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Smartphone Retinal Imaging: Addressing Technical and Clinical Challenges

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ABSTRACT

Smartphone-based retinal imaging is a method introduced to address the limitations of conventional methods of retinal imaging. An example of a conventional retinal imaging method is the desktop mydriatic and non-mydriatic fundus cameras which are known to be bulky, expensive, and highly dependent on trained professional users. For screening purposes specifically for low- and middle- income populations located at geographically remote areas, the smartphone-based retinal imaging method which are known to be portable, cost-effective, and easier-to-use is the most suitable alternative. This would help to increase the rate of patients getting early diseases diagnosis from the rural areas. However, smartphone-based retinal imaging still has significant limitations that need to be tackled for future improvement. Thus, this paper aims to address the technical and clinical challenges of smartphone-based retinal imaging based on existing studies. Besides this, this paper also reviewed existing smartphone-based retinal imaging devices and adapters where the current trend these devices and adapters are identified and discussed. Based on the research, smartphone-based retinal imaging method is still incapable of competing against reference standards from conventional methods based on the repeatability in obtaining clinically adequate image quality shown in the studies reviewed. Besides this, the current state of smartphone-based retinal imaging method has limited applicability due to several reasons such as the small size of field of view, highly dependent on dilation, and limited smartphone compatibility. Hence, more research into the optimization of smartphone-based retinal imaging method is necessary to improve its current state, in realizing its full potential.

1. Introduction

Retinal imaging is a process of observing the structures of the retina with the purpose of detecting various diseases such as eye diseases, diabetes, hypertension, and other cardiovascular diseases for diagnosis or early prevention [1]. In the age of rapid technology advancement, the method of retinal imaging has developed over the years and now comes in a variety of methods such as fundus imaging in the form of desktop mydriatic and non-mydriatic fundus cameras, handheld fundus cameras, and

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more advanced method such as optical coherence topography (OCT) and fluorescein angiography which are typically used in preparation of any retinal surgery [2]. These methods have several limitations in common with the major being expensive, bulky in size, and requires highly trained professional users [3,4]. The stated limitations set a limitation itself for patients from low- and middle- income populations living in geographically remote areas to access basic medical care such as early diagnosis and treatment [5]. Disease for instance diabetic retinopathy (DR), the leading cause of blindness is an example of a disease that should be detected early in reducing the risk of declining progression [1,3,6].

Thus, over the years, there has been a major effort in making retinal imaging more accessible in terms of cost and portability, and less dependent on the conventional methods. With the revolution of smartphones, smartphone-based retinal imaging is a method that was introduced to overcome the limitations due to its portability, low-cost, digital functionalities, and ability to smoothly integrate with the internet or artificial intelligence (AI) technology for non-contact operation [4]. The integration of smartphones in healthcare is a step forward in overcoming major issues. For example, a report was published that describes the state of the healthcare system after an earthquake had hit the North-West of Syria back in February 2023 [7]. The report highlights the lack of specialized staffs, lack of accessibility of basic healthcare facilities and services, and overburdened medical equipment in their hospital which further proves the importance of the research on smartphone-based retinal imaging.

In the early development of smartphone-based retinal imaging, the method simply involves holding a condenser lens towards a patient's eye together with a smartphone with proper alignment and distance [8]. Several studies have then developed adapters designed to hold a condenser lens and the concept is to simply attach the adapter to a smartphone [9-11]. Besides this, there are also experts and manufacturers that have developed full functioning smartphone-based retinal imaging devices such as the D-Eye (2015) by S.r.l, Pan Optic (2016) by Welch Allyn, and Peek Retina (2017) by Peek Vision. Hence, there are two types of smartphone-based retinal imaging methods that are currently in the market which are in the form of a full device, and adapters. A full device has its own optical configuration that typically houses its own illumination source which is re-directed to provide the retinal imaging path between the smartphone and the retina. The advancement in software and artificial intelligence leads to the development of mobile applications specialized in fundus photography which makes smartphone-based retinal imaging more efficient.

