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Fundus Abnormalities and Image Acquisition Techniques – A Survey

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ABSTRACT

Fundus imaging is a crucial measure of an ophthalmic practice. It documents the retina of the eye, the neurosensory nerve which transforms the visually capturing images into the electrical impulses, our brain understands. Fundus imaging is performed with retina which can be snapped straightforwardly as the pupil, which is used both as an entry and departure for the fundus camera's imaging light rays. Fundus imaging plays an important role to analyze and understand the medical position of human eye; it helps to diagnose the major fundus abnormalities such as Glaucoma, Diabetic Retinopathy (DR) and Age-related Macular Degeneration (AMD). The primary purpose of the paper is to offer the information concerning fundus Abnormalities, fine- quality fundus image capturing devices and also offer the list of the current data base available for experimentation in an efficient method.

KEY WORDS: Fundus Image, Retina, Glaucoma, Diabetic Retinopathy, Optic disc, Segmentation, Fundus Camera.

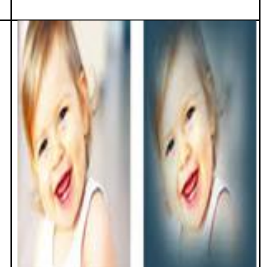
1. INTRODUCTION

The interior potion of eye, opposite to the lens is fundus; it can be noticed through the pupil. It consists of retina, cones, rods, optic disc, fovea, macula, blood vessels and posterior pole. Retina is the tissue contains ten retinal layers, where image is anticipated. Cones and rods are light sensitive cells, which is in charge of day time vision and night time vision, respectively. The optic nerve passes the information of the anticipated image from retina to brain. The head of the optic nerve is called optic disk which does not have blood vessels and is thus the blind spot of an eye. An oval spot close to the center of retina with diameter of approximately 1.5mm called macula. The fovea is located very close to the core of macula and it contains packed cone cells. Due to elevated quantity of light sensitive cells, the fovea is highly responsible for the most perfect vision. Images of fundus helps in diagnose many diseases including various retinopathies, ophthalmic pathologies, glaucoma, and general diseases including diabetes, hypertension or arteriosclerosis (Ho, 2003).

2. MATERIALS AND METHODS

Fundus Abnormalities are of many types, there are 56 common disorders and the researchers predicted the frequency of fundus disease will double over next decade. This section briefly establishes causes, symptoms, prevention methods for the major fundus abnormalities. The abnormalities and comparison of normal vision with various disease affected vision images are shown in Table.1.

Table.1. Fundus abnormalities and comparison of normal and affected image

Disease	Description	Risk Factor	Implications	Types	Treatment & Prevention	Comparison Image
Diabetic Retinopathy	Affects the Blood vessel and bleeds inside the eye	People with Diabetes (22% over 55)	Blurred, foggy or double vision, poor vision in low light, sensitivity in glare and light	Proliferative and Non-Proliferative Retinopathy	Premature diagnosis and treatment, Fine control of blood pressure, sugar level and cholesterol, Laser surgery	
Glaucoma	Affects the optic due to the pressure inside eye	Glaucoma, Diabetes, eye wound, apnea, migraine cataracts (8% over 40)	No symptoms in early stages, and occasional blurred vision	Open angle (common and painless), angle-closure (pain and redness)	Medication, Laser surgery, Eye drops	

AMD	Chronic degenerative condition, affects the inner vision	Ageing, Smoking, Family History (5% over 40)	Difficulty in distinguishing people faces and difficulty in reading books	Wet AMD, DRY AMD	Premature detection, laser surgery, photodynamic therapy, intra viral injection, control smoking, usual eye checkup	
Cataract	Cloudy lens inside eye	Exposure of UV light, Ageing, Long usage of corticosteroid, Smoking, Diabetes (33% over 55 age)	Blurred vision, blunted color vision, dual vision around lights	sub capsular cataract, nuclear cataract, cortical cataract	Surgery, magnifying lenses, eye glasses	
Refractive error	Disorder of eye	Family history, vitamin deficiency (43% of all age groups)	Implications based on severity	Long-Sightedness (hyperopia), Short-sightedness (myopia), astigmatism, presbyopia	Glasses, contact lens, surgery	

