The use of smartphones in ophthalmology: technological development and application

O uso de smartphones na oftalmologia: desenvolvimento tecnologico e aplicação

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Abstract

Objective: Technological development has promoted several advances in society, including the creation of smartphones, which have been increasingly used in medicine, especially in ophthalmology. This study aimed to review the use of smartphones in ophthalmology. Methods: In January of 2020, the MEDLINE and LILACS databases were selected to provide articles containing the terms "Ophthalmology" and "Smartphone", filtering the results between the years of 2015 and 2019. The evaluated outcomes were finally included into the following categories in the discussion: "Visual acuity", "Amblyopia and strabismus", "Anterior segment", "Posterior segment", "Glaucoma", "Community patient education and assistance" and "Neurophthalmology". Results: Smartphones can be useful in several different areas of ophthalmology and can provide the patients better understanding and adhesion to their treatment. Conclusion: Applications can be used as tools to facilitate the work of several professionals and improve the understanding of patients about their clinical conditions.

Keywords: Smartphones. Ophthalmology. Mobile Applications.

Resumo

Objetivo: O desenvolvimento tecnológico tem promovido diversos avanços na sociedade, incluindo a criação de smartphones, que têm sido cada vez mais utilizados na medicina, especialmente na oftalmologia. O objetivo deste estudo foi revisar o uso de smartphones na oftalmologia. Métodos: Durante o mês de janeiro de 2020, as bases de dados MEDLINE e LILACS foram selecionadas para buscar artigos contendo os termos “Oftalmologia” e “Smartphone”, filtrando os resultados entre os anos de 2015 e 2019. Os dados avaliados foram, finalmente, incluídos nas seguintes categorias na discussão: “Acuidade visual”, “Ambliopia e estrabismo”, “Segmento anterior”, “Segmento posterior”, “Glaucoma”, “Assistência e educação ao paciente da comunidade” e “Neurooftalmologia”. Resultados: Os smartphones podem ser úteis em diversas áreas da oftalmologia e podem fornecer os pacientes melhor entendimento e adesão ao tratamento. Conclusão: Aplicativos podem ser usados como ferramenta para facilitar o trabalho de diversos profissionais e melhorar o entendimento dos pacientes sobre suas condições clínicas.

Palavras-chave: Smartphones. Oftalmologia. Aplicativos Móveis.

INTRODUCTION

Technological development has promoted several advances to society, such as the creation of smartphones, which are becoming increasingly common. It was estimated that in 2020, 70% of the world population will be using these gadgets¹. Among physicians, they can be used as tools of great practicality and efficiency, mainly with the use of applications, which, in 2013, were more than 19,000 related to the health area².

It is worth pointing out features of smartphones such as arrhythmia detection, 3D anatomical guides for surgeons, rheumatoid arthritis monitoring, and general utilities related to clinical practice: quick response to diagnostic results, prevention of medical errors, better management, and data accessibility, among others¹³⁴⁵.

Concerning ophthalmology, there is a wide variety of uses for these gadgets, promoting mechanisms to replace already established equipments or using mobile applications that offer new features for the devices. This study aims to review the use of smartphones in ophthalmology.

METHODS

We utilized the Medline (PubMed) and LILACS databases for all articles published between 2015 and 2019 to perform a systematic review of the literature. Descriptors included were “Smartphones” AND “Ophthalmology”, intending to provide a general perspective of the smartphones and software applied to several ophthalmic conditions. Furthermore, we decided to include some works that we considered relevant to this review for further screening, as they brought relevant information notoriously in terms of apps.
Thus, in January 2020, four researchers independently analyzed the filtered data, according to a PRISMA protocol. Cross-sectional, cohort studies and case-control studies were included. Among the exclusion criteria were duplicates, review studies, unpublished articles, abstracts, theses, dissertations, book chapters, articles that did not use smartphones in ophthalmology, and articles considered not relevant to the subject matter. Abstracts considered interesting for the review were further evaluated. When considered to meet the criteria, the text was fully assessed and included in the final selection if approved.