The main contribution of this study is (i) addressing the technical and clinical challenges of smartphone-based retinal imaging and (ii) provide a comparative analysis of existing smartphone-based retinal imaging devices to identify the current trend that determines the efficiency and functionality of each device. The challenges and current trend of smartphone-based retinal imaging highlighted will expose the potential future work in this research area.

The consecutive sections of this paper are as follows: Section 2 describes the technical and clinical challenges of smartphone-based retinal imaging. Section 3 discusses the current trend of smartphone-based retinal imaging devices, while Section 4 presents concise discussion of the main findings. The last section concludes the study.

2. Challenges in Smartphone-Based Retinal Imaging

Despite the rapid advancement in smartphone-based retinal imaging, there are still limitations to the concept. As reported by Ryan *et al.,* [12], an evaluation of smartphone-based fundus photography was conducted and has found that descriptions on the techniques of smartphone-based fundus photography is still limited which suggests further research is required. Smartphone-based retinal imaging still lacks validation in defining the extent of its applicability. In a study by Wintergerst *et al.,* [13], there are studies that have shown that smartphone-based fundus imaging is still incapable of competing against reference standards in terms of image quality and sensitivity that have tested and reported on some retinal image acquisition devices only to find that most devices are still limited in terms of difficulty in obtaining images, alignment issues, and low accuracies of high rate of ungradable images obtained.

Besides this, despite being able to be utilized by all healthcare workers in general and not just skilled professionals, the use of smartphone-based retinal imaging devices still requires proper training. According to Rajalakshmi *et al.,* [14], at present, retinal images measured from smartphone-based retinal imaging devices need to be graded by trained graders or ophthalmologists (retinal specialists). Vilela *et al.,* [15] had also stated that its operation is still sparingly utilized by physicians who are not ophthalmologists due to certain technical difficulties and inadequate training. Furthermore, Jansen *et al.,* [16] have stated that till date it is uncertain whether non-expert operators can achieve sufficient results comparable to experts. Hence, it is important to identify the factors that affect the quality of images obtained.

From research conducted, there are several difficulties identified when operating a smartphone-based retinal image acquisition device. In the study by Iqbal [17], difficulties faced include obtaining the right adjustment of filming distance and positioning the device considering the glare from the condensing lens of the device itself as well as external reflections for example ceiling lights. Dilation also affects the quality of the retinal images. The study by Wintergerst *et al.,* [13] have stated that the most available smartphone-based retinal imaging devices require pupil dilation to achieve high quality of images but there also exist devices that do not require pupil dilation [13]. Pupil dilation affects field of view considerably. For instance, some studies have found that retinal image acquisition conducted on dilated pupils can achieve up to 56-degress or even more depending on the indirect ophthalmoscopy lens utilized meanwhile the retinal image acquisition in undilated pupils achieves only an estimated 20-degree field of view [13,18,19].

3. Current Trend of Smartphone-Based Retinal Imaging Devices

In this section, the current trend of smartphone-based retinal imaging devices and adapters both commercial and non-commercial, is examined based on seven categories which are smartphone compatibility, illumination source, maximum field of view, working distance and weight, dilation dependency, and mobile application. The categories selected for this study are based on categories presented in existing studies [3,5]. Categories such as the price, dimension, and size of images or video are excluded in this study. An unnamed non-commercial adapter has been labelled as Alpha for the purpose of this research. Table 1 shows the list of devices and adapters selected for the comparative analysis along with their specifications and main disadvantages. The devices are Peek Retina, Pan Optic, D-Eye, iNview, HEINE-iC2, and CellScope Retina, meanwhile the adapters are Paxos Scope, Choroida Fundus Explorer, and Alpha.

