Retinal Image Quality Assessment: Portable Eye Examination Kit Retina (Peek Retina)Tm Versus 3d-Printed Ophthalmoscope (3dpo)

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Abstract*: *Portable Eye Examination Kit retina (Peek Retina™, Peek Vision Ltd, UK) and 3D Printed Ophthalmoscope (3DPO) were identified to have acceptable image for retinal evaluation, however the retinal images quality in term of blood vessels visibility between both devices was uncertain. This study was conducted to compare the quality of image based on blood vessels visibility between Peek Retina and 3DPO for fractal dimension (Df) analysis. In this study, a total of 40 retinal images (nPEEK=20, n3DPO=20) of 20 participants were captured on random eyes. The best retinal images with good focus and significant retinal blood vessels visibility of Peek Retina and 3DPO were selected for image quality analysis. The retinal images were cropped approximately following the size of the cornea and resized to 900 by 900 pixels of resolution using GNU Image Manipulation Program Version 2.8.18 (GIMP). The images were randomly sorted as Retinal Image Quality Assessment (RIQA) generated by Google form. Likert scale was implemented to assess the preferences scale of retinal image quality in determining the visibility of retinal vasculature to be traced with four choices of response options (1; very difficult, 2; difficult, 3; easy and 4; very easy). Prior to the retinal image assessment, ten optometrists were asked to experience retinal blood vessels tracing and consequently evaluate the 40 images by choosing the scale options (1 to 4) based on visibility retinal blood vessels. Mann-Whitney test indicated that the blood vessel tracing was easier for Peek Retina (median = 3) than for 3DPO (median = 2), p < 0.0001. Retinal image captured by Peek Retina was rated as very easy (43.5%) for blood vessels tracing as compared to the image from 3DPO (17.0%)*Error! Reference source not found.. *Only 1.5% of the image captured by PEEK was considered as a very difficult for blood vessel tracing. Difficult and easy preference scales of blood vessel tracing for PEEK were 16.5% and 38.5% respectively. 34% of 3DPO retinal image was graded as difficult for blood vessel tracing followed by 28.5% (easy), 20.5% (very difficult) and 17.0% (very easy). The results indicate that a retinal image photographed by Peek Retina was more preferable in tracing retinal vascular network for Df analysis as compared to 3DPO.

Keywords: Peek Retina, 3DPO, retinal vessels, image quality

I. INTRODUCTION

Telemedicine is defined as the involvement of information and communication technologies (ICT) in providing rapid accessibility of health care services at different geographical locations to increase health outcome [1]. Recent advancement of ICT increases the usability of medical devices that can be used along with electronic mobile phone devices (smartphone) to improve the efficiency of health services in telemedicine network owing to its ubiquity, portability, low cost and connectivity [2]. The current innovation of smartphone technologies operated by Apple's iPhone operating system (iOS) or Android operating system equipped with advanced functional features have potential in providing rapid digital information. In combination with portable medical devices, digital information such as videos or images displayed by smartphone can be used for interpreting clinical evidence [3].

In ocular health care services, digital information such as fundus images is important for retinal assessment. Introduction of smartphone ophthalmoscope as a portable tele-ophthalmology device has evolved to modernize conventional method which involves stationary and bulky desktop fundus devices for retinal digital imaging system. Smartphone-based ophthalmoscope is considered as a portable ophthalmic device which operates with a smartphone camera attached with portable retinal adapters for fundus imaging. High-resolution autofocus camera and light emitting diode (LED) light source allow the retinal adapters to capture adequate retinal images quality relative to standard fundus camera [4–7].