A reference list of the authors included was elaborated after extracting data from all the reviewers independently, including the major topic approached in each manuscript and the year of publication. The evaluated outcomes were finally included into the following categories in the discussion: “Visual acuity”, “Amblyopia and strabismus”, “Anterior segment”, “Posterior segment”, “Glaucoma”, “Community patient education and assistance” and “Neuroophthalmology”. This division was performed primordially based on the usability of smartphones among different ophthalmological specialties, but also including information related to the patient’s educational experience and self-care.

**RESULTS**

During the years 2015 until 2019, 168 papers were found using the descriptors "Ophthalmology" and "Smartphones", and additional data included six articles. No duplicates were found, and after initial screening, 123 studies were eligible. In the final qualitative analysis, only 35 studies were eligible. In the final qualitative analysis, only 35 papers remained relevant to the subject matter (Figure 1).

![PRISMA Flow Diagram](image)

Thus, information was obtained about various mobile applications, software, gadgets, and functionalities inherent to smartphones (Table 1).
### Table 1. The main topics approached during the review containing articles that pointed relevant information among each group.

| Main topic approached     | Reference                      |
|---------------------------|--------------------------------|
| Visual acuity             | 2016 O’Neil⁸                    |
|                           | 2019 Hogarty⁹                   |
| Amblyopia and strabismus  | 2018 Peterseim¹²                |
|                           | 2018 Hashemi¹⁰                  |
|                           | 2018 Paudel¹³                   |
| Eyelids and anterior segment | 2014 Teichman²³               |
|                           | 2016 Chen¹⁹                     |
|                           | 2016 Mohammadpour¹⁴             |
|                           | 2017 Sanguansak¹⁸                |
|                           | 2018 Pallas²²                   |
|                           | 2019 Liu¹⁵                      |
|                           | 2019 Chandrakanth¹⁶              |
|                           | 2019 Snyder¹⁷                   |
|                           | 2020 Dias²⁰                     |
|                           | 2020 Fernandes Dias²¹           |
| Posterior segment         | 2015 Adam³¹                     |
|                           | 2015 Ryan³²                     |
|                           | 2016 Bastawrous²⁴                |
|                           | 2016 Oluleye²⁹                   |
|                           | 2016 Micheletti³⁰                |
|                           | 2016 Luwig³³                     |
|                           | 2016 Panwar³⁴                   |
|                           | 2017 Ademola-Popoola³⁵           |
|                           | 2017 Furdova²⁶                   |
|                           | 2018 Elloumi³⁵                   |
|                           | 2019 Lekha³⁷                     |
|                           | 2019 Patel²⁸                    |
| Glaucoma                  | 2016 Russo³⁶                     |
|                           | 2016 Bastawrous²⁴                |
|                           | 2016 Waisbourd⁹                  |
|                           | 2018 Tsapakis³⁸                  |
|                           | 2019 Alawa³⁷                     |
|                           | 2016 Alhihali⁴⁰                 |
|                           | 2019 Rono⁴¹                      |
|                           | 2018 McAnany⁴²                  |
|                           | 2019 Versek⁴³                   |

### DISCUSSION

#### Visual acuity

Reductions in visual functioning are correlated with a reduction in health and well-being, particularly in the elderly⁶,⁷. Visual acuity (VA) is the most common method of assessing visual function and is the gold standard for clinical trial results⁸,⁹. Patients with detected reductions in VA are targets for additional clinical assessments and, when necessary, surgical interventions. Therefore, we must have an accurate and reproducible measure of VA.

In another study, O’Neill et al. recruited 60 participants and compared VA remotely using the Snellen table, Chart Pro (v1.3 on an Apple iPad 9.7 "), and the "Snellen" app (DrBloggsLtd v1.2 on an iPhone 4; brightness 50% ) in a general practice consultation room. O’Neill found an average difference of less than one line between the physical graph and the APP with a high degree of correlation between the scores⁸.

