A pilot study for smartphone photography to assess bleb morphology and vasculature post-trabeculectomy

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ORIGINAL PAPER

A pilot study for smartphone photography to assess bleb morphology and vasculature post-trabeculectomy

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Abstract

Purpose The current grading systems used for bleb morphology assessment in patients post-trabeculectomy are based on standardized slit-lamp photographs and anterior segment imaging devices. The lack of availability of these expensive and non-portable devices in resource-deficient settings is a significant deterrent in their widespread utilization for proper post-operative management. The rapidly evolving utilization of smartphone photography has significantly benefited diagnostics of posterior segment disorders and is now being increasingly utilized for monitoring anterior segment pathologies as well as post-surgical course. In this study, we study a novel use of smartphones for bleb photography for assessing the morphological characteristics as vascularity and microcysts.

Methods In this pilot, observational study, we compared the trabeculectomy bleb images of five subjects, obtained by iPhone X (dual lens) and iPhone 6S (single lens). We captured two image sets with both smartphones first with a focussed torchlight and then with a built-in flash video light.

Results The images resulting from the newer iPhone X were substantially superior than those from iPhone 6S. For the 12-megapixel dual-camera set-up on the iPhone X, the $1 \times$ lens resulted in better images than the $2 \times$ lens with contrast and overall clarity of the area of interest. While the macro-lens attachment had promising results at $1 \times$ zoom, there is no added advantage of the macro-lens attachment as it resulted in considerable loss of image quality at twice the zoom. Using a 20 D lens helped attain higher magnification and better framing as it reduced the focussing distance needed to get sharp images. The images obtained from both smartphones were of higher quality when illuminated from an external source when compared to the native iPhone flash due to even exposure and fewer autofocus artefacts.

Conclusion Analyses of all image sets showed that the current generation in-built camera app on IOS and newer iPhone camera optics resulted in high-quality images of the ocular surface with high magnification without any loss in clarity.

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Introduction

Trabeculectomy has stood the test of time as the "gold standard" procedure for surgical management of glaucoma [1]. Amongst the different factors influencing outcomes of the procedure, formation of a "functional" filtration bleb is pivotal to ensure the desired therapeutic outcomes [2]. Post-operative healing and vascular changes alter the course of development of an optimal bleb, thereby requiring repeated assessment of the bleb morphology to predict potential success or failure of the procedure [3].

The current grading systems for bleb morphology assessment heavily rely on standardized photographs and sometimes may not accurately reflect the bleb condition [4, 5]. Blebs have been traditionally graded using advanced modern imaging modalities like anterior segment optical coherence tomography (AS-OCT) and ultrasound bio-microscopy (UBM) with relative success. However, lack of availability and limited portability of these devices deter their widespread utilization. This limits the capability of a treating ophthalmologist to assess the bleb and delve into the outcome of surgery. Furthermore, the need for an alternative, low-cost portable imaging device is essential in resource-deficient settings as trabeculectomy is the procedure of choice in these areas [6].

The smartphone revolution has made the device easy to use and affordable, thus making it ubiquitous [7]. The utilization of cell phones has expanded beyond traditional use and now encompasses high-quality on-the-go ophthalmic imaging. These devices are highly portable while being network friendly and hence serve as excellent tools for telemedicine [8]. The concerns regarding the ophthalmological safety for use of these devices have been aptly addressed with detailed analysis in the past for previous generations of the iPhone [9]. Even the newer generation iPhone X has been successfully used in previous studies without a single report of an adverse event related to its use in ophthalmic imaging [10–12]. Avenues in smartphone fundus photography are currently trodden in fair detail [13, 14]. The morphological assessment of the filtration bleb with inexpensive smartphone photography is, however, still an unexplored territory; therefore, in this report, we study the novel application of smartphones for bleb photography for assessing the morphological characteristics as vascularity and microcysts.

Materials and Methods

In this study, we performed the bleb imaging using by iPhone X (dual lens) [12 MP, f/1.8, 28 mm (wide angle; 1X), 1/3", 1.22 μm, PDAF (phase detection autofocus), OIS (optical imaging stabilization), and 12 MP, f/2.4, 52 mm (telephoto lens), 1/3.4", 1.0 μm, PDAF, OIS, 2 × optical zoom] and iPhone 6 s (single lens -12 MP, f/2.2, 29 mm (standard), 1/3", 1.22 μm, PDAF) with emphasis on the potential ability of iPhone images to serve as a potential teaching tool for training ophthalmologists for assessing post-trabeculectomy blebs. After obtaining an informed consent, five voluntary subjects who underwent trabeculectomy were enrolled in the study.