A retinal adapter has been developed based on direct or indirect ophthalmoscope optical principal which is able to provide satisfactory retinal images for screening and even for diagnosing and monitoring retinal pathologies. A previous study stated that retinal adapter through direct ophthalmoscope such as iExaminer (Welch Allyn, Skaneateles Falls, NY) attaches an iPhone to Welch's Allyn PanOptic Ophthalmoscope to digitally visualize the retina [8]. Parallel alignment between the optical axis and visual axis of the iPhone camera allows the light to illuminate the fundus for sharp retinal image capturing. Other than that, D-Eye adapter (D-EYE, Padova, Italy) designed with a beam splitter is able to direct the LED light to coaxially illuminate the retina through optical axis [9]. D-Eye was reported to produce good quality of images (relative to slit lamp fundus images) in the grading of diabetic retinopathy (DR) [10]. Similar to D-Eye adapter, quality of the retinal image captured by Remidio Fundus on Phone (FOP) camera (Remidio, Innovative Solutions, Pvt. Ltd., Bangalore) was also comparable with standard fundus camera in detecting DR [11]. Navitsky, (2013) reported on the application of Portable Eye Examination Kit Retina (Peek Retina™, Peek Vision Ltd, UK) which includes a prism to allow the alignment of light source to pass through the optical axis of smartphone camera [12]. The quality of fundus images captured by Peek Retina was found to have a good agreement in optic nerve head

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with desktop fundus camera in Nakuru Eye Disease Project in Kenya [11].

A method of using a smartphone as an indirect ophthalmoscope was first described by Lord, Shah, San Filippo, & Krishna, (2010). The method used a combination of LED light source and high-resolution smartphone camera with a 20D lens to obtain adequate retinal image resolution [13]. 3D Printed Ophthalmoscope (3DPO) is one of indirect smartphone ophthalmoscope developed by fixing the distance between lens and camera holder. It provides an acceptable quality of retinal images for both normal and abnormal retinal conditions [14,15]. Other smartphone-based indirect ophthalmoscope adapters such as Paxos Scope (Digisight, San Francisco, CA, USA), MII Rectam (Coimbatore, TN, India), and Volk iNview (Volk Optical, Inc. Mentor, OH) were used in capturing acceptable retinal image quality for screening and diagnosing diseases [8].

In reviewing the quality of retinal images captured by retinal adapters, it was found that most of the retinal adapters have good digital imaging system in providing adequate quality of fundus images for retinal assessment relative to standard fundus camera. Peek Retina and 3DPO were identified to have an acceptable image for retinal evaluation, however, the retinal images quality in term of blood vessels visibility between both devices was yet to be explored. Thus, this study was conducted to compare the quality of image based on blood vessels visibility between Peek Retina and 3DPO.

II. MATERIAL AND METHOD

A. Study Population

In this study, 40 retinal images (20 from PEEK and 20 from 3DPO) of 20 Malay participants, aged 20 to 27 years were captured to assess which images (either from PEEK or 3DPO) demonstrate better visibility of retinal blood vessels. The number of images was adopted from a previous study [16]. Participants were determined for eligibility into the study by fulfilling the criteria. Written consent which follows the tenets of the Helsinki Declaration was obtained from all participants prior to inclusion in the study.

B. Smartphone-assisted Fundus Photography

Advancement in the development of smartphone and portable fundus camera enhances the feasibility in screening retinal image [6]. A smartphone is a portable electronic device designated with a high-resolution camera and flashlight. These smartphone features coupled with portable retinal camera adapter contributes to the improvement of telemedicine technology to efficiently access and monitor retinal health status [4,16].

The Peek Retina was invented based on optics of direct ophthalmoscope. Direct ophthalmoscope uses a mirror for allowing the reflected light beam aligns with the viewing system which enables the observer to perceive the retina [17]. Optically, incident rays reflected from the ophthalmoscopic mirror travel parallel to the optical axis and converge towards retina causing it to be illuminated. The rays then travel from the retina and enter to observer's eye.

Instead of using a reflecting mirror, Peek Retina was designed using prism assembly to directly emit the light beam parallel to the optical axis of a smartphone camera to digitally display the retina image. Image produces by PEEK shares the same characteristics with direct ophthalmoscope which is magnified, erect and virtual image [18]. The Peek Retina adapter is able to view approximately 20° – 30° field of view of the fundus with clear focus depending on the resolution of the smartphone camera through dilated pupil [8,19]. Viewing the retinal image through non-dilated pupil is very limited [20]. The Peek Retina provides a start button to turn on and an illumination button to control the brightness.

