomatous optic neuropathy, macular oedema, AMD.

There are two concepts for using AI to relieve the workload of ophthalmologists and make screening methods more accessible to a wider range of patients. The first concept completely replaces the need for an in-office eye consultation, namely, AI decides on its own whether a patient requires referral to a tertiary referral centre or whether it is sufficient for them to continue the screening method. The other concept treats AI as a tool to triage patients who need an eye consultation. If the system does not find any pathological lesion, the patient will not be referred to an ophthalmologist. Pathological lesions are evaluated using telemedicine methods by a specialist who will ultimately provide a decision on further management.

CONCLUSIONS

Pandemic state caused the ophthalmologist's office visits to be limited to the minimum to protect the health and life of both patients and ophthalmologists. Ophthalmology methods have been accompanying specialists for many years and thus they can partially replace the standard examination even after the end of epidemic.

Popular communicators and applications make it much easier to make a proper diagnosis at a distance, and increasingly better cameras on mobile devices provide a reliable picture of local conditions. As technology continues to evolve, artificial intelligence perhaps will be able to diagnose patients more accurately than the best specialist.

Although many of the above-mentioned methods are very well tested and continuously improved, their availability and costs do not enable their widespread use.

DISCLOSURE

The authors declare no conflict of interest.

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