Ophthalmic Telemedicine in the Pandemic–Endemic World: Present and Future Perspectives

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COVID-19 restrictions have increased the need and use of telemedicine in ophthalmology but this approach requires remote data collection and reliable technologies to ensure accurate and safe examination and diagnosis. This article reviews the existing telemedicine technologies for age-related macular degeneration (AMD), diabetic retinopathy (DR) and paediatric ophthalmology, and discusses their applicability in the COVID-19 era. We conducted a literature search of PubMed using telemedicine keywords for all relevant pathologies (AMD, DR and paediatric ophthalmology) to identify English-language articles published between 2001 and 2021. We assessed whether existing telemedicine technologies would meet the needs of patients under COVID-19 restrictions. Our findings showed that there are reliable existing home-monitoring technologies. However, self-operated home optical coherence tomography is still an investigational technology for AMD monitoring and is not yet available for routine use. Computerized algorithms aimed at identifying DR pathology and/or deterioration in relevant parameters under investigation have shown excellent results. In paediatric ophthalmology, parents can conduct basic testing of their child's ophthalmic parameters; improvements in parental testing will require the development of quick and reliable automatic instruments. In conclusion, current technologies lend themselves to remote use for ophthalmic examination by non-professional individuals, which is particularly relevant for ophthalmic care provision in the pandemic setting. Further investigative effort is needed in order to improve home monitoring and computerized data processing.

Plain Language Summary

Since the COVID-19 pandemic has restricted face-to-face consultations, ophthalmologists need reliable ways to examine and diagnose patients remotely. The authors of this article searched for methods of monitoring common eye diseases in scientific papers published between 2001 and 2021. For diabetic retinopathy, retinal cameras that photograph the back of the eye can be used at home and give images that are as good as those in the clinic. However, at the moment, ophthalmologists need to use specialist equipment known as optical coherence tomography (OCT) in the clinic to diagnose diabetic macular edema, which is swelling that can occur within the macula (center of the retina). Patients can also use retinal cameras at home for screening of age-related macular degeneration (AMD). However, specialists need OCT images to more accurately assess, stage severity of the AMD, and to prescribe treatment options.

At present, children need face-to-face appointments for treatment of most common eye conditions. Telephone consultations are useful for sharing information or for parents to test their child's vision at home for conditions, such as eye movement deviations and 'lazy eye', or reduced vision in on eye (known as amblyopia). Scientists are developing new instruments that parents can use at home.

The pandemic has shown us that there are plenty of reliable methods for remote monitoring of eye diseases, but we still need clinic appointments.

Keywords

Telemedicine, SARS-CoV-2, COVID-19, age-related macular degeneration, diabetic retinopathy, paediatric ophthalmology, artificial intelligence, fundoscopy

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The common definition of telemedicine in general is the ability to remotely gain information about patients' health by means of technological devices in order to determine the need for medical intervention.[1] Publications regarding the possible role of telemedicine in diagnosis and follow-up of ophthalmic pathologies have been the subject of extensive discussion in professional literature prior to the COVID-19 pandemic.[2–10] Telemedicine has been used in ophthalmology for different purposes including consultation, screening, triage and remote supervision. The principal motivations for the use of telemedicine in ophthalmology prior to the COVID-19 pandemic were mainly driven by financial issues, as well as lack of access to state-of-the-art clinical care in remote locations, such as in rural areas or low-income populations without access to routine checkups.[2–3]

Diabetic retinopathy (DR) and glaucoma are the most common ocular conditions for which telemedicine has been used, with the technology for both conditions demonstrating substantial significant agreement with gold standard examinations by ophthalmology specialists.[4–10] The COVID-19 pandemic along with accelerated development of multiple technologies have been catalysts in the ongoing shift towards wide use of ophthalmic telemedicine. The COVID-19 pandemic has presented a meaningful motivation to use telemedicine, in addition to the recognized benefits of improved accessibility and cost-effectiveness. Telemedicine may be a particularly valuable tool for elderly patients and people with comorbidities such as diabetes and compromised immune systems, which places them at increased risk of severe disease if they contract COVID-19. Patients who are unable to attend the physician's clinic due to isolation or being at high risk need a means of accessing diagnostic and follow-up attention for ocular medical conditions. In addition, the need for medical care to be provided in a way that protects patients and medical care providers from the threat of contamination is an additional consideration. The advantages of a remote ophthalmic appointment in the COVID-19 era are self-explanatory in light of the abovementioned considerations.