There is currently insufficient evidence to recommend any VA measurement APP. This is partly due to confusion about the best control group to be used in studies (Snellen versus ETDRS) which, when associated with the wide variety of APP available, creates significant heterogeneity⁹.

#### Amblyopia and strabismus

Amblyopia is a developmental disorder in which there is a reduction in VA without detecting a structural cause¹⁰,¹¹. Amblyopia is caused due to the lack of clear stimuli in the retina (anisometropia or deprivation), or abnormal binocular interaction (strabismus) and is always secondary to another abnormality¹¹. The treatment essentially involves increasing the use of the amblyopic eye (traditionally done by tampon), as well as treating the cause.

Recently, research has investigated the potential utility of app for smartphones in the diagnosis and treatment of different aspects of amblyopia and related conditions. As strabismus is the main cause of amblyopia in children, developers have created an APP that helps identify strabismus or compensatory head positions, in addition to helping to monitor changes over time¹².

Peterseim et al. studied 206 participants and compared GoCheckKids vision screener software with the pediatric evaluation and found a sensitivity of 76.0 and specificity of 67.2% (15 false negatives) in detecting risk factors for amblyopia, indicating that an additional vision assessment would be necessary for these participants; furthermore, this study was limited by its small sample size¹².

Smartphone applications could be particularly useful for the assessment of strabismus as a proficient clinical method since the assessment requires a high degree of experience and
observation skills and is often performed on uncooperative patients (young children)\(^9\).

It is possible that amblyopia can be effectively treated with the assistance of the amblyopia game app; however, it is essential that this happen with appropriate scientific validation. In addition, it is important that these softwares include recommendations that are implemented under appropriate medical supervision and monitoring, given the possible consequences for vision if mismanaged. These findings may demonstrate significant problems with the governance of medical app\(^3\). Although there is a significant number of apps aimed at the treatment of amblyopia, only a small portion has the collaboration of ophthalmologists or medical research groups\(^13\).

Anterior segment

The use of a smartphone in the evaluation of the previous segment allows health professionals and even patients themselves to easily prepare photographs and videos of the eye records when the slit lamp is not available or to facilitate the examination of the eye structures or the presence of foreign bodies in the anterior chamber\(^14\). There are also devices that allow smartphones to be attached semi-permanently to the slit lamp, reducing assembly time in the case of concomitant use of these devices\(^15\).

With a smartphone containing a camera of at least eight megapixels and with the aid of 10 to 90D lenses, it is possible to assess eyelids, medial and lateral canthus, conjunctiva, limbus, cornea, iris, and pupil with the 90D lenses it is possible to view the crypts of the iris\(^14\). It is also possible to obtain images from the anterior camera by attaching intraocular lenses to the smartphone's camera\(^16\).

High-resolution photos of the ocular surface can be saved and easily the professional has access to the status of the conjunctiva and cornea, which can be useful in ophthalmic care, including in the monitoring of patients who have been treated for trachoma\(^14,17\).

In addition, anterior segment photos captured through adapters coupled to smartphones can be useful for managing patients after surgery\(^18\). When combined with visual acuity, intraocular pressure, and patient history, the images obtained can be acceptable in 93-100% of cases\(^18\).

The comparison between a smartphone (iPhone 5) and a camera (Canon EOS 10D) showed that the smartphone has good reproducibility. In low light the camera (Canon EOS 10D) for using a 22.7 mm x 15.1 mm CMOS sensor, demonstrating superior performance, compared to the iPhone 5 which uses a 4.54 mm x 3.42 mm CMOS sensor. With the iPhone's automatic ISO adjustment, backlit images benefit even in low light. The correlation between the two devices was moderate when evaluating nuclear opalescence, requiring more experience in classifying cataract images, and was excellent when analyzing correlations of cortical and subcapsular cataracts\(^19\).