3.1 Smartphone Compatibility

In this study, smartphone compatibility refers to the model of smartphone that is usable with the smartphone-based retinal imaging device or adapter. Based on the research conducted, existing smartphone-based retinal imaging devices mostly have limited compatibility where the device or adapter are sized in such a way that could only fit the dimension of specific model of smartphones or designed strictly according to the placement of a smartphone’s camera and flashlight. For example, the iNview is a device that is only compatible with the iPhone 5 and 6 series as it has a specific position and size of the opening for the smartphone's camera flash [20]. Referring to Table 1, the Pan Optic, D-Eye, iNview, HEINE-iC2, and CellScope Retina are only compatible with iPhones which are also older models of iPhones, ranging from the iPhone 5 series to iPhone 8 series. The Alpha is an adapter designed to hold a fixed dimension for the iPhone 5 but according to its developers, the adapter is modifiable to fit other smartphones [9]. On the other hand, the Peek Retina is a universal device that applies a clip-on concept onto any smartphone regardless of its dimension [5]. Similarly, the Choroida Fundus Explorer and Paxos Scope also have universal smartphone compatibility in the form of an adapter. The limited smartphone compatibility sets a major limitation to its usability [21] and prevents the exploration of other smartphone models that could have better features to optimize the smartphone-based retinal imaging device or adapter.

3.2 Maximum Field of View

Field of view in smartphone-based retinal imaging refers to the degree of retinal view or image formed at the viewer or that can be viewed by the device [5,22]. A study by Karakaya and Hacisoftaoglu [5] has compared the field of view of four devices which are the iNview, Peek Retina, D-Eye and Pan Optic. Figure 1 shows the comparison by Karakaya and Hacisoftaoglu [5] which shows that the iNview has the largest maximum field of view which is approximately 50°, meanwhile the Pan Optic, Peek Retina, and D-Eye have significantly smaller maximum field of view that ranges between 20° to 30°. The Choroida Fundus Explorer adapter has several supported lenses which are the Volk 20D and 28D, Nikon 20D, Kashsurg 20D, Heine 20D, and Ocular 20D. 20D lens generally have an approximately field of view of 45° meanwhile 28D has a field of view of 69°. The Paxos Scope has a field of view of 56° [23] which is slightly larger when compared to the iNview meanwhile the HEINE-iC2 has a field of view of 34°. Among the commercial devices listed in Table 1, the Choroida Fundus Explorer can provide the widest field of view if used with the 28D lens.

Referring to Table 1, two non-commercial devices were listed which are the CellScope Retina and Alpha. The CellScope Retina provides the biggest maximum field of view by implementing automation and software intelligence to generate a retinal photomontage of 100° field of view from five overlapping images (each has a field of view of approximately 50°) that are taken in a rapid sequence. The device was clinically tested for referral warranted diabetic retinopathy and was able to achieve an average sensitivity of 93.3% and specificity of 56.8% which shows that wider field of view results in better performance. In the study by Myung *et al.,* [9], the lens holder for Alpha was sized to specifically hold a Volk Panretinal 2.2 lens. The lens used can provide a maximum field of view of 73° which is considered wide and sufficient for retina viewing. The adapter was initially designed specifically to hold the Volk Panretinal 2.2 lens. It was then modified to be readily modified for holding other types of existing lenses.

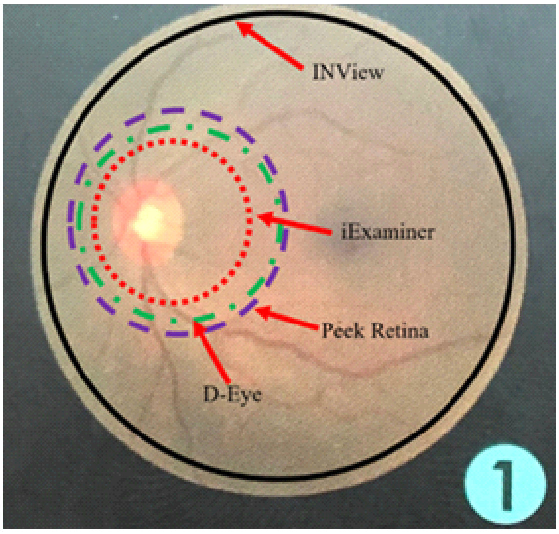

Fig. 1. Field of view comparison for iNview, Pan Optic, Peek Retina, and D-Eye [5]