3-DPO is a 3D-printed ophthalmoscope, designed by fixing the distance of plastic arm between smartphone and lens holder by applying the optical principle of indirect ophthalmoscope. The features of the image produced by indirect ophthalmoscope are virtually reverse and inverted. This is because reflected light beam from retina that is transmitted through the 20D lens is refracted and converged on the opposite side of the lens to form the image. The rays emerge and travel to finally form the image on the observer's eye. Using 3DPO, smartphone camera's flashlight is used as a light source to illuminate the retina while smartphone display screen acts as an observer's eye to visualize the image.

C. Retinal Image Photograph

Smartphones are a portable electronic device designated with high resolution camera and flash light features. These features allow smartphones coupled with smartphone-assisted fundus camera to capture retinal images [4,17]. In this study, the usage of smartphone Samsung SM-G925F (Samsung C&T Corp., Seoul and Republic of Korea) and its digital camera of 8 megapixels was adopted based on previous study [11. This smartphone was fastened in the rightful slot of either Peek Retina or 3-DPO to capture the retinal photograph. The camera operation was turned on and automatic focus was set up. Devices then were aligned 1cm for Peek Retina [21] and 5cm to 7cm for 3-DPO [22] from the participants' eye to capture a retinal image through the dilated pupil. Brightest light from illumination button of Peek Retina was used to capture a sharp image. When using 3-DPO with a 20D lens, camera flashlight was turned on to allow the light to illuminate the retina in order to produce a clear image.

Figure I The good focus of retinal image with visible ONH blood vessels of a 27 years old Malay female captured by Peek Retina

A single drop of proparacaine hydrochloride 0.5% (Alcaine, Alcon, USA) and tropicamide 1% (Mydriacyl, Alcon, USA) was instilled on a random eye to dilate the pupil. After the pupil dilated, retinal image centered on the optic nerve head (ONH) was captured thrice in dim illumination using both devices. The best image with a good focus and visible blood

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vessels from PEEK and 3-DPO was chosen and saved for further analysis. The examples of the retinal image selected from PEEK and 3DPO were illustrated in Figure **I** and Figure **II** respectively.

Figure II The retinal image of 22 years old Malay male captured by 3DPO

D. Retinal Image Quality Assessment (RIQA)

The best quality of image from each Peek Retina and 3-DPO was selected based on good retinal blood vessels visibility without any significant opacity [22]. GNU Image Manipulation Program (GIMP) was used to crop selected retinal image approximately following the size of the cornea to remove the noise (Figure **III** A) The cropped image then was resized to 900 by 900 pixels of resolution to standardize the retinal image size (Figure **III** B)

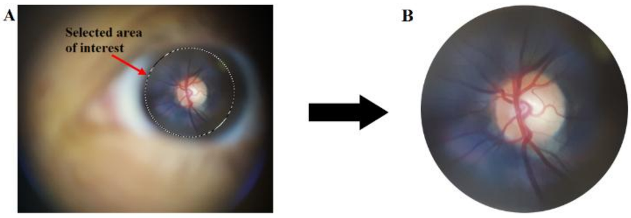

Figure III The region of interest was selected and cropped approximately following the size and shape of the cornea B) The cropped image was resized to the standard size of 900 by 900 of resolution

Forty cropped retinal images (20 from each device; PEEK and 3DPO) with its four choices of options were randomly arranged via Google form for evaluation of RIQA. Samsung Galaxy Tab A 8.0 SM-P355 (Samsung C&T Corp., Seoul, Republic of Korea) was used to display the evaluation form (containing the retinal images) with 21% (60.9 lux) of adjusted brightness [23]. Ten optometrists were selected as graders to subjectively evaluate the quality of the retinal image based on their prior knowledge with confidence [24]. Prior to the retinal image assessment, graders were instructed to experience blood vessels tracing to familiarize with the blood vasculatures tracing techniques. Then, they need to classify which retinal images have a good appearance of significant retinal vessel to be traced by rating the response options of 1; very difficult, 2; difficult, 3; easy and 4; very easy.

