iPhone 4s and iPhone 5s Imaging of the Eye

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Key Words

Eye · Imaging · Fundus · Photography · iPhone

Abstract

Background/Aims: To evaluate the technical feasibility of a consumer-grade cellular iPhone camera as an ocular imaging device compared to existing ophthalmic imaging equipment for documentation purposes. **Methods:** A comparison of iPhone 4s and 5s images was made with external facial images (macrophotography) using Nikon cameras, slit-lamp images (microphotography) using Zeiss photo slit-lamp camera, and fundus images (fundus photography) using RetCam II. **Results:** In an analysis of six consecutive patients with ophthalmic conditions, both iPhones achieved documentation of external findings (macrophotography) using standard camera modality, tap to focus, and built-in flash. Both iPhones achieved documentation of anterior segment findings (microphotography) during slit-lamp examination through oculars. Both iPhones achieved fundus imaging using standard video modality with continuous iPhone illumination through an ophthalmic lens. Comparison to standard ophthalmic cameras, macrophotography and microphotography were excellent. In comparison to RetCam fundus photography, iPhone fundus photography revealed smaller field

and was technically more difficult to obtain, but the quality was nearly similar to RetCam. **Conclusions:** iPhone versions 4s and 5s can provide excellent ophthalmic macrophotography and microphotography and adequate fundus photography. We believe that iPhone imaging could be most useful in settings where expensive, complicated, and cumbersome imaging equipment is unavailable.

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Introduction

In the field of ophthalmology, imaging is paramount in the diagnosis and documentation of ocular disease [1]. Efforts have been made to enhance image quality, simplify photographic equipment, and design more elegant and less invasive methodology. In the general public, consumer-oriented imaging technology has dramatically improved over the past 8 years, with the ability to produce high-resolution photographic images using a miniature camera embedded in a cellular telephone. The combination of the availability of consumer camera phones and the need for more universal ophthalmic imaging led to our interest in exploring a smartphone camera alternative to image the eye. We chose the universally available Apple

iPhone (Apple, Inc., Cupertino, Calif., USA) to explore the capability, quality, and technical feasibility of obtaining ophthalmic imaging using external, slit-lamp, and ocular fundus viewpoints. We intentionally used the iPhone and Apple's default applications only, removing any need to purchase special applications, coupling devices, or additional equipment. We compared the iPhone images to standard imaging techniques taken on the same day.

Methods

iPhone Hardware and Imaging Techniques

There were two versions of the iPhone used in this investigation, including the iPhone 4s and iPhone 5s. Each was used to take ocular photographs using techniques of external (macrophotography), slit-lamp (microphotography), and fundus imaging (fundus photography). The interface of each iPhone was similar, but the internal hardware was different.

The iPhone 4s was introduced to the public market in October 2011. This smartphone uses a 32-bit A5 microprocessor with a 3.5-inch retina display screen with 960×640 pixel resolution and 326 pixels per inch (ppi). The camera has an 8-megapixel image sensor, $f/2.4$ aperture, and a light-emitting diode (LED) flash. The software allows the user to change focus using the autofocus sensor and a tap-to-focus setting. The video mode on iPhone 4s records in 1,080 progressive scan (1080p) high definition (HD) with 30 frames per second (fps) and video stabilization.

The iPhone 5s was initially introduced in September 2012. This smartphone uses a 64-bit Apple A7 microprocessor and an M7 motion coprocessor with a 4-inch retina display screen of $1,136 \times 640$ pixel resolution and 326 ppi. The camera has a physically larger 8-megapixel image sensor with $1.5\text{-}\mu\text{m}$ pixels, which improves light sensitivity, and an $f/2.2$ maximum aperture. The camera uses the same two settings to focus as the iPhone 4s with autofocus and tap-to-focus settings, but additionally has image stabilization. Furthermore, the iPhone 4s has a single LED flash, whereas the iPhone 5s has a dual flash comprised of two LED units: one white and one amber. This flash allows the phone to capture images truer to natural color. Video recording on the iPhone 5s is similar to the iPhone 4s, with two major exceptions, that is, improvement in video stabilization and improvement in illumination in true color.