3.3 Illumination Source

Illumination source refers to the light source required to illuminate the retina sufficiently for retinal image acquisition [24,25]. Based on research conducted, there are two types of illumination sources applied in smartphone-based retinal image acquisition device which are external and internal. Internal implies that the device has its own adjustable light source where a retinal image path has been designed specifically to redirect the light source accordingly between the lenses and the retina. External implies that there is a light source mounted on the outside surface of the device or the device is dependent on the smartphone camera light itself. Based on Table 1, the Pan Optic, Peek Retina, HEINE-iC2, and CellScope Retina has an internal illumination source meanwhile the D-Eye, Volk iNview, Paxos Scope, Choroida Fundus Explorer and Alpha requires an external illumination source. The Pan Optic internal adjustable illumination source directly converges to a point at the cornea and diverges around the retina upon turning the device on. To control the level of illumination, the Pan Optic integrates a variation of filter options such as the cobalt-blue filter and red-free filter [5]. The red-free light filter enables a large amount of light meanwhile the cobalt-blue filter enables a small amount of light. Similarly, the CellScope Retina implements red and white LED illumination system where the white LED has higher intensity compared to the red LED. The red LED is set to be a continuous source where it is used during the process of optimizing the focus on the retina. The white LED is set to be a pulsed source where it is used when capturing the retinal images once the desired camera position has been obtained and the focus on the retina has been optimized [26]. This helps in reducing discomfort and constraint on the patients' eyes. Similarly, both the Peek Retina and the HEINE-iC2 provides three different levels of intensity which enables the users to use low intensity first during the focus fixation process and the highest intensity when acquiring the retinal images. In contrast, the D-Eye, Volk iNview, and Choroida Fundus Explorer requires an external illumination source, which would be from the smartphones camera flash to illuminate the retina. The Volk iNview has an opening for the illumination source with fixed dimensions that is only compatible with the iPhone 5s, 6, and 6s. This indicates that other smartphones that have their camera flash positioned differently are not usable with the Volk iNview. In contrast, the Choroida Fundus Explorer is designed to work simply as a universal adapter. Unlike the Volk iNview, it does not have a fixed opening for the smartphone's camera flash.

3.4 Dilation Dependency

Dilation dependency in smartphone-based retinal imaging refers to whether the device requires the patients' pupil to be dilated or not prior retinal imaging [27-30]. Referring to Table 1, according to respective manufactures, the Peek Retina, D-Eye, HEINE-iC2, Paxos Scope, CellScope Retina, and Alpha require pupil to be dilated before image acquisition meanwhile no dilation is required when using the Pan Optic and Volk iNview. The Pan Optic, Peek Retina, and D-Eye have considerably small field of views when compared to other devices. For example, the manufacturer of the Pan Optic has stated that no dilation is required for retinal imaging, but some studies such as the study by Day *et al.,* [31] have found that it is difficult to obtain retina images that are clinically adequate without dilation. A study by Mccomiskie *et al.,* [32] which involved a group of first year medical students trying out both conventional ophthalmoscope and the Pan Optic ophthalmoscope, have found that it was easier to use the Pan Optic ophthalmoscope on dilated pupils than undilated pupils. Another example is the D-Eye is only able to capture up to a 6º field of view from an undilated pupil but up to 20º field of view from dilated pupils at a distance of 1 cm [33]. In addition, the study by Karayaka and Hacisoftaoglu [5] have found that devices that have smaller field of view have lower classification accuracy. A study was conducted by [29] to analyze how pupil dilation affects the efficiency of smartphone-based fundus photography in terms of image quality for optic nerve head (ONH) imaging and vertical cup-to-disc ratio (vCDR) evaluation using the D-Eye. The study found that the efficiency of smartphone-based retinal image acquisition is significantly higher following dilation when compared to without dilation. Hence, based on the results obtained, the study concluded that dilation is best performed for smartphone-based fundus photography. However, it further stated that in cases where dilation is not possible for example in geographically remote areas where additional ophthalmic resources are not possible to be brought along, smartphone-based retinal image acquisition without dilation can be an alternative.

