

Fundus Photography in the 21st Century—A Review of Recent Technological Advances and Their Implications for Worldwide Healthcare

Nishtha Panwar, MTech,¹ Philemon Huang, MMed,²
Jiaying Lee, MBBS,² Pearse A. Keane, FRCOphth,^{3,4}
Tjin Swee Chuan, PhD,¹ Ashutosh Richhariya, PhD,⁵
Stephen Teoh,² Tock Han Lim,² and Rupesh Agrawal, FRCS²⁻⁴

¹School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.

²National Healthcare Group Eye Institute, Tan Tock Seng Hospital, Singapore.

³NIHR Biomedical Research Centre, Moorfields Eye Hospital NHS Foundation Trust, London, United Kingdom.

⁴Institute of Ophthalmology, University College London, London, United Kingdom.

⁵Institute of Translational Research, Engineering, and Advancement of Technology, L.V. Prasad Eye Institute, Hyderabad, India.

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Abstract

Background: The introduction of fundus photography has impacted retinal imaging and retinal screening programs significantly. **Literature Review:** Fundus cameras play a vital role in addressing the cause of preventive blindness. More attention is being turned to developing countries, where infrastructure and access to healthcare are limited. One of the major limitations for tele-ophthalmology is restricted access to the office-based fundus camera. **Results:** Recent advances in access to telecommunications coupled with introduction of portable cameras and smartphone-based fundus imaging systems have resulted in an exponential surge in available technologies for portable fundus photography. Retinal cameras in the near future would have to cater to these needs by featuring a low-cost, portable design with automated controls and digitalized images with Web-based transfer. **Conclusions:** In this review, we aim to highlight the advances of fundus photography for retinal screening as well as discuss the advantages, disadvantages, and implications of the various technologies that are currently available.

Key words: fundus camera, retinal photography, ophthalmic screening, tele-ophthalmology, portable camera system,

smartphone-based camera system, portable eye examination kit, slit-lamp adaptors

Introduction

Jackman and Webster¹ first published photographs of the retina in 1886. The next breakthrough was the first commercially available fundus camera produced by Carl Zeiss in 1926, following which considerable improvements to the field of view (FoV) were made.² In 1927, Metzger published stereoscopic fundus photographs taken with the method of side-to-side shifting, as reported by Donaldson.³ The invention of the electronic flash tube enabled light to be directed through the pupil, and Hansell and Beeson⁴ successfully attached it to the camera in 1953. A groundbreaking 148° FoV camera emerged in 1960 (the Pomerantzeff Equator-Plus fundus camera), and nerve fiber layer photography using the traditional camera by Carl Zeiss was first reported by Behrendt and Wilson⁵ in 1965. As reported by Dobbins,⁶ Steven Sasson invented the first digital camera at Eastman Kodak in 1975, and the subsequent shift from analog to digital revolutionized medical record keeping. In recent years, confocal scanning laser ophthalmoscopy has emerged as a solution to minimize aberrations through poor dilation and to produce high-contrast, detailed images.⁷ Through the years, camera systems have evolved to boast sharper images, nonmydriatic wide-field options, pupil tracking, and, most recently, portability. Popular manufacturers in the market today are Topcon, Zeiss, Canon, Nidek, Kowa, CSO, and CenterVue.

Traditional fundus cameras offer good-quality images but are bulky, office based, technician dependent, and costly. Besides access to the retinal imaging device, affordability is of paramount importance in screening programs, especially in the remotest of places. Recently, there have been significant technological advances that have radicalized retinal photography. Improvements in telecommunications and smartphones are two remarkable breakthroughs that have made ophthalmic screening in remote areas a realizable possibility (Fig. 1).

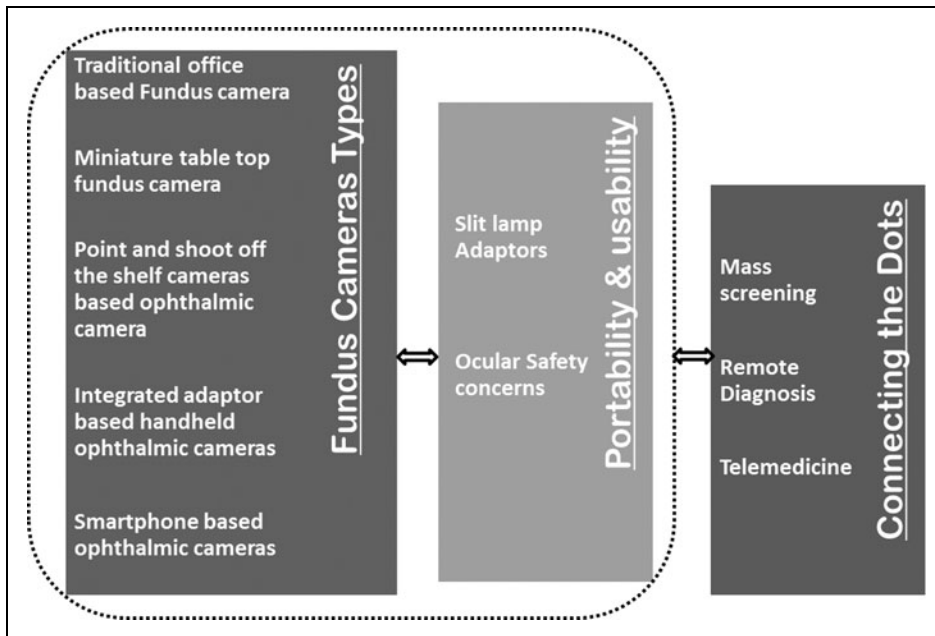


Fig. 1. Flowchart depicting evolution and scope of retinal screening and fundus photography.