The technique of iPhone external macrophotography was performed with the cellular phone camera placed approximately 4–7 inches from the eye in camera mode, planar to the surface of the eye and with flash activated for each image. The technique of iPhone external microphotography was performed through the slit lamp with the iPhone camera window placed adjacent to or less than 1 inch from either the right or left ocular, set in plano refraction mode, to demonstrate the highest resolution image of the tissue in study. The slit-lamp light source was angled approximately 45° to the right, if the right ocular was used and similarly to the left for imaging with the left ocular of the slit lamp. Flash was not employed. The technique of iPhone fundus photography consisted of utilizing the iPhone's video capture mode with continuous flash illumination and a 20- or 28-diopter condensing ophthalmic lens (Volk Optical Inc., Mentor, Ohio, USA) for visualization of the fundus. The lens was held approximately 3–5 inches from the ocu-

lar surface and the iPhone camera was held approximately 8–10 inches from the condensing lens. The iPhone was balanced planar to the condensing lens and fundus and the virtual image was visualized on the iPhone display screen for video capture. There was no special application or additional equipment for fundus image capture. Following video capture, selected frames were chosen as images to represent the fundus. Adult patients were imaged through the dilated pupil with iPhone fundus photography in the office and pediatric patients were imaged while under anesthesia for tumor monitoring.

Standard Ocular Imaging Hardware

The Photography Department of the Ocular Oncology Service at Wills Eye Hospital utilizes several types of photographic equipment to image portions of the eye and surrounding structures. The three types of photographs used for comparison in this analysis were external photographs (macrophotography), slit-lamp photographs (microphotography), and fundus photographs (fundus photography).

Standard external macrophotography was performed utilizing a Nikon D2x or Nikon D90 digital single-lens reflex (dSLR) camera, equipped with a 105-mm Nikon Micro-Nikkor telephoto macro lens and a Nikon SB-29s Macro Speedlight electronic ring flash (Nikon Corporation, Tokyo, Japan). This technique is used to obtain macrophotography of the eye in a $1\times$ life size, particularly of the eyelids and anterior segment structures.

Standard anterior segment microphotography was obtained using a Nikon D200 dSLR (Nikon Corporation) mounted to a Zeiss Photo Slit Lamp (Carl Zeiss Meditec, Dublin, Calif., USA). This technique allows more detailed imaging of the anterior structures of the eye including the conjunctiva, cornea, iris, and lens, up to $30\times$ life size. The photographic slit lamp also included multiple light sources to allow for multiple angles of illumination and variation of flash intensities.

Standard fundus photography was performed in children with clear media under anesthesia using the RetCam II (Clarity Medical Systems, Inc., Pleasanton, Calif., USA), allowing a 120° field of view. For adult patients, a 50° field of view using either a Zeiss FF450 fundus camera (Carl Zeiss Meditec) or a Topcon TRC-50DX fundus camera (Topcon Corporation, Tokyo, Japan) and high-resolution digital capture system (Merge Healthcare, Chicago, Ill., USA) was performed.

The imaging on iPhone cellular camera and standard cameras was performed on the same day by the same photographer (S.R.F.). A comparison of each set was created to aid analysis of the ease of image capture, field of view, image resolution, and color reproduction. All imaging, data collection, and analysis was conducted at Wills Eye Hospital.

Results

The iPhone 4s provided acceptable capture of macrophotography, microphotography, and fundus photography. Macrophotography was straightforward and comparable to standard techniques, yielding an excellent-quality photograph (fig. 1). The flash on the iPhone 4s produced a distinct color cast due to the single white LED

Color version available online

Fig. 1. Comparison of standard versus iPhone macrophotography. **a** Standard 1:5 magnification external macrophotography documenting phthisis bulbi from persistent fetal vasculature compared to similarly framed external photograph taken with the iPhone 4s (**b**) and the iPhone 5s (**c**). Perspective distortion from the short fo-

cal length of the iPhone lenses is evident, as well as a distinct color cast from the iPhone 4s single LED flash. Magnification on the dSLR camera is easily reproducible, while it is more random with the iPhone.

Color version available online

Fig. 2. Comparison of standard versus iPhone microphotography. **a** Standard 12x magnification slit-lamp photograph documenting a conjunctival nevus compared to similar magnification photographs taken through the slit lamp viewing ocular with the iPhone 4s (**b**) and the iPhone 5s (**c**). Images taken through the slit lamp

viewing ocular are softer in focus and have a distinct color cast. The resolution is also compromised with this technique, limiting fine detail in the iPhone images as compared to the traditional photographic slit lamp.