3.5 Working Distance and Weight of Device

Working distance of a retinal image acquisition device refers to the distance between the patient's eye and the front objective lens of the device [5]. There are two main factors that affect the working distance of retinal image acquisition devices which are the weight and length of the lens used [34]. Generally, wider field of view enables a longer working distance. The working distance of a device depends mainly on the lenses used in its optical configuration. Longer working distance enables easier composition where users can have more flexibility in terms of positioning the device towards patients. Furthermore, longer working distance may be more comfortable for both users and patients. Besides this, it also ensures the surface of the lenses do not touch the patients' eyelashes hence minimal cleaning is required for each testing. Referring to Table 1, the Peek Retina, Pan Optic, and D-Eye have a small field of view of 30º, 25º, and 20º respectively but all three devices have a working distance of 22 mm. Meanwhile, devices such as the iNview, HEINE-iC2, and Alpha that have wider field of view (>30º) has a longer working distance which are 65 mm, 30 mm, and 144 mm respectively. The Paxos Scope has an adjustable lens-to-smartphone sliding shaft of 146 mm that allows the working distance to be adjusted accordingly. From this observation, it is concluded that devices that have wider field of view allow longer working distance.

However, lenses that provide wide field of view are heavier, hence it requires proper support to hold the lens which leads to another factor which is the stabilization requirement of the device [34]. For example, the iNview ophthalmoscope uses the 25D lens for its optical configuration which is considerably large in size. To hold the 25D lens, the device uses a large end tube to hold the lens in place. This results in the device to be heavy which requires users to rely on patient's forehead as support for further stabilization. The wide field of view of the iNview compensates for the weight of the iNview, which is known to be the heaviest smartphone-based ophthalmoscope in the market [5].

3.6 Mobile Application

Mobile application refers to downloadable software programs designed specifically to run on a smartphone's operating system [35-36]. The main advantage of a device having its own mobile application is it allows advanced control on the device and efficient data transfer over the internet. Most of the devices listed in Table 1 have their own mobile application except the Alpha that allows the user to control the level of brightness and focus alignment. The Alpha uses an existing mobile application named Filmic Pro which provides similar controllable features. The iExaminer application developed by Welch Allyn has a simple GUI that requires user to sign up for an account. An individual profile can be created for each profile, allowing systematic data collection and storage. Besides this, the iExaminer also allows direct data transfer over the internet. One disadvantage of the iExaminer is that it only has a capture mode in video where images can only be obtained by stills from the video recorded which lowers the quality of the retina images taken. Furthermore, only five images can be saved for each eye in each session. In contrast, the application for the Peek Retina and D-Eye has an advantage of having two capture modes, which are recording videos, or capture multiple retinal images [5,19,37]. The image capture mode allows user to take an image of the retina directly so it will provide higher image quality when compared to the quality of images taken as still images from a recorded video. Hence, despite devices have their own mobile application, its efficiency in retinal imaging also depends on the features that are provided. Among the listed devices, the CellScope Retina has the most advanced mobile application which enables wide-field imaging of the retina and is integrated with eye-fixation and rapid imaging of multiple retinal fields features for image-stitching [26]. Further studies should explore the advanced technology implemented in the CellScope Retina.

Table 1
Summary table of existing smartphone-based retinal image acquisition device/adapter

Category	Name	Main Specification								Main Disadvantages
		Type	Smartphone Compatibility	Max. Field of View (°)	Illumination Source	Dilation Dependency	Working Distance (mm)	Weight (grams)	Mobile Application	
Commercial	Peek Retina by Peek Vision [38]	Full device	Universal	30	Internal	Required	22	30	Own mobile application	Small FOV, requires dilation
	Pan Optic by Welch Allyn [39]	Full device	iPhone 6/6s/6 plus only	25	Internal	Not required	22	390	Own mobile application	Limited smartphone compatibility, small FOV, works better with dilation