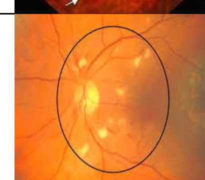
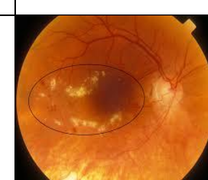
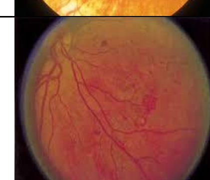
Segmentation of fundus abnormalities:

Blood vessel related abnormalities: The major blood vessel related abnormalities that can be perceived from examination of fundus include Micro aneurysms, Hemorrhages, Hard Exudates, Soft Exudates, and Neovascularization. Micro aneurysms are the lesions (Jack, 2003) that can be perceived at the early stages medically, the local extension of retina capillary and the outpunching of capillary walls observed as small dots which are tiny in size and round in shape. Micro aneurysms images are minor areas of balloon-like puffiness in the blood vessels and it is difficult in differentiate with further abnormality like hemorrhages, due to its tiny size and red color. Micro aneurysms are not fundamentally permanent; they come into the view for certain period of time and fade away. Hemorrhages are red, dot-blot or flame shaped regions, appears when micro aneurysms or capillaries break and blood leak out of the vessels. The red small spot sign is helped to envelop both small dot hemorrhages and micro aneurysms. Hard exudates lesions are yellow spots spotted in retina generally in the posterior pole near macula frequently seem in clusters or dirt-rings and are collected lipid break-down products from damaged blood vessels. Soft exudates lesions are cotton wool spots or micro-infarctions come into view when terminal retinal arterioles are obstructed, (Lars, 2000). It is small in size apparent white, light yellow-white or dull white with feathery boundaries, often showing striations parallel to the nerve fiber layer are the lesions included. Soft exudates are not that much noticeable like hard exudates. Neovascularization is the foundation of functional micro vascular networks where new blood vessels appear in the choroid of eye, it differs from angiogenesis in that angiogenesis is basically categorized by protrusion, extension of capillary buds and sprouts from pre-existing blood vessels. It is the utmost serious abnormality kind in diabetic retinopathy since numerous flow of blood may turn out loss of vision. (Daniel, 1992)

Retinal Pigment Epithelial (RPE) related Abnormalities: The leading retinal pigment epithelial related abnormalities include hypertrophy and drusen. Auto fluorescent substances are present in the retinal pigment epithelium (RPE), the pigmented cell layer of the retina is just outside the neurosensory retina that strengthens retinal visual cells, and is inflexibly enclosed to the underlying choroid and overlying retinal visual cells. (Cassin, 2001), (Boyer, 2000) Areas of retinal pigment epithelial (RPE) hypertrophy normally do not causes any kind of symptoms. They are naturally found in routine eye examinations. They may be fenced by a less pigmented tissue or reveal a sharp demarcation line. Drusen are the lumps, small yellow or white in color gathering of extracellular material build up between Bruch's membrane and the retinal pigment epithelium of the eye. Drusen is connected with Age macular de-generation (AMD), but it is totally different from another clinical entity, optic disc drusen is present on the optic nerve head (Davis, 2003) clinically, age-related drusen is classified into hard or soft exudates. If the drusen size is fewer than 63 µm in diameter is said to be hard drusen and if the drusen size is greater than 63µm then it is classified as soft drusen. The width of the average retinal vein as it crosses optic disc edge is considered to be 125µm.

Choroid related Abnormalities: Choroid is the pigmented, highly vascular cover of eye, having connective tissue, and lying between the retina and the sclera. It is densest at the remote extreme end of the eye (at 0.2 mm); though in the remote areas it restricts to 0.1 mm. It nourishes retina and to adjust retinal heat, to help in the control of intra-ocular pressure and the pigment absorbs extra light so evading reflection. Major Choroid related Abnormalities are Melanoma and uveitis. Choroidal melanoma pigment is due to naturally occurring melanin that comes from melanocyte cells in the choroidal layer. Choroidal melanoma is the greatest common major intra-ocular malignant tumor and second maximum common site of ten malignant melanoma sites in the body (Albert, 1994). Uveitis is an intra-ocular inflammation that involves the iris (iritis), frontal part of the ciliary body (anterior cyclitis), or both (iridocyclitis). Primary site of infection, as determined clinically, is the anterior chamber and/or anterior vitreous (Jabs, 2005). Uveitis often affects a portion of the eye called uvea. It also affects the retina, optic nerve, lens and vitreous, producing reduced vision or blindness.The various abnormal lesion categories, symptoms and the affected image are listed in Table.2.