According to World Health Organization statistics, the number of people with visual morbidity worldwide, as of 2010, was in excess of 285 million, of which 39 million were blind.⁸ The advances in fundus imaging will hopefully decrease preventable visual morbidity by allowing easy and timely fundus screening. This review attempts to summarize the evolutionary journey from traditional fundus cameras to the newest models in retinal photography. Most of these models, each with their image-forming parameters, are covered in the following sections, with technical specifications listed in *Table 1*.

Method of Literature Search

A comprehensive Medline and Scopus search was conducted initially using the following key words: “retinal imaging,” “fundus camera,” “ophthalmoscope,” “miniature,” “handheld,” “telemedicine,” and “smartphone fundus camera.” The original relevant articles were retrieved and evaluated. Also, because the review focuses on latest technological advancements in fundus imaging, search engines like Google and Bing were prompted for these key words. The information about commercial products was obtained from the online articles and Web pages of the respective companies, and major statistics reports were sought from the official database available on the World Health Organization Web site.⁸ The review relied primarily on articles written in English.

Traditional Fundus Camera

The design of the traditional fundus camera system is based on monocular indirect ophthalmoscopy.⁹ A common design by Knoll⁹ and others¹⁰ can be considered as a reference layout for a traditional table-top fundus camera. It consists of a sequence of optic components including objective and condensing lenses, beam splitters, mirrors, masks, diffusers, and polarizers, which altogether direct the illuminating light through the pupil of the eye, collecting light reflected from the retinal surface and relaying it to imaging optics forming an image of the retina on the detector screen.¹¹ Advanced versions of these systems are equipped with additional features like automated analysis and algorithms. Filters can be applied to camera systems for autofluorescence,

fundus fluorescein angiography, and indocyanine green angiography.¹²

LIMITATIONS OF TRADITIONAL FUNDUS CAMERAS

The need for a miniature fundus camera device has emerged from specific limitations that accompany the use of traditional table-top fundus cameras. First, they form a bulky system, incorporating a host of optical and mechanical components, and the alignment of every part with respect to another is a critical parameter for good-quality images. Second, the operation of such a sophisticated system requires skilled personnel. Third, the bulkiness and complexity of the instrument restrict its use only in high-end clinical settings, such that it is difficult to be accessible in remote rural settings. Fourth, the number of optical components and add-on features in more recent devices renders the cost of the cameras exorbitantly high for them to be installed in rural locales where much of the population is subjected to ailments amounting to visual morbidity.

Modern Table-Top Fundus Cameras

Advancements in the field of optical sources and detectors have led to miniaturization of optical assemblies at a lower cost. In line with these developments, miniature table-top fundus camera system designs have emerged that provide retinal images comparable to those of traditional fundus cameras.

ICAM

The iCam is a 4.5-kg table-top fundus camera designed by Optovue, Inc. (Fremont, CA).¹³ A near-infrared light-emitting diode (LED) provides illumination during alignment of the patient's eye, and the white LED is used for image capture. This allows for a smaller machine design, longer life expectancy, and less heat emission compared with the typical xenon flash lamp. LEDs maintain light characteristics such as color temperature, lumens of output, and distribution of light, which allows a controlled and reproducible illumination unit. The pupil is manually aligned using the split-image technique in the direction of each of the targets such that images of different regions of the retina are acquired. Computer interfacing is used for viewing images. *Figure 2* is an illustrative representation of the basic design methodology behind the iCam. iFusion is a combination of a nonmydriatic fundus camera (iCam) and spectral-domain optical coherence tomography (iVue).¹⁴

3NETHRA

3nethra is a portable, integrated table-top fundus camera designed and developed by Forus Inc. (Bengaluru, India).¹⁵ 3nethra Classic is the basic version, and 3nethra Royal incorporates an additional automated refractometer. Low-power LED light is used for image capture and can image both posterior and anterior segments. It has focus guidance, and images are viewed with a laptop computer. 3nethra intelligently uses a digital Web-based telemedicine feature to transmit images over to mobile phones and via e-mails, and the device is targeted at primary healthcare population eye screening.

DIGITAL RETINOGRAPHY SYSTEM

Designed by CenterVue (Padova, Italy), the digital retinography system (dRS) is also a nonmydriatic miniature table-top fundus camera¹⁶ requiring a pupil size of 4 mm. Marketed as being compact (19 kg), it has a built-in screen featuring patient autosensing, autoalignment, and autofocus, and usage requires minimal operator skill. The illumination schematic is presented in *Figure 3*.