The subjects were seated comfortably in a chair, and the examiner (GK) sat facing them at the same level. The subjects were explained about the procedure to avoid the menace reflex and repeated blinking and were asked to fix their gaze towards the floor, while the examiner lifted the upper lid with his non-dominant hand. Optical stabilization prevented the unintentional shake from interfering during image acquisition. Using the native camera app for IOS on iPhone X (dual-lens set-up) and iPhone 6S (single-lens set-up), high-quality images of the supra-limbic area of the operated eye were taken with the native lenses, a + 20 D lens, and macro-lens attachment to obtain the best results and perform a comparative analysis. Two different light sources were used sequentially with the image sets: a focussed beam from a pen torch and a more diffuse light beam from the built-in flashlight in the smartphones to compare and choose the best illumination setting. The newer native camera app of iPhone X allowed for an adequate functionality needed to obtain sharp and well-exposed images of the eye. When the phone was pulled to an adequate focusing distance from the ocular surface, the area of interest was long pressed on the screen for obtaining a sharp focus using the focus and exposure box on the screen. (Supplementary data 1). With an upward or

downward motion on the screen, the exposure stops of the image were fine-tuned along with the gauge that appeared next to the focus box. This technique was followed sequentially, first with no additional lenses using the $1 \times$ lens and the $2 \times$ telephoto lens on the iPhone X (dual lens) and standard lens on iPhone 6S. Subsequently, images were also taken with a + 20 D lens(3x) and an inexpensive $10 \times$ macro-lens attachment (*Universal Clip Lens)* for smartphones to attain a higher magnification optically [15].

The examiner performed the imaging under optimal conditions for better imaging results on both smartphones, including:

- Focusing distance (fd): All photographs were taken at the minimum focus distance possible for both smartphones in order to maximize the usable resolution of the images, thus obtained for better results. The minimum focus distance would vary depending upon the lens set-up being used, and our standard values are mentioned in Table 1.

  - Twenty D lens: We used the VOLK 20 D (Volk Optical, Inc., Enterprise Drive, Mentor, OH) lens to enhance the magnification(3x) and clarity of the imaging results. The lens was aligned with the smartphone such that the margins of the lens were not visible in the frame being captured. The lens–smartphone set-up was then placed again at the minimum possible focussing distance where sharp and well-framed image could be captured.
  - $10 \times$ Macro-lens attachment: Using the *Universal Clip* Macro-Lens for smartphones, we were able to minimize the focussing distance, thereby obtaining a much higher magnification without a compromise in quality.

- Exposure: Using the tap to focus and expose box, the exposure of the image could be dramatically fine-tuned to eliminate overexposure, glares, and loss of detail in the area of interest. Ideal exposure implied mean adequate exposure of the area of interest without any loss of detail due to glaring or overexposure.

Two image sets were captured with both smartphones with the focussed torchlight initially and then with the built-in flash video light. Figures 1 and 2 are the representative image sets from iPhone X, while Fig. 3 shows bleb images from iPhone 6S. The newer native camera app in these smartphones allowed for high-quality stills image capture while video recording, and that is what we relied on when using the built-in video light.

We used the best images obtained by the iPhones and compared them to images obtained with the slit-lamp camera. Using the Wuerzburg bleb classification system (WBCS), the blebs were graded on the basis of vascularity, presence of corkscrew vessels, encapsulation status, and microcysts [16]. As microcysts across the bleb surface cannot be graded using bleb images, the scores obtained without microcysts on the slit lamp were used for comparison (Table 1).

Additionally, we processed the images using the image processing software ImageJ (version 1.48; National Institutes of Health, Bethesda, MD) for analysis of the bleb area. The images were initially calibrated using the intercanthal distance measured using a scale. The bleb areas were manually selected in all the images (Table 2). We used the Pearson correlation to evaluate the correlation between the bleb classification scores and the areas obtained using ImageJ analysis.

