

Diabetic Retinopathy Monitoring Using Smartphone: A Review

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Abstract—At a Global level Diabetic retinopathy is the essential root of blindness among Diabetic patients. According to WHO in India by 2030 nearly 79.4 million people will suffer from Diabetic Mellitus and 18% of the diabetic population suffered by Diabetic retinopathy. Early detection is necessary to reduce the risk of blindness in case of diabetic Retinopathy. Traditionally Fundus cameras are used for screening of Diabetic Retinopathy but its access is limited to primary health care center also required skilled person and high cost. Now a days to overcome the limitations of fundus camera, smartphone-based fundus camera is used for monitoring the Diabetic retinopathy. This paper illustrates the need of smartphone and elaborates the use of smartphones as fundus camera by using different types of wearable devices/adapters. Smartphone based fundus camera acts as an alternative for examining the fundus for eye care physicians.

Index Terms— Diabetic Retinopathy, Smartphone, Retina, Fundus Camera

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I. Introduction

Diabetic retinopathy is a condition that may occur in people with diabetes. Diabetic retinopathy is a retinal abnormality causes serious sight-threatening complication in diabetes patients. One of major cause of diabetic retinopathy is poor control of blood glucose and blood pressure in long term which causes damage to small blood vessels all over the body including retina. Burst of micro and damaged blood vessels causes leakage of blood and other fluids swelling of retinal tissue and thereby blurred vision in both eyes. DR is progressively degenerative if developing diabetic retinopathy in any diabetic person is directly related to duration of uncontrolled diabetes. Untreated diabetic retinopathy increases the risk of causing blindness.

At the initial stage Diabetic Retinopathy does not show any complication. At the advance stage symptoms appear but the treatment is difficult and may lead to blindness. As mentioned by Surendran TS et al. In India, 80 million patients having diabetes mellitus out of which 23 million will be at risk of diabetic retinopathy [1]. Also as mentioned in the union health ministry's first National Diabetes and Diabetic Survey (2015-19) has stated that prevalence of Diabetic Retinopathy is 16.9 percent and prevalence of sight threatening DR is 3.6 per cent [18]. It is essential to do the early detection of diabetic retinopathy to prevent vision loss or blindness. It is necessary to have regular retinal screening.

Conventionally ophthalmologists used fundus examination for screening of retinopathy [2]. Retinal imaging using smartphone has been emerged as one of the recent cost-effective way of screening [2].

According to imaging technology news, all over the world 80 percent of physicians are using smartphones for viewing patient's images in their medical practice [11].

Now days, smartphones are integral part of our daily life. Smartphones with apps convert it into portable medical diagnosis device. As per mentioned in the International Telecommunication Union (ITU) report that at end of 2019, 4.1 billion people using the internet [10].

II. Method

We studied and reviewed the literature on smartphone-based technology for screening of diabetic patients' eye. We compared each device company, mydriatic versus non mydriatic capturing, cost, required device and app, image recording. This data gathered from literature, website of relevant product. The product cost was gathered either from the company's official website or from the survey paper.

III. Diabetic Retinopathy

Figure 1 shows Normal eye and effect of Diabetic Retinopathy on human eye. As the disease progress shows different stages and types. At the early stage structure of blood vessel changes and fluid buildup cause swelling, blood vessel begins to bleed. In the advanced stage blood vessels damaged and detached. This cause breakdown of retinal blood vessels leading to the growth of new, unhealthy blood vessels called as neovascularization.

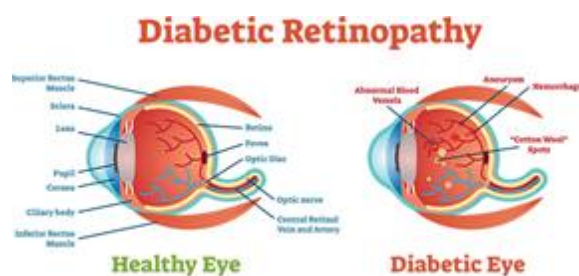


Figure 1: Normal eye and effect of diabetic retinopathy on human eye. (Source: American Optometric Association <https://www.aoa.org/>)

For traditional Retinal examination, an ophthalmoscope maybe of two types as directs ophthalmoscope approach and indirect ophthalmoscope approach. The direct ophthalmoscope, is also called as Augenspiegel-eyemirror is invented by Von Helmholtz in 1851. Improvement in Direct ophthalmoscope processed with the time advancement and direct ophthalmoscope passes from various stages of improvement by incorporating concave and convex lens, the camera attachment for improving image clarity with refraction error correction in patients and/or examiner for the documentation purposes [5].