EASYSCAN

EasyScan is an 11-kg retinal imaging system developed by iOptics (Den Haag, The Netherlands),¹⁷ which works on the principle of scanning laser ophthalmoscopy¹⁸ and boasts high-resolution images up to the sixth bifurcation. There are three capture modes: green (532 nm), near-infrared (785 nm), and combined (pseudo-color). It is fully automated with iris detection, autofocus, autocapture, and auto-exposure. No external power source is required, and the images are viewed on a computer screen connected to the device for uploading.

TRC-NW8FPLUS

The nonmydriatic retinal camera developed by Topcon (Tokyo, Japan)¹⁹ has the feature of autofocus, which helps in image acquisition in difficult conditions like excess accommodation, and has the option of autoshoot, which helps in quicker capture, which is beneficial in cases of eyes with poor or variable fixation. High-resolution images are acquired with the help of a true red-free filter, which is replaceable to acquire the color images with a 45° angle of coverage. Good-quality images can be taken with lower flash intensities, and stereophotography is also possible.

VISUCAM 200

This nonmydriatic fundus camera from Zeiss (Oberkochen, Germany) has the optional feature of macular pigment optical density assessments for age-related macular degeneration. Weighing 30 kg, VISUCAM 200 comes with a pupil size marker and positional aid along with the autofocus and autoflash options.²⁰ Wide-field imaging generates an auto-montage for panoramic retinal views. Images can be transferred via through a network for comprehensive report management by Zeiss Systems.

NONMYD7

The fourth-generation nonmydriatic fundus camera from Kowa (Torrance, CA), Nonmyd7 is provided with a special feature that allows magnification over 20° FoV to image the optic nerve head.²¹ Small pupil mode can be activated, and the software montage function can create mosaics using the four fixed dots switching-type internal fixation targets. The images are uploaded to Kowa's VK-2 digital imaging software.

CANON CR-2

The CR-2 non-mydriatic digital retinal camera from Canon (Tokyo) uses low-power LEDs for illumination and photography.²² It has autofocus, autofundus, and autocapture modes and a digital filter processor. It provides 45° and 35° viewing angles in small pupil mode (pupil size, 3.3 mm). The CR-2 PLUS AF has an additional fundus autofluorescence imaging modality for undilated pupils.

OCULUS IMAGECAM 2 DIGITAL SLIT LAMP CAMERA

Different segments of the eye, such as anterior segment, fundus, sclera, etc., can be conveniently imaged by setting suitable exposure time, light magnification, and white balance.²³ Additional video sequences can be recorded by the high-resolution, digital video camera in the beam path of the slit lamp.

Table 1. Technical Specifications of Fundus Cameras Under Different Categories

CATEGORY, NAME	DESIGN PRINCIPLE	PUPIL	FIELD OF VIEW	FOCUSING RANGE	FIXATION TARGETS	IMAGE SENSOR/ DISPLAY	ADDITIONAL FEATURES
Miniature table-top design							
iCam ¹³	Reflective imaging using white light	Nonmydriatic	45°	Manual, -35D to 30D	7	12-bit CCD, 5.2 MP, computer interface	Multiple image views, image sharpening, color, post-processing for red-free images
3nethra (Classic and Royal) ¹⁵	Reflective imaging using white light	Nonmydriatic	45°	Adjustable, -18D to +18D Sph and -8D to +8D Cyl (Royal)	Not specified	3 MP, computer interface	Corneal imaging, color, red-free images
dRS ¹⁶	Reflective imaging using white light	Nonmydriatic	45° H 40° V	Autofocus, -15D to +15D	7	5 MP, 10.4-inch touchscreen color display; WiFi and Ethernet connected	Multiple field acquisition, color, red-free, stereo pair images
EasyScan ¹⁷	Confocal SLO, with green, NIR	Nonmydriatic	60° H 45° V	Autofocus	Not specified	Photodetector-based computer interface; network connectivity	Enhanced view of periphery, better resolution, automated iris detection, pseudo-color
Topcon TRC-NW8Fplus ¹⁹	Reflective imaging using white light	Nonmydriatic	45°	Autofocus, -13D to 12D (without lens correction)	Internal/external fixation target (can be selected)	8 MP digital SRL camera	Stereo photography, color, red-free images, fluorescein angiography
Zeiss VISUCAM 200 ²⁰	Reflective imaging using white light	Nonmydriatic	45° and 30°	Autofocus -35D to +35D	Internal/external fixation target (can be selected)	CCD 5.0 MP, 19-inch TFT	Color, red-free images, blue and red autofluorescence, anterior segment imaging, stereo image mode
Kowa Nonmyd ⁷²¹	Reflective imaging using white light	Nonmydriatic	45°	Not specified	Not specified	12 MP digital camera	Optic nerve head color, red-free images, pseudo-3D display
Canon CR-2 ²²	Reflective imaging using white light	Nonmydriatic	45°	Autofocus	Internal and external	18 MP EOS digital camera	Cobalt- and red-free imaging
OCULUS Image-Cam 2 digital slit lamp camera ²³	Slit lamp-based	Not specified	Not specified	Not specified	Not specified	2 MP resolution	Viewer software for anterior segment, fundus, sclera, etc., with USB interface
California ultra-widefield retinal imaging ²⁴	Reflective imaging using multiple wavelengths	Nonmydriatic	200°	Not specified	Not specified	Not specified	Composite color, red-free, autofluorescence, fluorescein angiography, indocyanine green angiography
Point-and-shoot off-the-shelf digital camera-based ¹¹	Conventional optics+ camera lens	Mydriatic	50°	Manual	No	Camera CMOS sensor	-

continued →

Table 1. Technical Specifications of Fundus Cameras Under Different Categories *continued*