Applications, such as Eye Axis Check, can be used to capture and edit photographs of a protractor with 360\(^\circ\) axis marking, being able to help in the preoperative and intraoperative toric intraocular lens alignment\(^20\). This app can also be used to check the alignment of intrastromal corneal ring segments for keratoconus, presenting a fast learning curve and minimum differences in terms of axis compared to the marks made manually\(^20,21\).

The toriCAM is another app designed to assess the alignment of the toric intraocular lens, presenting reductions in the mean error of the markings from 3.18\(^\circ\) ± 2.22\(^\circ\) to 1.28\(^\circ\) ± 1.34\(^\circ\) on both freehand and slit-lamp methods\(^22\).

It is also possible to evaluate the alignment of toric intraocular lens with a computer software, such as the ImageJ, by photographing images of the inserted lens and sending them to the software's platform, enabling a cost-effective and fast alternative to check the position of intraocular lens\(^23\).

Posterior segment

The fundus evaluation is important for the diagnosis and monitoring of diseases, such as diabetic retinopathy, glaucoma, age-related macular degeneration, premature retinopathy, and systemic diseases such as hypertension, HIV / AIDS, and syphilis\(^24\). Usually, direct or indirect ophthalmoscopy is used to evaluate the fundus, but high-cost equipment is required, which often has a low learning curve and limitations in the field of view\(^25\). In addition, in some hospitals, for example, this examination is often not performed due to the absence of an ophthalmologist. As smartphones are more affordable, cheaper, and portable, their advanced technology in capturing images can be a good alternative\(^25,26\).

The use of apps can be useful especially in young children, where it is not possible to obtain a good evaluation with indirect ophthalmoscopy. Beyond that smartphones are also useful in emergency cases, where the indirect ophthalmoscope may not be readily available and while screening retinopathy of prematurity, the main cause of childhood blindness, enabling the documentation and identification of severe forms of the disease in areas with little resource\(^27\). Smartphones can also be useful for the diagnosis of other diseases in children, such as retinoblastoma, Coats' disease, commotion retinae, and optic nerve hypoplasia\(^28\).

By attaching a 20D lens to a smartphone, it is possible to replicate the exam, generating a cheaper method for fundus analysis. In addition, it is possible to store images and send data, allowing the sharing of images\(^29\). The smartphone camera can help physicians to monitor retinopathies, which can help to clarify the patient’s condition and, consequently, improve adherence to the treatment\(^30\).
Several studies indicate that the fundus examination performed using a smartphone shows similar results to those obtained by ophthalmoscopes. This technique is especially useful in underdeveloped countries, which do not have a wide variety of technological resources. However, some studies show divergent results of sensitivity and specificity when comparing the smartphone with conventional methods of fundus evaluation. There is also specialized equipment to facilitate this technique, such as the PexusScope, a portable device that can be easily attached to the smartphone, allowing a better analysis of the anterior and posterior segments. Other gadgets that help the fundus examination with the smartphone are iExaminer, Ocular CellScope, Portable Eye Examination Kit, and D-Eye System.

There are also methods that combine software on the computer with the use of the smartphone camera to assess more specific structures. Eloumi et al., through the combination of software and smartphone, developed a method for assessing the optic nerve head in patients with diabetic retinopathy, showing, in their study, good reliability and fast execution time.

The innovative role in research, education, and information sharing and the potential in ophthalmological practice is recognized, however, the use of a smartphone as a non-standardized diagnostic tool should be carefully considered.

**Glaucoma**

Visualization and interpretation of findings related to the optic nerve are essential in the ophthalmological examination. A study of 110 patients with ocular hypertension and open-angle glaucoma who had their cup-to-disc ratio analyzed by two glaucoma specialists demonstrated that ophthalmoscopy performed by a smartphone associated with a D-EYE adapter (D-EYE, Padova, Italy) did not present results that were statistically different from those presented by slit-lamp biomicroscopy, suggesting that the smartphone could be an alternative to this method.