A thoughtful definition of the medical examination elements that can be implemented in remote encounters is crucial for the success of telemedicine. Previous publications have identified a variety of modalities that would be relevant for ophthalmic assessment via remote connection, including scans of clinical findings, self-measurement of visual acuity and intraocular pressure, home monitoring and retinal imaging.[4,9,11–20]. Some of these examinations can take place with a simple smartphone, while others necessitate the use of specialized medical equipment.
Telemedicine requires a secure remote platform to ensure data privacy. As for every scientific study and statistical analysis, approval by the institutional review board is needed and appropriate patient consent to using the data collected during telemedicine encounters is crucial. In such case, all relevant data should be coded in a way that protects the patient's personal details from being revealed to anyone other than their treating medical team.

The aims of the present review are:

- to describe the status of telemedicine in different ophthalmological subspecialties in the era of COVID-19
- to outline further potential uses for this innovative modality for provision of medical care in light of the limitations posed on traditional means due to COVID-19 restrictions
- to identify unmet needs for ophthalmic telemedicine in the COVID-19 era.

Methods

A literature search of PubMed was conducted using telemedicine keywords for the pathologies of age-related macular degeneration (AMD), diabetic retinopathy (DR) and paediatric ophthalmology, to identify English-language articles published between 2001 and 2021. Search terms included: Telemedicine, teleophthalmology, SARS-CoV-2,

telehealth, COVID-19, age-related macular degeneration, home monitoring, diabetic retinopathy, paediatric ophthalmology, imaging, optical coherence tomography, artificial intelligence, deep learning algorithm, fundoscopy, diabetic macular oedema, anti-VEGF injections, strabismus.

Diabetic retinopathy

The estimated worldwide prevalence of diabetes in 2015 was 415 million people.[21] By 2040, this number is expected to undergo an immense surge to approximately 614 million. DR is the leading cause of blindness and visual impairment in working-aged adults in the Western world.[10,12,22–24] In addition to its significant negative impact on quality of life, DR is also related to other diabetes complications and mortality.[23–26] Screening for DR is of great value due to a lack of symptoms until the later stages of disease and the improved effectiveness of early treatment, whereas delayed diagnosis and treatment may lead to irreversible ocular damage. With over 20% of telemedicine usage in ophthalmology, DR is the most common condition for disease-specific telemedicine diagnosis and follow-up.[4]

In both DR screening and follow-up, the in-person encounter is based on visualization of the fundus and identifying DR elements based on the examiner's expertise. Two different goals in the process need to be met when using telemedicine as a substitute for the clinic visit:

- obtaining a high-quality fundus scan for evaluation of possible presence and severity of DR elements; additional data from optical coherence tomography (OCT) might be necessary
- interpreting fundus imaging findings regarding the presence or dynamics of changes in the DR elements; this can be achieved by either an expert ophthalmologist reviewing the data, or an artificial intelligence (AI) and/or deep learning algorithm (DLA) aimed at analysing these data.

Fundoscopy

The possibility of acquiring a fundus scan that can be used as a substitute for retinal examination during an in-person appointment has been extensively evaluated in recent years.[9,10,14–18,22–24] Various cameras have been used for this purpose and the general agreement is that a non-dilated fundus scan is equal[10,25–32] or superior to an in-person appointment[33] for both DR screening and follow-up.[9,34–36] Based on these data, technological developments in retinal imaging seem to offer a reasonable substitute for in-person examination and can meet the needs for social distancing in a pandemic setting.

Screening for diabetic macular oedema (DMO) is performed as part of the screening process for DR. In contrast to biomicroscopy, where retinal thickening is discriminated by the clinician, detection of macular thickening on monocular non-stereoscopic fundus images relies on surrogate markers, such as intraretinal lipids, microaneurysms and haemorrhages in proximity to the fovea.[37] The positive predictive value of non-stereoscopic fundus imaging for DMO detection remains relatively low.[30,34,37–39] In cases where these surrogate markers are absent, DMO might be missed, whereas OCT might rule out DMO in suspect cases.[39–42] A large study including 3,170 patients identified with diabetic maculopathy on fundus images, found that only 243 (7.7%) were found to have DMO on OCT.[43] Such a high rate of false-positive results causes not only financial burden on healthcare systems but may also result in

unnecessary patient anxiety. However, only a minority of DR screening programmes use OCT in addition to fundus photography.[29,31,33] UK screening programmes have added OCT examinations in community settings as a cost-effective strategy.[41,43,44]