CATEGORY, NAME	DESIGN PRINCIPLE	PUPIL	FIELD OF VIEW	FOCUSING RANGE	FIXATION TARGETS	IMAGE SENSOR/ DISPLAY	ADDITIONAL FEATURES
Integrated adaptor-detector-based (hand-held)							
iExaminer ³⁵ + PanOptic ophthalmoscope ²⁵	iPhone + PanOptic ophthalmoscope	Nonmydriatic	25°	-20D to +20D	No	iPhone 4S camera	Color, corneal imaging, cobalt blue filter
Volk Pictor ²⁶	Reflective imaging using white light	Nonmydriatic	40°	-20D to +20D	9	5 MP, TFT LCD detector, WiFi/USB connectivity	Color, corneal imaging
VersaCam ²⁷	Reflective imaging using white light	Nonmydriatic	40°	-20D to +20D	Not specified	2 MP camera, 3.5-inch color LCD	Color imaging
JedMed Horus Scope ²⁸	Reflective imaging	Nonmydriatic	Not specified	5-30 mm	Not specified	2 MP HD camera, 3.5-inch color LCD, PC connectivity through USB	Color imaging, general examinations for ear, nose, and throat and women's health
Optomed Smart-scope ²⁹	Conventional optics	Nonmydriatic	40°	-20D to +20D	Not specified	5 MP CMOS image sensor, 2.4-inch TFT LCD detector, PC connectivity through USB	Anterior eye module, otoscope, dermatoscope
Kowa Genesis-D ³⁰	Conventional optics	Mydriatic	Not specified	Not specified	Not specified	2 MP digital camera, 2.5-inch TFT LCD display	—
Riester ri-screen multifunctional digital camera system ³¹	Slit lamp-based	Nonmydriatic	25° or 40°	25° or 40°	Not specified	3.5-inch full HD full color TFT-LCD display	Additional modules for otoscopy and dermatoscopy
Smartphone-based (hand-held)							
Ocular Cellscope ³³	iPhone + conventional optics	Not specified	55°	Autofocus	No	iPhone	—
PEEK ³⁴	iPhone + external lens	Not specified	Not specified	Filmic Pro application	No	iPhone	—
Harvard Medical School prototype ³⁶	iPhone + external lens	Mydriatic	Not specified	Filmic Pro application	No	iPhone	—

3D, three-dimensional; CCD, charge-coupled device; Cyl, cylindrical; D, diopters; H, horizontal; HD, high-definition; LCD, liquid crystal display; MP, megapixels; NIR, near-infrared; PC, personal computer; PEEK, Portable Eye Examination Kit; SLO, scanning laser ophthalmoscopy; Sph, spherical; V, vertical; TFT, thin-film transistor.

CALIFORNIA ULTRA-WIDEFIELD RETINAL IMAGING

This recent mini-table-top version for retinal screening from Optos (Dunfermline, Scotland, United Kingdom)²⁴ offers an ultra-widefield that covers as wide as 200° or up to 82% of the retina capture in a single image. It includes an additional imaging modality: indocyanine green can be simultaneously captured with other imaging modalities through interweaved angiography.

LIMITATIONS OF MODERN TABLE-TOP FUNDUS CAMERAS

Most of the models have incorporated add-on features that contribute to additional size and weight of the camera.

Patients have to be seated upright for photographs to be taken. It is essentially an office-based procedure, hence warranting a visit to the clinic. The overall cost of most table-top models is high, and application in primary healthcare may be limited due to financial constraints. These factors limit their use to high-end speciality healthcare units.

Modified Hand-Held Fundus Cameras Using Off-the-Shelf Point-and-Shoot Cameras

Research groups have incorporated low-cost commercially available optics into digital cameras, depicted in *Figure 4*, for acquiring retinal images.¹¹ These prototype designs are light and