The constraint in direct ophthalmoscope is in camera attachment cost and in field of view (FOV). The indirect ophthalmoscope was invented by GiraudTeulon which provided a larger visualization of FOV and stereopsis. The indirect ophthalmoscope went through much advancement, from teaching mirror attachment to the insertion of making camera videography attachment in digital translation. This digital version is used for teaching in the education field, archiving and teleconsultation. The limitation of digital indirect ophthalmoscope is somewhat bulky, provides steep approach of learning and too expensive also [5].

Smartphone based fundus photography devices would be handheld, portable and user friendly. Smartphone can be used easily in clinics and for operations on adults and mainly in young children. Smartphones are easily usable for group test examination like camps for eye testing. These can also be used in inadequate situations like imperfect conditions in an accident or in an emergency room where indirect ophthalmoscope and fundus camera is not easily available for use because of high cost.

The cost of Smartphone along with 20D lenses about 500 US Dollars whereas the cost of normal fundus camera is about 10,000 US Dollars which is very high in comparison with Smartphone. At times, fundus camera and indirect ophthalmoscope may be available for use but using that equipment is not possible due to bad electricity supply in underdeveloped areas. The advantage of Smartphone is inexpensive and easily available, portable lighter weight device. Also, the technology advancement for capturing, storing and sharing of fundus images and data connectivity which provides easy way of consultation prove it the best devices for retinal ophthalmoscope.

In medical imaging the role of smartphones has been widen to enclose a broad range of functions such as screening and detecting retinal diseases. Smartphones with apps are used by physician in their daily medical practice to view and diagnosis the patient's images. [11]. Similarly, smartphones empower ophthalmologists to view record and share results from the images in a more economical way.

This literature survey exhibits that Diabetic Retinopathy monitoring can be done successfully by using smartphone-based fundus camera.

This paper presents the different types of a innovative smartphone based retinal imaging device used for retinal imaging as shown figure 1.

Ophthalmologists in India

As mentioned by Raj Kumar et.al. In 1993, limited numbers of ophthalmic surgeons are available in India. Also mentioned that a national ophthalmologist: population ratio is uneven in all regions in India. For example, mean average is 1:9,000(Chandigarh) and 1:608000(Nagaland)[20].

Ocular Surgery News Europe/Asia-Pacific Edition (Archive), March 2002 reported that India has 10000 ophthalmic surgeon and 2000 optometrists [19]. This count is very less as compared to the existing population of India.

Prevalence of diabetic retinopathy in India

The studies conducted in India to calculate the prevalence of DR. There is wide variation in the prevalence in this Table1 stated studies. In this paper, most of people underwent retinal examination by clinician and stereographic fundus photography. The National Diabetic Retinopathy Screening Service, UK, and the Joslin retina network, USA follows the standard practice of retina examination that is "Photographic documentation"

Retina fundus examination having its own advantages compared to other methods. It gives accurate examination and permanent documentation and transmission. Smartphone based retina examination is one of the low-cost solutions.