Table.2. Abnormal lesion categories

Lesion type	Physiognomies	Signs	Caused by	Affected Image
Micro aneurysm	Color - Dark red Size - very small (single to multiple Micro aneurysm) Shape - round in shape	Swelling or tiny aneurysm in the side of retinal blood vessels and sometimes found in retina of the eye	People with Diabetes	
Hemorrhage	Color – Red Size – Dot-plot (small to large) Shape - Flame- shaped regions	Abnormal Blood leaks out of the blood vessel in the retina, and the membrane in the inner side of the eye.	Ruptured of permeable capillaries, Diabetes	
Hard exudates	Color - Yellow waxy, shiny, or glistening Size - Small to medium Shape - No any regular Clear edges	Lipid residues of serous leakage from damaged capillaries. It caused by the breakdown of the blood-retina barrier	Diabetic Retinopathy	
Soft exudates	Color - Pale yellow-white or grayish-white Size - Small to medium Shape - Oval shaped dim edges	(Micro infarcts), a dead tissue caused by a loss of blood flow	Hypertensive Retinopathy and Diabetic Retinopathy	
Neo vascular	Color – Red Size – Varies from small to large Shape – Irregular	New Blood vessel formation especially in abnormal tissue	Diabetic Retinopathy	
Hypertrophy	Color - jet-black to gray Size - varies Shape - flat, with a halo around its edges	These tumors are more commonly found in the peripheral retina where thickness is more difficult to judge by ophthalmoscopy	Age-related macular degeneration	

Drusen	Color – Yellow Size - Varies Shape - Round	Yellow dots deposit underneath the retina	Age-related macular degeneration	
Malanoma	Color - grey-white Size - varies Shape - dome or mushroom	Cloudiness in lens.	Glaucoma	
Uveitis	Color – red Size - varies Shape – varies	Intra-ocular inflammation of uvea(The uvea includes the iris,choroid, and the ciliary body)	Glaucoma, Cataracts	

Acquisition of fine-quality fundus images: The acquisition of fine-quality fundus images for experimentation purpose can be done in two ways as follows:

Online fundus image database: Enormous amount of retinal online fundus image database is obtained nowadays, some of the database sources are offering freely for research purposes are shown in Table.3.

High-Resolution Fundus (HRF) Image Database: The High Resolution Fundus Image public database contains three groups of images: 15 images of healthy patients, 15 images of patients affected by diabetic retinopathy and 15 images are of glaucomatous patients. This dataset help the researchers to make comparative studies on automatic segmentation algorithms on retinal images. The dataset can be downloaded from available online public websites (Al-Diri, 2009). The dataset images are captured with 18 image pairs of the same eye from 18 human subjects by Canon CR-1 fundus camera with the Field Of View (FOV) of 45°. The size of the image is 3504 x 2336 pixels and entire images are 24-bits per pixel and are stored in JPEG format. The masks determining the field of view are offered for particular datasets.

Method to evaluate segmentation and indexing techniques in the field of retinal ophthalmology (MESSIDOR): The Messidor public dataset contains 1200 eye fundus color numerical images (800 images are by pupil dilation and 400 images are without dilation) and these images were packed in 3 sets, one per ophthalmologic department. Each set is partitioned into 4 subsets contains each 100 images are in TIFF format plus an Excel file with medical diagnosis for all images. The images are captured using 8 bits per color plane at 1440 x 960, 2240 x1488 or 2304 x 1536 pixels.

An online retinal fundus image database for glaucoma analysis and research (ORIGA): ORIGA (-light) database involves clinical ground truth retinal images to share with the public mainly for the detection of disease related with glaucoma. In-house image segmentation and grading tool is developed to facilitate the construction of ORIGA (-light). A benchmarking method is projected, concentrating on optic disc, optic cup segmentation and Cup-to-Disc Ratio (CDR). Presently, ORIGA (-light) contains 650 fundus images (168 glaucoma images and 482 non-glaucoma images) annotated by trained professionals from Singapore eye research institute with high pixel quality (Zhang, 2010).

Standard Diabetic Retinopathy Database Calibration level 0 (DIARETDB0): The DIARETDB0 database contains 130 fundus images (20 normal images and 110 abnormal images contain signs of micro aneurysms, hemorrhages, hard exudates, soft exudates, and neovascularization). The database images are captured with 50° FOV digital fundus camera with indefinite camera settings. This database is otherwise called as calibration level 0 fundus images.