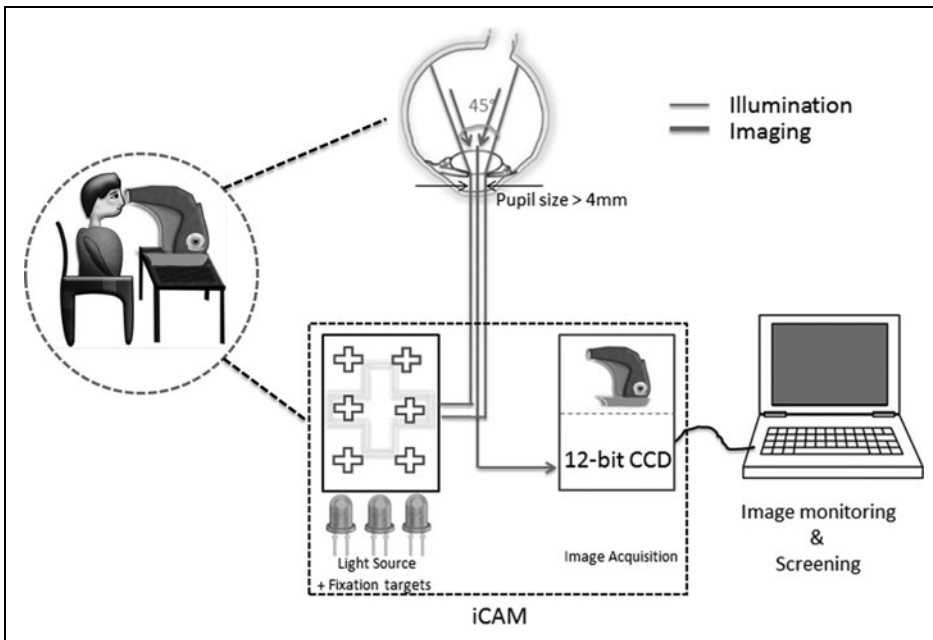


Fig. 2. Illustrative representation of the miniature table-top fundus camera iCam. The table-top device images the retina by light-emitting diode illumination covering different parts of the retina through fixation targets. CCD, charge-coupled device.

capable of acquiring quality fundus images. The light sources used for illumination are LEDs and the xenon flash lamp. The camera-based CMOS sensor with its automatic focus and exposure capabilities provides a 50° retinal FoV. The images produced by the prototype camera in the study were comparable to standard fundus cameras.¹¹

LIMITATIONS OF MODIFIED HAND-HELD FUNDUS CAMERAS USING DIGITAL POINT-AND-SHOOT CAMERAS

Although commercial point-and-shoot cameras offer an easy, lightweight, and portable alternative, there are no fixation targets on the camera for proper focusing. In addition, reflections from cornea and common optics cause artifacts in images, limiting the use of such prototypes in clinical settings.

Integrated Adaptor-Detector-Based Hand-Held Ophthalmic Cameras

To overcome the technical issues highlighted in previous sections, illumi-

nating optics were integrated with high-resolution detectors to ensure a consistent high-definition image capture. The basic architecture of the integrated adaptor-detector-based hand-held camera design is shown in *Figure 5*. The following section elaborates on commercially available designs.

PANOPTIC OPHTHALMOSCOPE

The PanOptic™ ophthalmoscope, developed by WelchAllyn (Skaneateles Falls, NY), uses a halogen lamp for illumination providing a 5× zoom for images acquired through undilated pupils.²⁵ The device can be accessorized with a smartphone (Apple [Cupertino, CA] iPhone®) for acquiring, storing, and transferring fundus images.

VOLK PICTOR

Volk Pictor enables nonmydriatic fundus examination with an improved 40° FoV.²⁶ It has modifications allowing still images and videos of the optic disc, macula, and retinal vasculature. The illumination levels

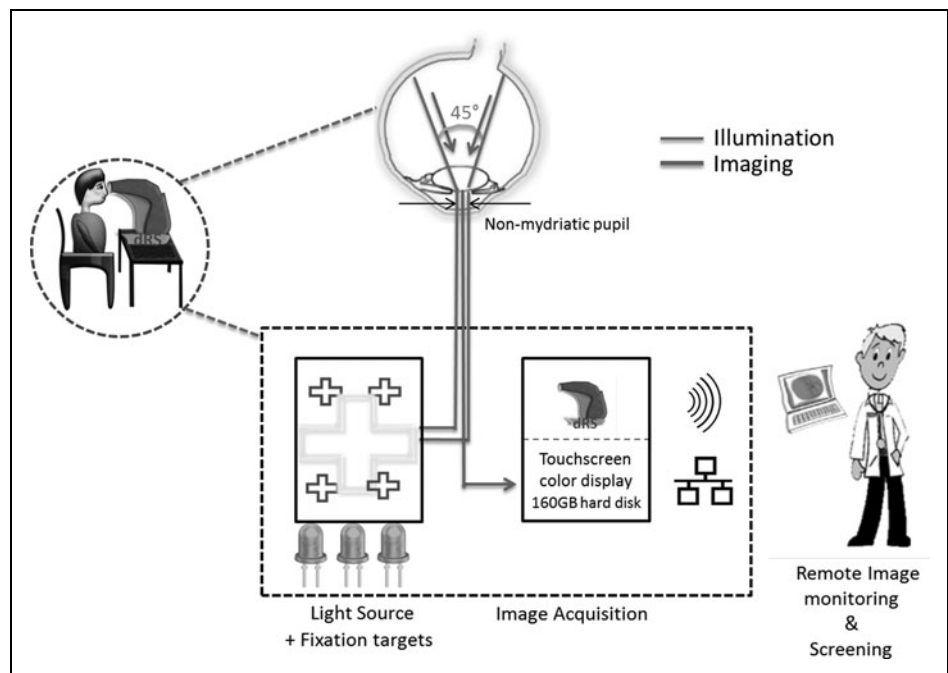


Fig. 3. Diagrammatic representation of fundus imaging by the digital retinography system (dRS). Equipped with wireless and Ethernet connectivity, this miniature table-top version also acquires fundus images through light-emitting diode illumination and fixation targets.