E. Statistical Analysis

Statistical Package for Social Science (SPSS) software version 21 was used to execute statistical procedures. Normality test was performed using the Shapiro-Wilk test to assess the data distribution. As the data not normally distributed, non-parametric test, Mann-Whitney was implemented to determine which devices, either Peek Retina or 3-DPO have good image quality in term of blood vessels visibility to be traced. The significance level (p) was taken at <0.05.

III. RESULT

A total of 20 Malay participants aged 23.9 ± 1.6 years were recruited in this study. The mean refractive error is -0.92 ± 1.21 DS. The mean intraocular pressure (IOP) and anterior chamber angle (ACA) obtained from the participants were 14.30 ± 1.72 mmHg and 3.8 ± 0.4 grade respectively. The mean IOP and ACA were within normal limit. This showed that all the participants were eligible to participate in this study. The demographic data are summarized in **Error! Reference source not found.**.

Forty retinal images (20 using PEEK, 20 using 3DPO) were captured of the participants on random eyes. 40 retinal samples were graded by ten selected optometrist aged 29.4 ± 6.7 years with 6.0 ± 6.3 years of working experiences based on four scales of preferences. The means of preference scale of blood vessel tracing for PEEK (n=200) and 3DPO (n=200) are 3.24 ± 0.78 and 2.42 ± 1.00 respectively.

A Mann-Whitney test indicated that the blood vessel tracing was easier for Peek Retina (median = 3) than for 3DPO (median = 2), p< 0.0001. Retinal image captured by Peek Retina was rated as very easy (43.5%) for blood vessels tracing as compared to image from 3DPO (17.0%; Figure **IV**)**Error! Reference source not found.**. Only 1.5% of image captured by PEEK was considered as very difficult for blood vessel tracing. Difficult and easy preference scales of blood vessel tracing for PEEK were 16.5% and 38.5%, respectively. A total of 34% of 3DPO retinal images was graded as difficult for blood vessel tracing followed by 28.5% (easy), 20.5% (very difficult) and 17.0% (very easy). All the data are displayed in Table **II**.

Table I Participants' demographics information (n=20)

Participants' Characteristics	Mean ± SD
Age (years)	23.9 ± 1.6
Refractive error (DS)	-0.92 ± 1.21
IOP (mmHg)	14.30 ± 1.72
ACA (grade)	3.8 ± 0.4

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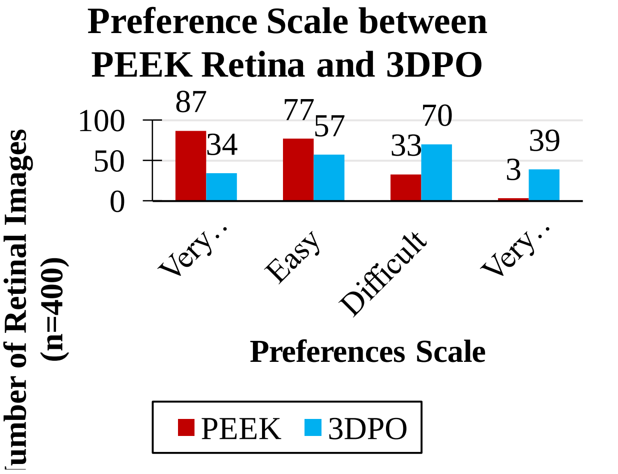

Figure IV Bar graph of blood vessel tracing preference scales between two types of portable fundus cameras

Table II Comparison of blood vessel tracing preference scales between Peek Retina (n=200) and 3DPO (n=200)

Preference Scale of Blood Vessel Tracing (SCALE)	Number of Images (%)		Total Number (%) (n=400)
	Peek RetinaTM (n=200)	3DPO (n=200)	
Very Difficult (1)	3 (1.5)	41 (20.5)	44 (11.0)
Difficult (2)	33 (16.5)	68 (34.0)	101 (25.3)
Easy (3)	77 (38.5)	57 (28.5)	134 (33.5)
Very Easy (4)	87 (43.5)	34 (17.0)	121 (30.3)
Median (IQR)	3 (3 to 4)	2 (2 to 3)	
p-value (Mann Whitney U test)	<0.0001		