flash; however, this cast was both consistent and subtle enough to allow the image to be utilized in documentation and diagnosis. Microphotography using the iPhone 4s proved straightforward to perform, generally taking the photographer one to two attempts to become proficient in the technique (fig. 2). One difficulty that was overcome was that the standard viewing illumination settings on the slit lamp caused overexposure of the images on the iPhone. To address this issue, the slit-lamp illumination was lowered in intensity and made more diffuse leading to more acceptable exposure but with slightly di-

minished contrast compared to images taken using standard slit-lamp methods. Another difficulty with the iPhone 4s microphotography was steady stabilization of the iPhone adherent to or within 1 inch of the eyepiece. Multiple photographs were taken to ensure capture of at least a few acceptable images with proper focus, exposure, and contrast. Fundus photography with the iPhone 4s was the most challenging to obtain (fig. 3). This required complete attention of the photographer to balancing the ophthalmic 20-diopter condensing lens in one hand and the iPhone 4s in the other hand, perfectly planar and ap-

Fig. 3. Comparison of standard versus iPhone fundus photography. **a** Standard RetCam color fundus photograph of a retinoblastoma compared with iPhone 4s image (**b**) taken through a 20-diopter condensing lens. **c** iPhone field of view circled in black and comparative image with the iPhone 5s and 20-diopter lens (**d**). Overall field of view is greatly diminished with the 20-diopter lens and iPhone; however, the ability to record fine detail in the retina is comparable between the RetCam and iPhones. Being able to record video on the iPhone also allows for acquiring a dynamic examination of the fundus, shifting views to image the tumor and surrounding retina.

Table 1. Comparison of iPhone 4s and iPhone 5s photography of the eye with standard photography

	iPhone photography		Standard photography			
	iPhone 4s	iPhone 5s	Nikon camera	Zeiss slit-lamp camera	Zeiss and Topcon fundus cameras	RetCam
Eyelid	****	****	****	**	na	**
Cornea	**	**	****	****	na	*
Conjunctiva	***	***	****	****	na	*
Lens	*	*	**	****	na	*
Retina	**	**	na	na	****	****
Disc	**	**	na	na	****	****

**** Outstanding. *** Good. ** Fair. * Poor. na = Not applicable.

proximately 8–10 inches apart. The iPhone 4s was in continuous illumination and in video capture mode. The condensing lens or iPhone were adjusted in millimeter increments to achieve a clear and complete view of the fundus. This often required several attempts to master for best focus and image quality. The iPhone 4s capture was in video mode so an extra step was required to view the video and select specific frames to represent iPhone fundus photography. Using the iPhone 4s, multiple fundus

images were obtained, but when compared to RetCam imaging, the field of view was more limited and resolution was poorer. Despite these drawbacks, the images were sufficient for documentation, but not of the quality achieved with standard RetCam.

The iPhone 5s demonstrated improved ability to produce quality images more so than the iPhone 4s, particularly in macrophotography and fundus photography. Macrophotography was a relatively simple process with

Fig. 4. iPhone 5s imaging of normal dark fundus.

Fig. 5. iPhone 5s imaging of normal light fundus.

iPhone 5s and iPhone 4s, but iPhone 5s provided more natural color balance due to the improved LED flash. Microphotography using the iPhone 5s was similar to the iPhone 4s, and produced comparable images with no detectable difference in quality. Fundus photography was notably easier with iPhone 5s compared to iPhone 4s, due to improvements in video image stabilization and auto-focus with the iPhone 5s. Image capture was in video mode with continuous light illumination through a condensing lens, similar to the iPhone 4s. Selected frames from the video provided better-quality fundus images with improved focus, resolution, exposure, and contrast compared to the iPhone 4s. Persistent drawbacks of small field of view and technical difficulty in balancing the camera and lens remained.

A direct comparison of images taken using the iPhone 4s and iPhone 5s with standard cameras was conducted to demonstrate the quality of iPhone images (table 1). Regarding macrophotography, iPhone 4s and iPhone 5s performed equivalent to standard Nikon camera with all three providing outstanding images of the eyelids. Regarding microphotography, iPhone 4s and iPhone 5s performed fairly well with imaging of the conjunctiva judged good, cornea fair, and lens poor, all assessed as poorer image quality compared to Zeiss slit lamp, but, nevertheless, useful for documentation. Regarding fundus photography, iPhone 4s and iPhone 5s performed fair and were judged to have poorer image quality and smaller field of view than Zeiss, Topcon, and RetCam fundus cameras, but, again, useful for documentation and diagnosis (fig. 4–6).

Fig. 6. iPhone 5s imaging of regressed retinoblastoma.