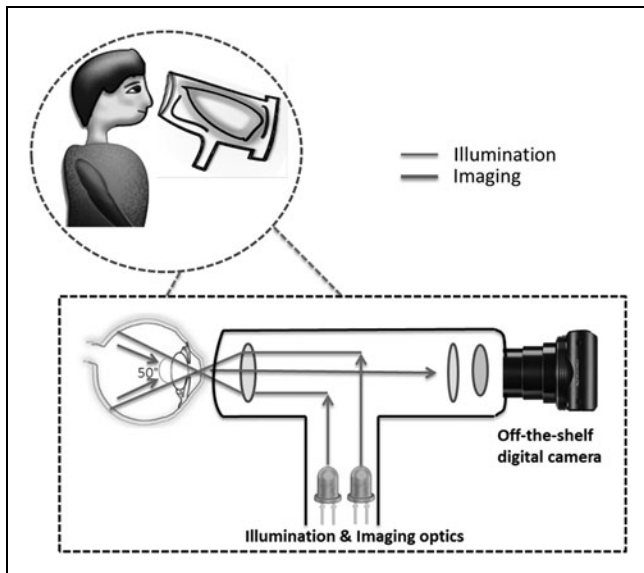


Fig. 4. Modified hand-held fundus cameras using off-the-shelf point-and-shoot cameras. Additional optical components are assembled to transform a commercial digital camera into a fundus camera.

and focusing can be adjusted to produce high-resolution reflection-free images. The attached detector increases the overall cost, and the acquired images require a wired interface for transfer.

VERSACAM

VersaCam from Nidek Co., Ltd. (Gamagori, Japan) enables one-handed operation by an ophthalmoscopic adaptor to

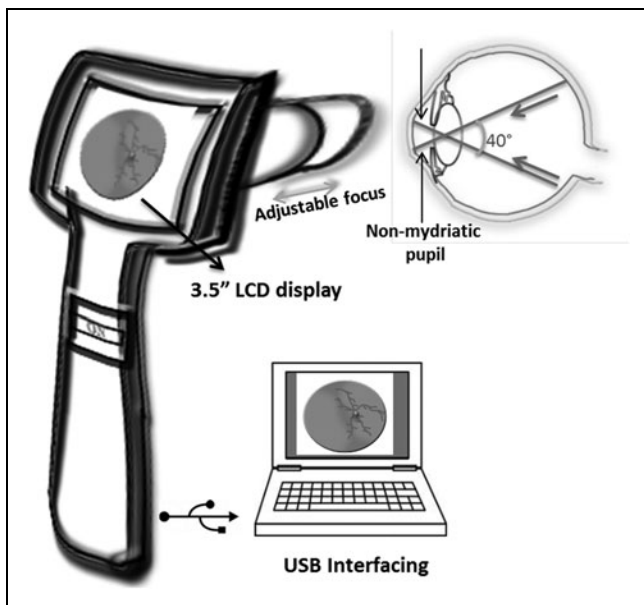


Fig. 5. Integrated adaptor-detector-based hand-held ophthalmic cameras. The optical assembly is integrated with a display console, making it a user-friendly hand-held instrument. LCD, liquid crystal display.

image the retina.²⁷ It is a lightweight, portable device, weighing 400 g. The infrared and white LEDs provide illumination for nonmydriatic capture. Good-quality images of normal healthy fundus have been demonstrated. Acquired images are transferred via a mini-USB to a computer.

HORUS SCOPE

The Horus Scope from JedMed (St. Louis, MO) is a hand-held ophthalmoscopic adaptor for viewing the retina and capturing video and still images that can be easily transferred to the personal computer.²⁸ The built-in infrared technology allows nonmydriatic imaging capturing. Although the focusing range is adjustable, there is no information about the FoV of retina covered.

SMARTSCOPE

The Smartscope[®] from Optomed (Oulu, Finland) offers a FoV of 40° while imaging through an undilated pupil (3.5 mm).²⁹ IR and white LEDs are used for image targeting and capturing. The compact optical module offers adjustable focus. The acquired images have been demonstrated to distinguish diabetic retinopathy, age-related macular degeneration, retinopathy of prematurity, and glaucoma.²⁹

GENESIS-D

A hand-held digital retinal camera from Kowa Optimed consists of a compact flash memory and an liquid crystal display monitor.³⁰ It has an indirect lens holder accessory with the VK-2 digital imaging system and electronic medical record connectivity and also facilitates telemedicine. Mydriasis is required for color photography and fundus fluorescein angiography.

RIESTER RI-SCREEN MULTIFUNCTIONAL DIGITAL CAMERA SYSTEM

This slit lamp-based system, along with attachable ophthalmoscopic lens, enables retinal ophthalmic imaging and nonmydriatic eye fundus examination.³¹ The Riester (Jungingen, Germany) ri-screen provides digital images and video to support screening and documentation of ocular lesions and anomalies.

LIMITATIONS OF HAND-HELD OPHTHALMIC CAMERAS

There are no qualitative reports showing the comparison of images acquired by these cameras with the standard fundus cameras in clinical trials. The manual alignment of the illuminating beam with the optical axis is a crucial requirement for good-quality images and is time consuming. Most important is that technical descriptions about the illumination and imaging light energies and their adherence to ocular safety limits are not stated.