Table 1: Review on Prevalence of Diabetic Retinopathy in India

	Title of Paper	Source	Objective	Subjects	Prevalence (%)
1	Prevalence of diabetic retinopathy in India: The All India Ophthalmological Society Diabetic Retinopathy Eye Screening Study 2014	Salil S Gadkari, Quresh B Maskati, and Barun Kumar Nayak Indian J Ophthalmol. 2016 Jan; 64(1): 38–44. doi: 10.4103/0301-4738.178144	To evaluate the prevalence of diabetic retinopathy (DR) in diabetic patients across the nation and attempt to establish history-based risk factors.	5130	21.7
2	Prevalence of diabetic retinopathy in India: SankaraNethralaya Diabetic Retinopathy Epidemiology and Molecular Genetics Study report 2.	Raman R et.al. Ophthalmology. 2009 Feb;116(2):311-8. doi: 10.1016/j.ophtha.2008.09.010. Epub 2008 Dec 12.	To estimate the prevalence of diabetic retinopathy in an urban Indian population older than 40 years.	5999	18
3	Prevalence of Diabetic Retinopathy in Urban India: The Chennai Urban Rural Epidemiology Study (CURES) Eye Study, I	Mohan Rema et. al. Investigative Ophthalmology & Visual Science July 2005, Vol.46, 2328-2333. doi:https://doi.org/10.1167/iovs.05-0019	To assess the prevalence of diabetic retinopathy (DR) in type 2 diabetic subjects in urban India using four-field stereo color photography.	1382	17.6
4	Prevalence of Diabetic Retinopathy in Type 2 Diabetic Patients Attending Tertiary Care Hospital In Sikkim	Karma Loday Bhutia et.al. Published Online: 25-OCT-2017 DOI:http://dx.doi.org/10.7869/djo.306	To estimate the prevalence of Diabetic Retinopathy and to find its association with age, gender and disease severity among type 2 diabetes mellitus.	1000	17.4
5	Population based assessment of diabetic retinopathy in an urban population in southern India.	Lalit Dandona et.al. BMJ Journal, Volume 83, Issue 8 1.	To assess the prevalence of diabetic retinopathy and the visual impairment caused by it in an urban population in southern India in order to determine its public health significance.	2522	22.4



Figure 1: Current generation portable smartphone based fundus camera for diabetic retinopathy (A) Smartphone and condensing lens technique (B) oDocs Fundus - Smartphone Fundus Camera (<http://www.odocs-tech.com/fundus/#>) (C) Welch Allyn iExaminer 6P (<https://www.welchallyn.com/en/microsites/iexaminer.html>) (D) Cellscope Retina (<https://www.biorxiv.org/content/10.1101/364265v1.full>) (E) Portable Eye Examination Kit (PEEK) (www.peekvision.org/) (F) JaizRetiCAM (G) Portable Retinal SystemD-Eye (https://www.d-eyecare.com/en_IN)

IV. TYPES OF SMARTPHONE BASED FUNDUS CAMERA

A) Smartphone and 20D lens technique: This is a simple technique of fundus photography. In this technique a smartphone with condensing lens are used to capture the fundus images. A 20D lens used as condensing lens with or without a Koeppel lens. As mentioned in paper to make this system as indirect ophthalmoscope used the coaxial light source to capture retina a digital images [12]. Good quality images can be captured by using this technique. In this system smartphone inbuilt camera captures a fundus image on the screen of smartphone through the condensing lens. This system works on the principle of an indirect ophthalmoscope (Figure 1) [9]. The primary requirement is that image should be capture in dark area because there is no cover between the smartphone and the lens to protect the light from coming in and provoking reflections. Skill person is required to capture the retinal images as the distance between the lens and the eye is not fixed [8].

B) oDocs Fundus:

This is a smartphone-based fundus camera. It is designed files are available on company websites for Do-it-yourself (DIY) spirits. Therefore, it is an open-source smartphone fundus camera. This device uses phone's inbuilt light source with condensing lens. Its working principle is similar to indirect ophthalmoscopy. oDocs fundus provides field view of up to 40 degree. In 2015, ODOCS eye care officially launched the oDocs Fundus. It is most widely used smartphone based imaging adapter [7]. It consists of a rod that attached to the mobile phone on one side, and to a 20D lens on the other side. It is compatible with Apple iPhone series 5/6/7/8. Main features of oDocs Fundus camera are Retinal imaging adapter with Bi-Aspheric lens, lens with Anti-reflective coating, 3D printed Durable Nylon (SLS). **oDocs Fundus (Assembled)** available in the market for around \$ 165. The oDocs VisoScope is the upgraded model. It designed with superior anti-reflective properties and field view 50° with this it adds retinal imaging capability to your iPhone. For the ease of image acquisition, it used iOS app oDocsCapture.