	D-Eye by S.r.l [19]	Full device	iPhone 5/5s/6/6s/6 plus/6s plus/SE/7 only	20	External (from smartphone)	Required	22	25	Own mobile application	Limited smartphone compatibility, small FOV, requires dilation
	iNview by Volk [40]	Full device	iPhone 5/6/6s only	50	External (from smartphone)	Not required	65	332	Own mobile application	Heavy due to large end tube to hold lens which affects stability, limited smartphone compatibility
	HEINE-iC2 by Heine Optotechnik [41]	Full device	iPhone 5/5s/SE/6/6s/7/8 only	34	Internal	Required	30	300	Own mobile application	Limited smartphone compatibility, requires dilation
	Paxos Scope by Digisight Technologies [23]	Adapter	Universal	56	External (built in adapter)	Required	146 (adjustable with 146mm as max.)	Not stated	Own mobile application	Limited smartphone compatibility
	Choroida Fundus Explorer by Choroida [42]	Adapter	Universal	69	External (from smartphone)	Not stated	Depends on lens used	60	None	Null studies conducted on device
	CellScope Retina by [26]	Full device	iPhone 5s only	100	Internal	Required	Not stated	310	Own mobile application	Limited smartphone compatibility, requires dilation
Non-commercial	Alpha by [9]	Adapter	iPhone 5 only	73	External (from smartphone)	Required	144	Not stated	Used Filmic Pro	Limited smartphone compatibility, requires dilation

4. Discussion

From research conducted, most existing devices have restricted usability. For instance, the Pan Optic, D-Eye, iNview, and HEINE-iC2 are only compatible with Apple's smartphones. The CellScope Retina and Alpha are also developed and tested using iPhones only. In addition, these devices are only compatible with the older models of iPhones for instance the iPhone 5, 6, 7, and 8 which are no longer in production and not supported by the latest iPhone operating system (iOS). Thus, this sets a limitation to its usage presently. Among the listed devices and adapters in Table 1, only the Peek Retina, Paxos Scope, and Choroida Fundus Explorer are universal.

According to Pujari [4], determining whether the maximum field of view provided by a smartphone-based retinal image acquisition device is sufficient or not can be subjective. It correlates to the end-users' area of interest. For instance, if the area of interest sought by the user is an image of the optic disc, a small field of view is sufficient. Meanwhile, for retina images, they require a bigger field of view that can be further divided into two types which are regular field of view and a wide field, depending on the type, severity, or identifiers of diseases. In contrast, the study by Karakaya and Hacisoftaoglu [5] have investigated the effect of field of view sizes on diabetic retinopathy detection using deep learning and have found that the efficiency of the detection increases with retinal images that have a larger field of view. Earlier smartphone-based retinal image acquisition devices such as the D-Eye (2015), Pan Optic (2016), and Peek Retina (2017) provides a small field of view (less than 30°). Devices such as the iNview, Paxos Scope, and CellScope Retina have shown that a wide field of view provides higher quality of retinal images.

Furthermore, having an internal illumination source has shown to be a common characteristic among existing smartphone-based retinal image acquisition devices. According to the research, devices or adapters that have their own illumination source or have an extra external illumination source are preferred [4]. A disadvantage for devices that rely on the smartphone's camera flash as the main illumination source is the brightness of the smartphone camera's flash may not be sufficient to illuminate the retina. Besides this, the brightness of a smartphone's camera flash is uncontrollable meanwhile devices that have their own illumination source are typically adjustable where the user can control accordingly. Another disadvantages of relying on the smartphone's camera flash is the position of the camera flash may not be compatible with the ophthalmoscope to provide a retinal imaging path due to the fixed position of the smartphone's illumination source as demonstrated by devices such as the iNview, Pan Optic, Paxos Scope, and HEINE-iC2. In addition, a device's illumination source correlates to the device's dilation dependency. Having its own adjustable light source that redirects the light into the pupil suggests that no dilation is required for some devices as the fundus are illuminated sufficiently. Furthermore, it is beneficial for the illumination source to have different brightness levels because this allows less stress on the patient's eyes. A constant level of bright white illumination source may be uncomfortable or constraining for patients which leads to frequent gaze shifts and motions [26].