The site location for fundus imaging or OCT scans is a major consideration when adapting telemedicine modalities to a pandemic setting. While many of the suggested systems are performed in a primary clinic or at a designated site, the main motivation for the use of telemedicine during a pandemic is the need for social distancing and for minimizing person-to-person exposure. COVID-19 restrictions called for modalities that can be operated by patients themselves, without contact with medical personnel or exposures to other patients. Technologies that can be self-operated and use relatively uncomplicated instruments such as Smartphones have been suggested.[13–15,35,45]

Interpretation of findings

Interpretation of fundus imaging and OCT results requires trained human graders with specialized knowledge and expertise in diabetic ocular conditions. This assessment is time-consuming and requires human resources, which limit the implementation of teleophthalmology for DR screening and follow-up. In recent years, a plethora of data have been published regarding the use of AI and DLA in the interpretation of retinal photographs and OCT scans in DR screening and follow-up.[7,46–52]

The basic logic of telemedicine operation for DR screening relies on the 'clearance' of cases that do not indicate DR or any progression of a former DR condition (for follow-up programmes) and the referral only of patients with treatable findings for further assessment by a retina specialist. Notably, most patients who were screened by telemedicine during the pandemic did not require a specialist examination and were found to be suitable for further follow-up by telemedicine.[46] Furthermore, the strategy of telemedicine followed by referral to specialist examination of selected cases has been found to be more efficient than providing an examination for all.[53]

One anecdotal report demonstrated the advantages of telemedicine during the COVID-19 pandemic, when an ophthalmologist, who himself had been diagnosed with COVID-19, was able to advise his patients regarding their DR findings, based on fundus imaging and OCT results that had been sent to him.[54]

In summary, the unmet needs of telemedicine for DR diagnosis during this pandemic relate mainly to an improved ability of the patient to obtain retinal images. While performing imaging at a community clinic was a fair solution before the pandemic, efforts towards home equipment need to be enforced. This includes fundus photography, as well as portable OCT solutions.

Age-related macular degeneration

AMD is the leading cause of blindness for people aged over 50 years in the Western world. Injections of anti-vascular endothelial growth factor (VEGF) agents are the most common treatment for this condition.[55,56]

Retinal imaging for AMD screening[33,57–62] and follow-up in the telemedicine setting have been proven to be as efficient as those conducted during an in-person appointment.[59,62-64] Successful operation of the camera by the patient has been previously reported.[16,64] While DR screening can be largely performed based on fundus images alone, OCT imaging is crucial in the assessment of disease stage and need for treatment in AMD. Prior to the pandemic, it was shown that a telemedicine model that included retinography, OCT images and visual acuity data was a useful alternative to in-person appointments for the follow-up of patients with AMD.[562,63] A home-based daily visual-field monitoring system has been shown to be feasible and cost-effective for patients who are at risk for developing exudative AMD.[64]

Furthermore, DLAs have been shown to be reliable in detecting AMD from fundus images, and even outperformed human graders in AMD classification.[65–70]

The option of performing OCT assessment in a patient's home setting represents a promising alternative paradigm to conventional disease monitoring. In addition to the safety, convenience and flexibility of this approach for elderly patients with limited mobility, home monitoring would offer a huge advantage during a pandemic as it allows for frequent, even daily, imaging. Conversion from the non-neovascular to the exudative stage can be detected at the very early stages by identification of retinal fluid. Moreover, decisions regarding re-treatment with anti-VEGF injections could be taken while avoiding both unnecessary injections and unnecessary clinic visits. In order to introduce home OCT monitoring, AI/DLA interpretation of data is required and secure cloud services are needed. Different AI/DLA algorithms have been developed to provide fully automated detection of retinal pathologies on OCT.[68–70] A pilot prospective study recently reported on longitudinal daily OCT self-imaging at home by patients with AMD.[17] The elderly participants were able to perform self-imaging with satisfactory quality of images.

The efforts to establish automated evaluation systems for AMD screening and follow-up were extensive prior to the current pandemic. The developments achieved in this field may well serve to cope with the constraints inflicted by the pandemic. It is encouraging that patients have previously reported high rates of satisfaction with teleophthalmology.[71]

Paediatric ophthalmology and strabismus

Urgent and new cases of paediatric cataract, glaucoma, ocular trauma and suspected low vision or strabismus cannot be evaluated or treated by telemedicine, and in-person, frontal examination is mandatory.