Table 1 Wuerzburg classification of the bleb photographs from slit lamp, iPhone 6S, and iPhone X

S No	Slit-lamp bleb photograph						iPhone 6S bleb photograph				iPhone X bleb photograph			
	Vascularity	CV	EC	MC	Total	Comp	Vascularity	CV	EC	Total	Vascularity	CV	EC	Total
1	0	0	1	3	4	1	0	0	2	2	0	0	2	2
2	3	2	0	1	6	5	2	3	0	5	2	2	3	7
3	1	2	1	2	6	4	2	2	1	5	2	2	1	5
4	3	3	0	3	9	6	2	2	0	4	3	3	0	6
5	3	1	0	3	7	4	3	2	0	5	3	2	0	5

CV corkscrew vessels, *EC* encapsulation, *MC* microcysts, *Comp* comparative

Fig. 1 Set of images clicked with iPhone X using a pen torch with different magnifications and attachments, with Exchangeable Image File (Exif) data on the lower right corner of each image

Fig. 2 Set of images clicked with iPhone X using built-in flash with different magnifications and attachments, with Exchangeable Image File (Exif) data on the lower right corner of each image

Fig. 3 Set of images clicked with iPhone 6S using a pen torch and built-in flash with different attachments

Table 2 Bleb area (mm^2) as measured by iPhone 6S, iPhone X, and slit-lamp photographs

S No	iPhone 6S	iPhone X	Slit lamp
1	149.32	109.53	115.11
2	75.25	126.67	146.63
3	46.38	43.41	43.51
4	73.18	78.91	80.42
5	24.82	28.48	26.06

Results

The image analysis sets showed that the current generation in-built camera app on IOS and newer iPhone camera optics resulted in high-quality images of the ocular surface with high magnification without any loss in clarity.

Comparing the dual-camera set-up (iPhone X) and the single-camera set-up (iPhone 6S)

For the 12-megapixel dual-camera set-up on the iPhone X, the 1 × lens resulted in sharper images than the 2 × lens with contrast and overall clarity of the area of interest as it has a smaller aperture. It becomes especially evident with the macro-lens attachment where there was a considerable loss in image quality at twice the zoom that was not utilitarian with the attachment. However, the 2 × optical zoom

provided potentially better images when using no attachment or using the 20 D lens as it allowed for better framing of the area of interest without considerable loss in quality (Supplementary data 2).

More cropping of the image was necessary to obtain similar framing using a 1 × lens in these scenarios, which decreased the image quality. The 12-megapixel single-camera set-up on the iPhone 6S behaved more or less similar to the 1 × camera on the iPhone X. We could obtain usable, high-quality images from the older model. However, there was significantly better image quality with the iPhone X because of dual optical image stabilization and better image processing.

Comparing various scenarios and the attachments

The 2 × optical zoom lens on the dual-camera set-up in the newer iPhone X resulted in highly detailed images with great contrast and clarity for appropriate assessment of the surface as well as deep vascularization.

Although images obtained with no attachments retained a significant amount of detail for bleb morphology assessment, better results were obtained using the 20 D lens, which helped attain higher magnification and better framing as it reduced the focussing distance needed to get sharp images. The best results were obtained using a Universal Clip Macro-Lens for smartphones as it allowed the focus distance to be reduced even further with extraordinary

retention of detail and clarity. The focusing distance for both iPhone X (dual lens) and the iPhone 6S (single lens) was 7–9 cms without attachments, 2.5–4.5 cms using the 20D lens, and 1.5–2.5 cms using the macrolens attachment.

Overall, image quality in any scenario varied greatly with changing illumination. We got the best results with a focussed beam of yellow pen torch held conveniently to illuminate the area of interest while maintaining some illumination evenly on the entire ocular surface. However, the results obtained using the diffuse built-in camera flashlight were comparable in many scenarios, thereby supporting the notion that bleb photography is possible using just a smartphone.