Smartphone-Based Ophthalmic Cameras

Smartphones equipped with faster processors, larger storage memory, smaller batteries, and advanced operating systems have paved the way for numerous applications (apps). Research on the use of smartphones for medicine is growing, but there are limited data about their utility, feasibility, and their impact as medical tools.

Technological advancements allow smartphone-based attachments³²⁻³⁵ and integrated lens adaptors to transform the smartphone into a fundus camera (Fig. 6).³⁶ Some versions use apps designed for screening of abnormalities based on artificial intelligence-driven algorithms. The following section gives an overview of the smartphone-based fundus camera systems.

IEXAMINER

The Welch Allyn iExaminer™ turns the PanOptic ophthalmoscope into a mobile digital imaging device.³⁵ Figure 7 is an illustration of the system. It aligns the optical axis of the PanOptic ophthalmoscope to the visual axis of the iPhone 4 or 4S camera to capture high-resolution pictures of the fundus and retinal nerve. There is an iExaminer app that enables storing and printing of images.

OCULAR CELLSCOPE

A mobile phone-based retinal camera has been described by researchers at the Francis I. Proctor Foundation and the University of California, San Francisco, named the Ocular

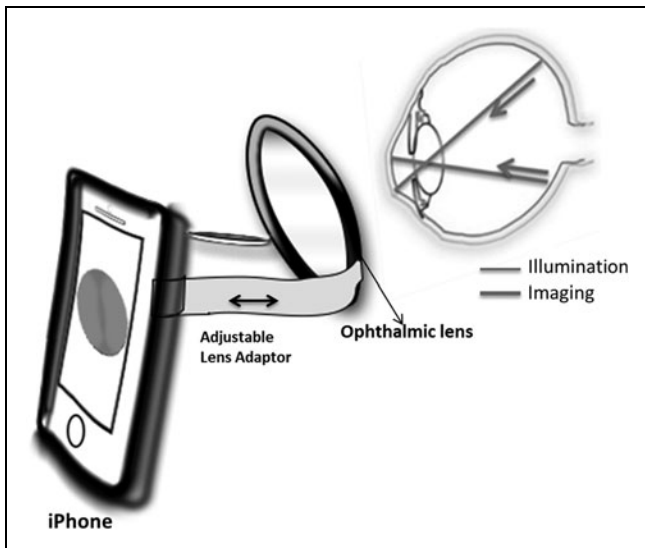


Fig. 6. Smartphone-based fundus camera system. An external ophthalmic lens is placed in front of the smartphone's lens for acquiring retinal images using the phone's built-in flash for illumination.

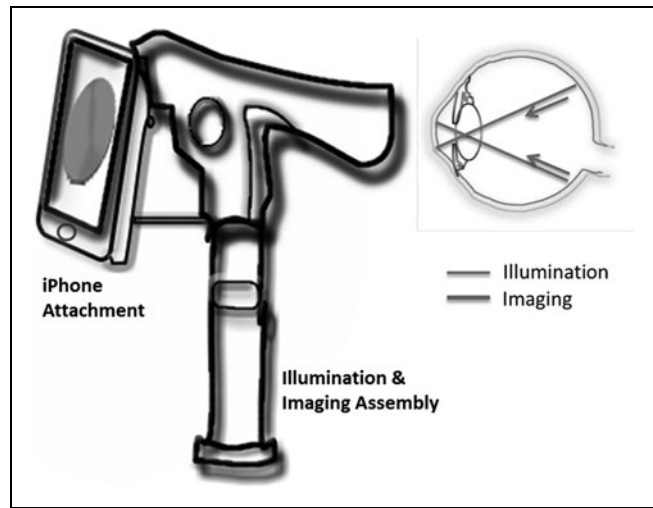


Fig. 7. Adaptor-based fundus camera system. A smartphone is used as a display console for retinal images, and illumination and imaging optics are integrated to it externally.

CellScope.³³ It comprises a mobile phone, a housing that contains the illuminating and collecting optics, and an integrated phone holder that ensures alignment with the phone's camera. Both the optical components and the iPhone are integrated within a polymer casing. It uses a single 54D ophthalmic lens for focusing and capturing reflected light, in turn using the autofocus mechanism of the iPhone's camera to correct for variability in axial length and refractive error in the subject's eye. The illumination is provided by three white LEDs powered by the iPhone itself. However, artifacts are seen in final images, even though the cross-polarization technique is used for reducing back reflections.

PORTABLE EYE EXAMINATION KIT

Andrew Bastawrous and collaborators have developed a clip-on hardware and an app for less than \$100 US that can be used for imaging the retina, as reported by Navitsky.³⁴ The Portable Eye Examination Kit (PEEK) facilitates automatic grading of acquired images, with an additional option of sending the images to experts around the world. The team conducted extensive field trials on thousands of patients over the past 3 years over 100 locations. The system also has the capability to store GPS data for each patient screened for ease of referencing.