Standard Diabetic Retinopathy Database Calibration level 1 (DIARETDB1): The DIARETDB1database contains 89 color fundus images (5 normal images and 84 images of diabetic retinopathy). In this database images are captured using 50° FOV digital fundus camera with indefinite camera settings. This database is otherwise called as calibration level 1 fundus images.

Drions-DB: The database of DRIONS-DB consists of 110 color fundus images. The ophthalmology service at miguel servet university Hospital, Saragossa (Spain) collected 124 fundus images randomly from an eye fundus image database. The collected images are stored in a slide format, to make it into digital format they are digitized by high resolution scanner HP-PhotoSmart-S20. The images are captured in the resolution of 600x400 pixels and 8 bits/pixel.

Digital retinal analysis for vessel extraction (Drive): DRIVE is a database primarily created for segmenting the blood vessels in diabetic retinopathy retinal image screening in the Netherlands. It consists of 40 images as training data and 20 images as a data testing (Staal, 2004). The images are captured using Canon CR5 non-mydriatic 3CCD camera. The captured images enclosed in the dataset are essentially used for clinical diagnoses.

Structured analysis of the retina (STARE): STARE dataset totally offers 81 images comprising of 31 abnormal images and 50 normal retinal images which recommend some diseases of the retina, such as exudates and hemorrhages that occur in the ONH (Gold Baum, 2000). The analog data are captured by Topcon TRV-50 fundus camera with the degree of 35 FOV. The captured data are digitized to produce images with the resolution of 605×700 pixels and stored in 24-bits color space. All of these images were hand-labeled to produce ground truth vessels segmentation. Since the images are labeled by different dissimilar observers, different physical segmentations are available. STARE database is created to develop research related to the diagnosis automatically on human eye.

E-ophtha: e-ophtha is a retinal fundus image database especially designed for scientific study in diabetic retinopathy (DR). The database contains two sub databases named e-ophtha-MA (Micro aneurysms), and e-ophtha-EX (EXudates). A form with personal information needs to be completed to download the databases. Database of images with exudates contains 47 images and 35 images without lesion. Database of images with micro aneurysms contains 148 images of micro aneurysms or minor hemorrhages and 233 images without lesion.

Rim-one: RIM-ONE is a fundus image dataset mainly used for research activities related to glaucoma disease and focused on ONH segmentation, provided by different experts. It includes images of 118 healthy images, images of 12 early glaucoma images, images of 14 Moderate glaucoma images, images of 14 severe glaucoma images and images of 11 ocular hypertension(OHT) images. The database images were developed from three different private hospitals of Spain namely Hospital universitario de canarias, Hospital clinico sancarlos and Hospital universitario miguel servet. The foremost aim of the database is to design an automated software system that supports to glaucoma diagnosing (Fumero, 2011).

HEI-MED: The Hamilton eye institute macular edema dataset (HEI-MED) (formerly DMED) is a dataset consists of 169 fundus images. The collected images are used to diagnose exudates and diabetic macular edema. The images are collected and developed by Hamilton eye Institute, Image science and Machine vision group at ORNL with the collaboration of the universite de Bourgogne. In addition to the fundus images and the ground truth, the database provide other anonymous clinical metadata about the patients, the manually identified optic nerve location, the machine segmented vasculature and a Mat lab class to seamlessly access all the data and metadata without having to deal with the internal format of the files.

Vicavr: The VICAVR database presently comprises of 58 images. The images are captured by Topcon non-mydriatic camera NW-100 model with a resolution of 768x584. The database contains the quality of the blood vessel measured at different ranges from the optic disc and also the blood vessel type (artery/vein) categorized by three professionals.

Table.3. Online fundus image database

SNo	Database	Images	Pixel Size	Ground Truth
1	HRF	45	3504 x 2336	Blood Vessel
2	MESSIDOR	1200	1440 x 960, 1490 x 960, 2240 x 1488 or 2304 x1536	Retinopathy Grading
3	ORIGA	650	Varies	Optic Disc
4	DIARETDB0	130	Varies in size	Micro anerusym, Hemorrhages, Hard and Soft Exudates
5	DIARETDB1	89	Varies in size	Microanerusym, Hemorrages, Hard Exudates, and Soft Exudates
6	DRIONS-DB	110	600 x 400	Optic Nerve
7	DRIVE	40	565 x 584	Blood Vessel
8	STARE	81	605 x 700	Blood Vessel
9	E-OPHTHA	82 (e-ophtha-EX), 381 (e-ophtha-MA)	Varies	Micro anerusym, Hemorrhages
10	RIM-ONE	169	High resolution Images	Optic Nerve
11	HEI-MED	169	High resolution Images	Optic Nerve