Discussion

Mobile cellular phones have been designed for portability, capability, and ease of use. With increasing technology and competition, phone manufacturers are adding improved features and multiple functions to their products. File sharing, high-resolution screens, and flash cameras have become default features in ‘smart’ mobile

phones. The iPhone is one of many marketplace products that demonstrate high-quality 'smart' phone capability including high-resolution digital camera, uncomplicated interface, and compact design. Using such a versatile and universally available iPhone for ocular imaging could possibly change the course of ophthalmic imaging.

The application of mobile phone camera to ophthalmic imaging could first be useful in developing countries where advanced and expensive imaging technology and equipment is unaffordable. This technology could also be remarkably useful for the busy clinician in a developed nation to provide rapid imaging without the overhead expense of cameras and ancillary staff. Patient flow in clinics could be improved as the patient would not need to move to an ophthalmic photography department, but, instead, the photography department would move to the patient. The patient could be imaged promptly in the single examination room with reduction in wait time, a benefit for all patients, particularly the elderly, handicapped, and others managing time away from work and family. The iPhone also allows third-party applications (apps) that customize the user's experience. Some of these apps can be utilized to conduct several parts of the ophthalmic examination [2]. Students and residents could benefit from this technology by having access to medical information at their fingertips, and this could also allow the clinician to send images to more experienced ophthalmologists for consultation [3].

In this analysis, we compared iPhone to standard photography in a busy outpatient setting. The images were obtained in all cases by a qualified ophthalmic photographer (S.R.F.) and judged by a medical student (M.J.), ophthalmic photographer (S.R.F.), and ophthalmologist (C.L.S.). We found that the iPhone demonstrated outstanding capability for macrophotography with excellent imaging, fair to good capability of microphotography, and fair capability for fundus photography. Despite the fact that iPhone 4s and iPhone 5s provided lower-quality fundus imaging compared to standard cameras, the technology was sufficient to document disease and could prove to be useful in clinics without formal imaging centers. Importantly, our technique of ophthalmic imaging, including fundus imaging, required no additional purchase of application or mechanical devices. We found that the best method for imaging the fundus was in video capture mode with continuous illumination, then selecting frames for documentation.

In addition to comparing iPhone to standard photography, we compared iPhone 4s to iPhone 5s. It was clearly apparent that the iPhone 5s provided more natural il-

lumination with the two-color LED flash for macrophotography and microphotography as well as in the continuous illumination video mode for fundus imaging compared to iPhone 4s. Still, even with its shortcomings, the iPhone 4s produced acceptable macrophotography, microphotography, and fundus photography. We anticipate that future developments in iPhone technology might provide further improvements to allow for better illumination, resolution, and wide-angle imaging, to make this device even more valuable for ophthalmic imaging.

Previous reports have demonstrated mobile phone fundus photography, but with the need to purchase third-party applications to provide more granular control of imaging settings for fundus imaging [4]. In our testing, we ran a trial run using an application that has been advertised to control photographic resolution (Filmic Pro; Cinegenix LLC, Seattle, Wash., USA), but found that the process without the application was less complicated, less expensive, and produced images of equal quality. In fact, we found iPhone 4s and 5s features such as the flash illumination and autofocus to be well designed for ophthalmic imaging, requiring no coarse manual adjustment.

There is an important patient privacy consideration when using iPhone or any portable device in a clinical setting, as patient information should be confidential and secure. Mobile phones typically allow for personal identification number (PIN) code access locks and encryption of data. iPhone in particular allows for remote locking and secure erasing of the device, and the iPhone 5s allows for bio-identity-based (BioID) locking. Such security and data safety methods should be used to ensure patient privacy.

There is an important consideration with illumination on the iPhone. The iPhone flash camera is not specifically designed to take fundus photography. Pairing the iPhone illumination source with a condensing lens provides ample illumination of the retina. Kim et al. [5] investigated the iPhone 4 and found that the retinal illumination is below the thermal and photochemical limits set by the International Organization for Standardization.

In summary, iPhone 4s and iPhone 5s can provide outstanding macrophotography, good microphotography, and fair fundus photography, without the need for third-party applications or special hardware devices. The photographer or clinician can quickly acquire skills for macrophotography and microphotography, but fundus photography is more challenging and requires practice and experience.

Acknowledgements

Support provided by Eye Tumor Research Foundation, Philadelphia, Pa. (C.L.S.). The funders had no role in the design and conduct of the study, in the collection, analysis and interpretation of the data, and in the preparation, review or approval of the manuscript. C.L.S. has had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Statement of Ethics

The study adhered to the tenets of the Declaration of Helsinki, and approval from the institutional review board of Wills Eye Hospital was obtained.

Disclosure Statement

No conflicting relationship exists for any author.

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