As for dilation dependency, most existing smartphone-based retinal imaging devices require pupils to be dilated. Despite some manufacturers stating that their device can be used without pupil dilation, studies have shown that dilated pupils evidently make it easier to use their device and allows a wider field of view [29,31,32]. However, the safety risk of pupil dilation remains as a concern and the convenience of not having to involve pupil dilation is preferred [28,30]. An advantage that non-mydriatic ophthalmoscopes (dilation not required) have over mydriatic ophthalmoscope (dilation required) is removing the possibility of mydriatic-induced angle closure glaucoma in the absence of ophthalmic professionals based on past incidences [28]. The safety of patients who have dilated pupils are exposed to certain risks as it causes pupils to remain unresponsive to light for several hours [30]. Furthermore, devices that require no dilation simplify the application of smartphone-based retinal image acquisition in terms of time taken and reducing the load or equipment to be brought for screening purposes in geographically remote areas. Dilation takes between 15 to 30 minutes [30] which is not practical in emergency situations. Moreover, dilating drops are not always available and there is also a risk of doctors in emergency situations not being familiar with dilating drops [30]. Nonetheless, undilated pupils evidently limit the field of view that can be captured using smartphone-based ophthalmoscopes.

A similar case for the working distance and weight of a device, a longer working distances provide general benefits such as flexibility and comfortability, however, a longer working distance typically involves lenses of higher dioptric power, which are on the heavier side, hence requires more stability. Last but not least, among existing smartphone-based retinal image acquisition devices listed in the study, only the Alpha does not have its own mobile application. In general, devices that have their own mobile application allow efficient data transfer between platforms and have certain advanced controls. However, the application used by the Alpha, which is the Filmic Pro was able to allow user to control the focus alignment and brightness of flash.

5. Conclusion

Smartphone-based retinal imaging has a great potential in providing an accessible and low-cost diagnosis method that could improve the current healthcare systems especially in situations where patients are limited in getting proper disease screening and early treatment. This research identifies the technical and clinical challenges discussed in existing studies on smartphone-based retinal imaging. Most studies found that the performance of smartphone-based retinal imaging has yet to be able to compete against reference standards in obtaining good quality of images and accuracy rate. Furthermore, several studies have also shown that this method still requires proper amount of training even for specialists and medical personnels, and the optimum parameters such as the optimum working distance and positioning during the process of smartphone-based retinal imaging still requires further research.

Besides this, this study also investigates existing smartphone-based retinal imaging devices and adapters and identifies the common specifications that set some limitations to its efficiency. Based on research conducted, most existing smartphone-based retinal imaging devices have limited smartphone compatibility. When it comes to the field of view, there are contradicting views on the best maximum field of view. There are studies that have shown that size of field of view affects the efficiency of disease detection while other studies state its subjective to the area of interest. Besides this, an internal illumination sources provides general advantages over an external illumination source for example a smartphone’s camera flash is not adjustable through the camera application that it comes with, but an internal illumination has its own control system. Secondly, a smartphone’s camera flash may not be sufficient to provide a retinal imaging path. The contradicting performance rate stated by the manufacturers and the one from studies on devices that are not dilation dependent also shows further research is needed. While dilation does improve significantly of the efficiency and quality of image taken for smartphone-based retinal imaging devices, the concern on the safety risk remains, as well as the preferred convenience of not needing to conduct pupil dilation. Moreover, it is also identified that devices that have higher dioptric power have longer working distance but are typically heavier and larger, which directly affects the overall stability of the device. Lastly, most of the existing smartphone-based devices come with their own mobile application which provides users with more control over the configuration. In cases where the device does not have its own mobile application, it uses an external mobile application.

For future work, more emphasis should be applied on the importance of smartphone-compatibility of smartphone-based retinal imaging devices or adapters. Besides this, in-depth research is still required to improve the current state smartphone-based retinal imaging method, specifically for non-mydriatic settings, for better image quality. Thus, it is necessary to explore in-depth on how to optimize the technical specification of smartphone-based retinal imaging devices to achieve clinically adequate results.

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