12	VICAVR	58	768 x 584	For calculation of anterior vein ratio

3. RESULTS AND DISCUSSIONS

Fundus imaging plays an important role in an ophthalmic practice for diagnosis and sharing of fundus photography images for experimentation. It also helps for photo documentation and to identify intra-ocular pathologies. The first report of the use of the smartphones was in 2010 showed that these smart devices might be helpful for many clinical and educational tools, including capturing pictures of the eye like fundus image, slit-lamp photos, and external photos. (Lord, 2010) The acquisition of fine- quality images needs a mixture of suitable optics and perfect lighting, normally done with a contracting lens and coaxial light source (Bastawrous, 2012).

Image Transfer Device: The fundus camera images are moved to the smart phone and directed to another traditional workstation. The transfer of images to these devices is readily available through existing ophthalmic digital software. Then these images can be easily sent for remote workstation for consultation or on another smartphone. Fundus photo image estimation of diabetic retinopathy is presented to be alike when studied at a traditional workstation or on an iPhone (Apple, Cupertino, CA) (Kumar, 2012). All image acquisition and transmission must handle with more attention to the privacy of personal data in agreement with the Data Protection Act.

Digital camera: A digital camera is attached to fundus examination devices like ophthalmoscope or a slit lamp. Smartphone cameras are furnished with fine resolution video capabilities and high-megapixel images of 1,080 pixels. Fundus lens of 78 or 90D and a smartphone attached to the slit-lamp eyepiece are used to capture fundus image in ancient times. Even though the performance and the result were fruitful, the image acquisition was difficult and the captured images were of low quality, and image. This method is useful for anterior segment imaging, still for fundus imaging newer techniques for image acquisition are simpler and of higher quality (Figure.1) (Kumar, 2012) Smartphone adaptor method that aligns and attaches an iPhone to WelchAllyn's Panoptic Ophthalmoscope, to use the iPhone's camera to acquire the optic nerve and to capture images of the retina, in combination with i-Examiner App (Figure.2.) (WelchAllyn, 2015) This device can capture fundus images with 25 degree field of view without dilation of the pupil. Although fine quality images are acquired with this device, particularly the optic nerve, fundus imaging is limited by the narrow field of view.

Several slit-lamp adaptors are produced for fundus imaging with smartphones simplifies add-on of the phone to existing slit lamps and align the smartphone camera with the ophthalmic of the slit lamp. The images are focused and acquired through the smartphones built-in camera apps and optical lens. Some of the adaptors include Zarf's (Spokane, WA) iPhone adapter, Eye Photo Doc (Fullerton, CA), and Keeler's (Broomall, PA) Portable Slit Lamp iPhone 4 image adapters are mainly designed for anterior-segmentation of the image. The use of these adaptors for slit-lamp smartphone fundus imaging is successful; however, the image quality has been poor due to difficulty with illumination and optics through the 78- or 90-D lenses on the slit-lamp.

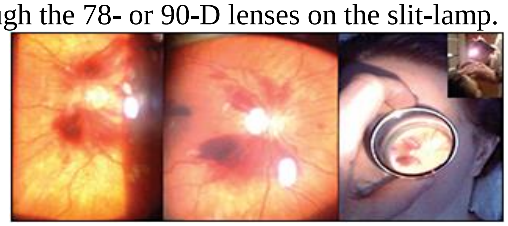


Figure.1. iPhone fundus images of right and left eye taken through a slit-lamp with 78-D lens.