C) iExaminer:

Ophthalmoscope manufacturer Welch Allyn Inc comes up with an "iExaminer". It is a smartphone based digital imaging device to view and capture images of the eye. The iExaminer ophthalmoscope is able to capture the retinal images with field of view 25° (FOV) without dilating the pupil using 6 series of iPhone 6, 6S and 6 plus. The system cost is 1000€ excluding the cost of smartphones [3].

D) CellScope Retina:

It is a portable easy to use smartphone-based retinal camera. It enables fully integrated wide-field retinal imaging. It is light weighs approximately 310g. It consists of a smartphone with inbuilt camera and optics lens for capturing retina images. Optics are housed in three-dimensional (3D)-printed plastic case [6]. To illuminate retina and minimize unwanted reflections, a polarizing wire grid beam splitter is used. A 54-diopter ophthalmic lens is used. The drawback is that artefact present in the final image [3] and it's a mydriatic device that requires dilated pupils. This is time-consuming and uncomfortable for patients.

E) Peek:

Peek is acronym of Portable Eye Examination Kit. Peek Vision come up with this smartphone-based eye examination kit. It helps the health worker to carry out eye examination anywhere in the world. It consists of a unique clip-on camera adapter and apps. Clip-on camera helps to test vision and apps enable images to be stored and shared. It allows the capturing of 30° FOV. The cost of peek retina model is £180. Smartphone based ophthalmoscope that enables retina imaging through a dilated pupil.

F) JaizRetiCAM Plus based fundus camera is having a metallic tube. The one end of metallic tube is connected with 20D lens and the other end attached with silicone case, the iPhone is connected with this silicone case [3]. The cost of JaizRetiCam plus smartphone 20,000 Rs excluding cost of Smartphone. The quality of the image depends on the quality of Smartphone camera. This device use VOLK 20D as a condensing lens. 20D lens is not a part product. This type required fully dilated pupil for retinal imaging. Quality of image also depends on the extent of pupil dilation [6].

G) D-Eye: It is a digital retinal camera. It works on the principal of direct ophthalmoscopy. Optical device attached magnetically to a smartphone. It is optical device attached to the smartphone magnetically. To eliminate corneal purkinje reflections the cross-polarization design is used. D-Eye captures the images with a field-of-view up to 20°. D-Eye is compatible with Samsung Galaxy S series such as S4 and Galaxy S5 and Apple iPhone series such as 5, iPhone 5s and iPhone 6. The D-Eye module is a small, portable module with gives good retinal imaging at clinical resolution. The price of D-Eye would be approximately \$400[3]. D-Eye is a Smartphone based direct ophthalmoscope. It proved to be handheld and convenient to use regardless of patients position whether the patient was standing, sitting, or lying down [4].

Table 2. Comparison of Portable smartphone-based fundus camera for Diabetic Retinopathy Screening

Device Technology /	Company Developer /	Nonmydriatic	Price	Required devices/ software	Image recorded
Smartphone and Lens	Multiple	No	\$ 500	20D lens, Filmic Pro App	No
oDocs Fundus	ODOCS eyecare	Yes	\$ 165	iPhone and Android smartphones	Yes
iExaminer	Welch-Allyn	No	1000€	iPhone 6,6S and 6 Plus	Yes
CellScope Retina	UC Berkeley	No	N/A	iPhone	Yes
Portable Eye Examination Kit (PEEK)	PEEK collaboration	Yes	£199.94	iPhone	Yes
JaizRetiCAM Plus	Jaiz- ARIS	Yes	\$281	iPhone "Ullman Indirect App"	Yes
D-Eye Portable Retinal Imaging System	D-Eye	Yes	\$435.00	iPhone 6/7/8	Yes

V. Conclusion

Fundus on phone plays an important role as medical diagnostic tools. Smartphone is a better option as it is portable, large storage capacity, security and wireless connectivity. A mobile phone-based retinal camera could soon play an important role in operation theaters or immobilized patients or children. As compared to the traditional fundus camera, Smartphone based fundus camera are becoming affordable and more reliable. By using such type of modalities, Early detection of Diabetic Retinopathy is possible. This will prevent the diabetic patients to become blind. Now a days, newer smartphones with high resolution cameras with sensors are incorporated to improve the quality of the images.

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