D-EYE SYSTEM

Similar to the PEEK system, the D-eye System uses an add-on adaptor with an built-in lens attachment to the smartphone.³⁷ It started as a prospective clinic-based comparative study conducted in the ophthalmic diabetic center of the

Spedali Civili di Brescia, Brescia, Italy. With the D-eye adaptor attached to the smartphone, it is able to capture a FoV of approximately 20°.

OTHER SIMILAR PROTOTYPES

A similar approach has been demonstrated in human and rabbit eyes by a team of ophthalmologists from Harvard Medical School, Boston, MA.³² They used the iPhone camera’s built-in flash for acquiring images and an external 20D lens for focusing. They used the Filmic Pro app (£5.99) for control of light intensity, exposure, and focus. A Koeppe lens was used for imaging patients under anesthesia. Still images were then retrieved from the recorded video. When imaging the fundus of rabbits, 28D or 30D lenses have shown to give better results.

LIMITATIONS OF SMARTPHONE-BASED OPHTHALMIC CAMERAS

The light sources of the iPhone 5 or higher versions need to be verified against safety standards.³⁸ Beam alignment is problematic with the use of smartphone-based imaging systems. The iPhone’s built-in flash has a fairly high intensity, which constricts the pupil. Thus, image capture is difficult and requires pupillary dilation or the use of special apps to tailor the intensity and exposure time of flash for optimal illumination. At the moment, such lens adaptors use the built-in flash of the iPhone itself as a coaxial light source, but efforts are being put to design lens adaptors with provision of including coaxial light sources like external LEDs with varying intensity levels.^{11,32,33}

The Future of Ophthalmic Photography

There has been a recent surge of telecommunications in the developing world. For example, teledensity in India has increased from a mere 12.1% to 74.02%, registering a growth of 600% during the past 5 years.³⁹ There are many portable systems used today, and most of the gadgets can be used by semiskilled personnel. The advent of telemedicine (Fig. 8) could create a greater community outreach by decentralizing the delivery of healthcare services. In third-world settings where residents in rural areas have limited access to proper healthcare, a cost-effective, practical tool for accurate screening of the retina is of significant relevance in facilitating appropriate referral to an eye specialist in a timely manner.

Smartphones have become an integral part of the medical field lately to provide fast and clear access to electronically mailed digital images,⁴⁰ instant messaging and virtual private

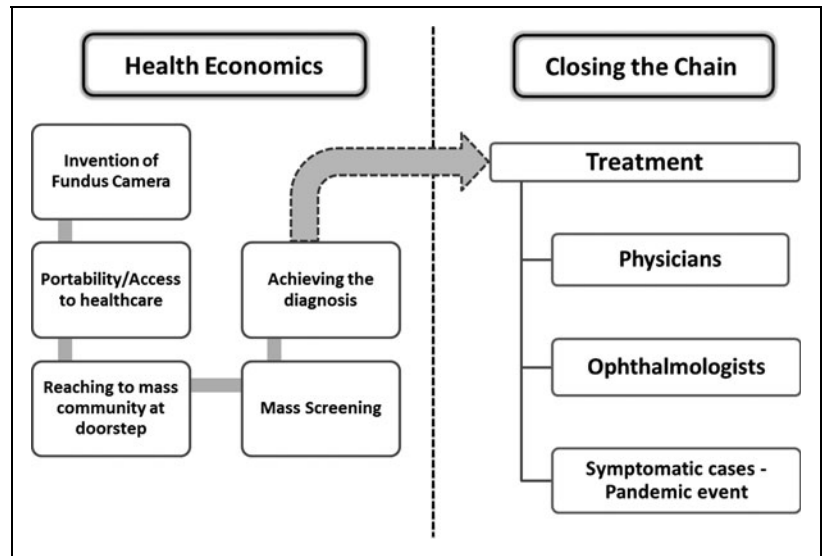


Fig. 8. The proposed complete cycle of tele-ophthalmology.

network,⁴¹ user-interface services,⁴² and mobile healthcare computing devices.⁴³ Statistical analysis for comparison of the quality of nonmydriatic fundus photographs displayed on an iPhone 3G against a desktop computer has shown the iPhone’s image quality to be superior to that same image viewed on a computer display.⁴⁴ This unexpected phenomenon has been attributed to the advanced features of the smartphone’s display (i.e., higher dot pitch and brightness). Nevertheless, the smartphone cannot, in its present form, replace the current value of in-person ophthalmic examination, but it remains a very promising device for ophthalmic telemedicine.

Conclusions

New inexpensive, portable, easy-to-operate fundus cameras have revolutionized retinal screening programs, which have grown exponentially over the last decade.^{11,45,46} Tele-ophthalmology is already making waves in linking remote villages to ophthalmologists. Ocular fundoscopic examination in young children is being made easier with nonmydriatic fundus cameras, especially to diagnose conditions such as retinopathy of prematurity and retinoblastoma.

In this overview we have outlined the technical advantages and disadvantages of all the different systems. However, the assessment of these camera systems needs to be validated in clinical studies.

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Address correspondence to:

Rupesh Agrawal, FRCS

National Healthcare Group Eye Institute

Tan Tock Seng Hospital

Singapore 308433

E-mail: rupesh_agrawal@ttsh.com.sg

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