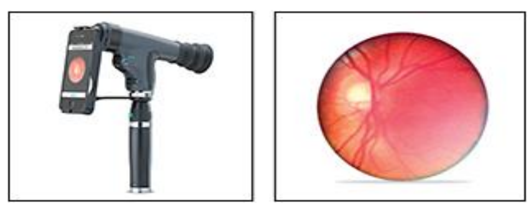


Figure.2. Panoptic ophthalmoscope with iPhone (left). Optic nerve cupping image obtained with iExaminer (right)

Camera with hardware attachment: Hardware attachments for smartphone fundoscopy have been developed with built-in optical devices to image the fundus without any external equipment. An adapter which is a less expensive alternative to a direct ophthalmoscope and can acquire fine-quality fundus images using Samsung (Ridgefield Park, NJ) Galaxy S III smartphone, it captures the fundus image, including the optic nerve (Giardini, 2014). D-Eye adapter which magnetically attaches with the smartphone to capture fundus images of an approximately 200º FOV (Figure.3.) Using images captured with the device attached they showed substantial conformity in rating the level of diabetic retinopathy between the smartphone fundoscopy and slit-lamp fundus examination by masked examiners. (Russo, 2015)

Camera without hardware attachment: Traditional fundus cameras are very costly and have difficulties with compatibility, transportability and accessibility, and. In contrast, smartphones are relatively inexpensive, readily available, easy to operate, and compatible across various platforms and systems, making them ideal for use in remote areas of the world also. A method of fundoscopy over indirect ophthalmoscopy using smartphone camera and video abilities, an economical app that is freely accessible in an ophthalmic practice, such as a 20 D lens. This method cracks the iPhone into an indirect ophthalmoscope, by means of coaxial light source of smartphones flash to acquire fundus images through video recording. For this technique, a light source, a video app, a still image extraction app, and a lens for retinal examination (20 D or 28 D) are needed. Fundus images are taken in the video mode for easy acquisition. The Filmic Pro app (Cinegenix LLC, Seattle, WA) was created to provide control of focus, exposure and light intensity which are required to get fine-quality fundus images with this method. Fine-quality images are then removed from the videos using the apps, such as movie to image (Dream Online, Inc., Tokyo, Japan) or Video 2 Photo (PacoLabs, Paris, France). Fine-quality fundus images can be attained with this easy, efficient and economical technique (Figure.4). In this technique a 3-dimensional printed lens holder attachment is used for the iPhone to capture the image.

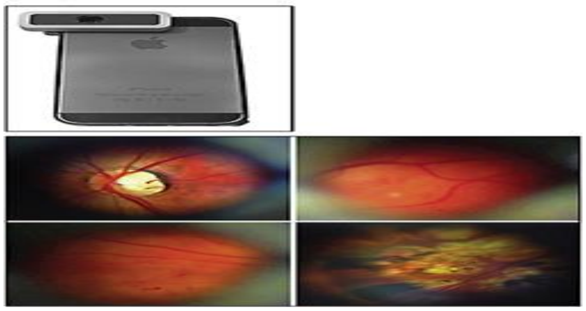


Figure.3. D-Eye attached to the smartphone.(Top image) diabetic retinopathy taken with D-Eye.(Top left) Optic disc with no noticeable diabetic retinopathy. (Top right) Mild nonproliferative diabetic retinopathy. (Bottom left) Moderate nonproliferative diabetic retinopathy. (Bottom right).

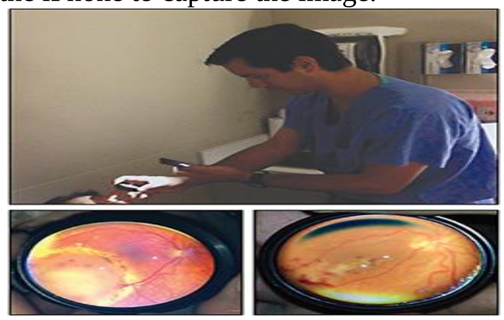


Figure.4. User holding iPhone for filming with the Filmic Pro app in one hand and a 20-D lens for focus in other hand.(Top image) retinoblastoma imaged during examination under anesthesia. (Bottom left) retinal vasculitis imaged in an emergency department setting.(Bottom right)

4. CONCLUSION

The smart phone fundoscopy can be attained with multiple techniques. Newer smart phones are capable of capturing excellent fine-quality images with and without hardware attachments. Simpler techniques, such as that described by Haddock (Myung, 2015) only requires an android smart phone and a lens without any additional hardware, making it ideal for rural settings or poor resource areas. Other techniques require hardware attachments that, when readily available, make the technique easier to master and that may improve image quality. The existing works on smart phone funduscopy recommends that the limits and applications of the method lie in the quality of image and field of view, and also universalizing its accessibility on all kinds of smart phones, including iOS, Android, Windows (Microsoft, Redmond, WA), and other new operating systems. Additional validation studies will be needed to integrate this technology or equipment into daily practice.

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