On using the macro-lens attachment on the iPhone X using the diffuse light, however, the results were not of high quality as there was considerable flaring of the phone's flashlight due to the physical arrangement of the torch on the back of the phone. This resulted in a loss of contrast and clarity in the image. Similar but slightly different results were noticed in this scenario for the iPhone 6S, where the physical arrangement was such that the macro-attachment's frame cast a shadow onto the ocular surface, thereby rendering a part of the frame darker. No such aberrations were noticed when using the focussed pen-torch illumination, where the images yielded the best results from all our scenarios. On image analysis, the images from iPhone X showed better correlation with slit-lamp images indicating better performance than the iPhone 6S images. The iPhone 6S images showed a Pearson correlation coefficient of 0.717 (p 0.172) and 0.683 (p 0.204) with slit-lamp images for the WBCS and bleb area analysis, respectively.

The iPhone X images showed a significant Pearson correlation coefficient of 0.929 (p 0.023) and 0.996 ($p < 0.001$) with slit-lamp images for the Wuerzburg classification and bleb area analysis, respectively.

Discussion

Initially, the use of smartphones in ophthalmology was merely confined to study high-quality fundus images. A thorough literature search yielded no evidence of their utilization for assessing trabeculectomy bleb morphology. A close assessment of bleb morphology in immediate post-operative period, for features such as corkscrewing of vessels and microcysts, is vital to detect early signs of fibrosis and impending failure [17]. The bleb photographs aid in uniformly assessing and communicating morphologic features of both limbus-based and fornix-based filtration blebs [18]. It is not possible for all operating surgeons to have ready access to a slit-lamp-based anterior segment photography system at each follow-up; thus, smartphone bleb photography can help overcome these hurdles.

Smartphone photography for posterior segment examination has been explored in detail to achieve high-quality ophthalmic images. Fundus photography techniques using lens adapters, 20D lens holders, smartphone cases, etc., are few modalities that have been used for smartphone-based fundus imaging [13, 19, 20]. More recently, unmodified iPhone X has been used to perform high-resolution direct ophthalmoscopy [12]. Smartphones have also been used in conjunction with slit lamp to obtain high-quality images by obtaining alignment with slit-lamp scopes, use of adapters, etc. [21, 22]. In a recent work, smartphone illumination has been used as a light source for slit-lamp examination in settings where there may be slit-lamp bulb failure, power cuts, or lack of electricity per se [23].

A combination of artificial intelligence with smartphone-photography holds promise of widespread high-quality ophthalmic care delivery at low cost. In a recent study, artificial intelligence-based diabetic retinopathy detection was achieved using smartphone photography-based fundus images [24]. More work in this area is warranted to expand applicability and improve reliability. Smartphone photography-based remote assessments and testing using store-and-forward and real-time telemedicine encounters have also provided ophthalmology practices a way to continue eye care delivery amidst this pandemic [25, 26].

Our study is the first application of smartphone photography for trabeculectomy bleb morphology assessment. We know that the signs for a functional bleb are the presence of microcysts, low conjunctival vascularization, absence of corkscrew vessels, moderate height, large area, and lack of encapsulation [27]. WBCS helps predict the post-trabeculectomy intraocular pressure control if at least 7 points are scored [16]. The item height is usually excluded from the score as it may have favourable and unfavourable aspects as the filtering bleb can be prominent either in over-filtering or in encapsulated blebs.

The primary limitation of WBCS is that it is not always possible to grade microcysts in every part of the filtering bleb solely from photographs, and therefore, some cases might need the help of a slit lamp [28]. Through this pilot observation, we found that the iPhone X images were comparable to slit-lamp photographs for bleb morphology assessment. Though iPhone-based documentation is a direct and straightforward technique, the critical factors for excellent quality image acquisition were stable holding of the phone, careful negotiation, and timely focusing on the area of interest. Further studies with large samples using simultaneous smartphone bleb photography and slit-lamp photography on the reproducibility of bleb images, both in terms of different examiners and successive session comparisons, will add more credibility to this method.

Conclusion

Our pilot study shows evidence that high-quality imaging that enables reliable trabeculectomy bleb morphology assessment is possible using smartphone photography. Attachments such as Universal Clip Lens and 20D lens help improve image quality and resolution when using standard iPhone camera, while higher magnification camera such as $2 \times$ may be better off as a standalone set-up. Smartphone photography holds high promise for anterior segment photography and telemedicine applications warranting more work in this area.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights No new drugs or techniques were tried on patients. Ophthalmic photography using smartphone which is non-invasive was carried out on consenting patients.

Informed consent Written informed consent was obtained from all enrolees.

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