However, telemedicine in paediatric ophthalmology can be used either as a 'home visit', where parents acquire the relevant information, or as a professional consultation between an expert paediatric ophthalmologist and a general ophthalmologist. Telemedicine is not suitable for measurement of refraction in new patients in order to treat, for example, accommodative esotropia or to prescribe new glasses for a child with suspected new refractive amblyopia. New strabismus can be demonstrated by scans; however, proper measurements using prism bars at the clinic are needed for treatment decisions. Nonetheless, telemedicine can be useful in 'home visits' for continuous patient care.[72]

The main objective tools used by paediatric ophthalmologists in remote examinations are vision examinations and scans of the outer segments of the eyes, performed by parents, as well as face images to evaluate alignment. Using the findings from these remote tests, ophthalmologists are able to recommend continuity of treatment with spectacles or patching for lazy eye. Relying on vision tests, ophthalmologists were able to recommend continuity of treatment with spectacles or patching for lazy eye.

The first and most relevant challenge of telemedicine in paediatric ophthalmology is providing visual acuity tests that parents can conduct quickly and accurately before cooperation from the child is lost. Electronic device applications such as Kay-iSight®[18] (Kay Pictures, Tring, UK) were

developed to account for this need, allowing parents to evaluate and report their children's visual acuity to ophthalmologists. Other relevant websites available for physicians and families include Safe Eyes America® (www.safeeyesamerica.org)[19] mainly for visual acuity tests, and Alaska Blind Child Discovery® (www.abcd-vision.org),[20] which gathers all aspects of home-based screening for parents including videos and charts that can be printed, and also includes stereoacuity tests. In order to evaluate eye movements and strabismus, an application that is mostly directed by ophthalmologists, called 9 GAZE®[73] (See Vision, LCC, Richmond, VA, USA), has also been used during telemedicine consultations.

This ability to evaluate visual acuity and eye alignment may be a key factor in assessing the risk for amblyopia, and has particular importance during pandemic restrictions that affect children's attendance at school, where routine assessments for amblyopia usually take place.

'Expert advice' is mainly relevant to retinopathy of prematurity and strabismus.[74–77] The crucial question regarding telemedicine use in paediatric ophthalmology remains the reliability of the telemedicine findings. The reliability of telemedicine in the diagnosis and management plans of selected paediatric ophthalmology pathologies was examined in a prospective analysis comparing telemedicine-based examinations versus in-person examinations in 210 patients (348 examinations).[21] In this research, an optometrist conducted examinations using digital equipment and live-streamed the examination to a paediatric ophthalmologist who recorded diagnoses and management plans, then re-examined patients in person. The management plans or diagnoses determined by telemedicine and in-person examinations were compared. For patients who suffered from strabismus as a primary diagnosis (131 patients, 62.4% of all participants), excellent and almost perfect agreement was observed for angle measurements between the two modes of examination. No primary diagnoses changed, and no management plans changed following in-person examination. Overall, 54/55 patients who consented to surgery at the initial visit did so before they were informed that they would also receive a further in-person examination by the paediatric ophthalmologist; this approach was taken to determine how comfortable participants were with the telemedicine examination and management plan. Families felt comfortable with the quality of the telemedicine examination (98.5%) and reported that they would be willing to repeat the same examination in the future (97.1%).

These results confirm the possible role of telemedicine in the diagnosis and management of certain pathologies in paediatric ophthalmology. However, there is a need for better accessibility of remote instrumentation for parents, especially when this approach is used in order to enable social distancing during a pandemic. A further shortcoming requiring additions to the existing armamentarium of telemedicine equipment for paediatric ophthalmology, is the ability to perform objective refraction and fundus imaging at home using a quick self-focusing adapted camera.

Although this article focuses on the use of telemedicine for AMD, DR and paediatric ophthalmology in a pandemic setting, the actual scope of possible use is much wider and includes additional fields in ophthalmology. Availability of facial, slit lamp and fundus photography, as well as home OCT can be used for postoperative follow-up after routine surgery, glaucoma screening and follow-up (in combination with home self-tonometry), dry eye and oculoplastics.

Conclusion

In conclusion, while telemedicine solutions in ophthalmology were available before the COVID-19 pandemic, their advantages in times of social distancing, lockdowns and quarantines offer an alternative to in-person screening and follow-up visits. Although the reliability of teleophthalmology has been demonstrated, and developments in technology and AI continue to progress, there remain obstacles to widespread implementation. This devastating pandemic might help reduce some of the barriers and pave the road to a wider use of remote technologies, benefiting patients by providing improved detection, earlier treatment, and finally improved visual outcomes. ❑

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