Another study evaluated fundus photographs of non-clinicians who used an adapter called Peek Retina and a low-cost smartphone, obtaining images of the optic nerve in a pattern that allows its classification, comparing with images acquired through a camera operated by an ophthalmologist. This showed that the evaluation of the optical disc could be performed with the use of smartphones aided by this adapter. Thus; its great potential to help in the detection of preventable causes of blindness has been hypothesized. It was observed agreement between the images of the camera and the ones from Peek Retina, showing a high degree of confidence to measure a real change in the increase of the optic nerve excavation over time.

Although stereoscopic images are the preference in the evaluation and classification of the optic nerve, it has been shown that the images obtained with the smartphone camera do not represent significant disadvantages in the classification of the probability of glaucoma. The smartphone ophthalmoscopy, considering its connectivity and portability, allows the benefit of this technology to be used in the screening of glaucoma, especially in environments with few resources, a place where the early detection of eye diseases is hampered due to the high cost and low portability of devices for fundoscopic evaluation.

Devices are also being produced that enable visual field examinations with the use of smartphones aided by adapters, as well as virtual reality glasses, producing results similar to conventional examinations, which may suggest a more practical and economical alternative to assess glaucoma patients.

When assessing the interest in having the Glaucoma App, a glaucoma follow-up app with several functionalities, both patients and caregivers were pointed to be likely to download and use this type of APP, especially the ones who wore less than 65 years. However, the interest rates in the APP tended to be lower with the possibility of acquiring the app for 3$ instead of downloading it for free.

**Community patient education and assistance**

The information given to the patient about his disease has a crucial impact on the process of understanding his clinical condition and prognosis. This is often essential for effective adherence to treatment, so patient-centered education is one of the pillars of medical intervention, thus some apps are developed to deepen patient’s knowledge about his disease.

A study carried out in Saudi Arabia showed that although individual and group sessions were the main source of information about pathological conditions in ophthalmology; however mobile applications already represented a viable alternative to develop this knowledge, which can facilitate patient follow-up.

In addition, there are features that aim to facilitate the screening and referral system of patients with opthalmic problems, such as the Peak Community Eye Health system, which includes the Peak Community Screening App, a tool that can be used by community agents to facilitate the screening of patients with the need for ophthalmological monitoring, also sending notifications of text messages to patients, generating letters of reference and showing the availability of services.

**Neurophthalmology**

Pupillometry can be performed using the smartphone camera’s infrared function, allowing the acquisition of results highly similar to those of the sensitometry. In addition, there are devices under development that constitute faster and more practical methods for neurophthalmological explanations, such as the NeuroDotVR, a gadget with a smartphone and a headset that allow quantitative measurement of visual evoked potentials and local electric fields, allowing diagnostic and therapeutic stimuli, including several other features.
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Strengths and limitations

This review shows a global overview of the utilities of smartphones in the diagnosis, treatment, and follow-up of many ophthalmic diseases, and also provides relevant aspects of these technologies in medical education and patient’s comprehension of ocular conditions. However, although there are a significant number of APP related to ophthalmology, only a small percentage of those tools have been evaluated with a scientific approach, leading to a limited number of original manuscripts discussing the usability of specific apps.

Future perspectives

We believe that the use of medical apps is growing rapidly, leading to the development of new tools with innovative functionalities, which can be useful to provide less expensive or more dynamic solutions for several activities, especially in ophthalmology. This can also represent a resource for the empowerment of self-care by patients, as the new technologies can be more accessible and intuitive. Thus, more studies might have to be developed to precisely assess the real impacts of these technological advances.

CONCLUSION

The growing use of smartphones around the world has transformed the health area in several aspects. In ophthalmology, the use of mobile applications, adapters, and cameras attached to smartphones have been facilitating the work and several professionals and the understanding of many patients about their respective diagnoses.

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