IV. DISCUSSION

Digitized fundus photography is imperative in assisting the clinicians to subjectively analyze and interpret any retinal abnormalities. Standard desktop fundus camera contributed to providing good quality of fundus images for diagnosis accuracy. Recently, advancement in ICT transformed the standard tabletop instrument by the establishment of smartphone ophthalmoscope as a portable tele-ophthalmology device. Literature reported that smartphone-assisted fundus camera, Peek Retina and 3DPO are able to obtain adequate retinal images quality for further clinical interpretation [8,11,22,10]. However, the quality of retinal images (in term of blood vessels visibility) between both devices was uncertain. Thus, this study was conducted to determine the comparison of the retinal vessels visibility between retinal images captured by Peek Retina and 3DPO.

In the current study, retinal vasculature visibility of Peek Retina (median = 3) were found to be significantly visible than 3DPO (median = 2) for tracing purposes. The current results (Table II) showed that the retinal image of 20° to 30° field of view was mostly very easy (43.5%) for retinal blood vessels tracing in Peek Retina as compared to 3DPO (17%). Images by PEEK was proven to have a satisfactory resolution of retinal image quality in differentiating the ONH retinal vasculatures and its background. This is in line with a study which reported Peek Retina provided adequate fundus images relative to standard desktop fundus camera for ONH grading [11].

Previous studies reported smartphone-assisted fundus camera of 3DPO was able to photograph high quality stereoscopic retinal images to visualize both normal and abnormal retina [4,14]. The development of 3DPO attached with smartphone shared a similar optical principle of indirect ophthalmoscope in illuminating the retina. The large proportion of light emitted by smartphone LED light source facilitates the 3DPO to coaxially illuminate the fundus without external light source [13] to enhance retinal image quality. High intensity LED flashlight of the camera provides an advantage in capturing good images in transparent or hazy media with a wider field of view as compared to smartphone-based direct ophthalmoscope fundus camera [8,16].

The different types of smartphone and software used between previous studies [4,14] and the current study may contribute to the different results. The iPhone 4 and iPhone 5 operate with its high definition app (Filmic Pro; Cinegenix LLC, Seattle, WA) are reported to capture better resolution of retinal photographs due to the abilities of its compatible apps in controlling the intensity of light, focus and exposure [4,27]. In comparison with the current study, the retinal image was captured using Samsung SM-G925F (Samsung C&T Corp., Seoul, Republic of Korea) functioned with its app (Camera MX, Version 4.7.166, MAGIX software, Berlin, Germany). This app lacks manual controls features to adjust the focus and exposure intensity in producing high quality of images.

In this study, it is interesting to note that retinal image captured by 3DPO was graded as more difficult (34%) for blood vessels tracing as compared to the image captured by Peek Retina (16.5%). The retinal images captured using PEEK were more preferable by the graders (optometrist) for retinal image tracing as they stated that Peek Retina produced more prominence retinal vascular without any significant opacities as compared to 3DPO. This statement was supported by a study [24] which mentioned that sharp and visible retinal blood vessels were classified as good quality images.

Based on the graders' point of view in the vasculatures tracing, appearance of light reflects on the retinal image capture by 3DPO would cover the existing retinal vasculatures hence causing an interruption in producing self-similar vascular network tracing during blood vessels segmentation. Even the LED light source from the smartphone directly illuminates the fundus. The smartphone flashlight is not considered as a focused beam which consequently causes the presence of artefacts on the retinal images [13]. In contrast with Peek Retina, it was designed with a prism to direct the light beam to the optical axis of the smartphone camera [12] and produces good retinal images.

Based on previous studies, a smartphone-assisted fundus camera (either Peek Retina or 3DPO) was recognized as an inexpensive and powerful

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portable tool in generating satisfactory fundus images for retinal assessment especially during screening [8,11,14,25]. However, in the current study, it has been shown that the retinal image photographed by the Peek Retina was more preferable in tracing retinal vascular network for further analysis.

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