Selfie fundus imaging for diabetic retinopathy screening

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BACKGROUND: Regular screening for retinopathy and timely intervention reduces blindness from diabetes by 90%. Screening is currently dependent on the interpretation of images captured by trained technicians. Inherent barriers of accessibility and affordability with this approach impede widespread success of retinopathy screening programs. Herein, we report our observations on the potential of a novel approach, Selfie Fundus Imaging (SFI), to enhance diabetic retinopathy screening.

METHODS: The study was undertaken over a two-month period during COVID 19 lockdown. 60 diabetic patients participated in the study. Retinal images were captured using three different approaches, handheld smartphone-based photographs captured by patients themselves after a short video-assisted training session (SFI group), and smartphone-based photographs captured by a trained technician and photographs taken on desktop conventional digital fundus camera (Gold standard). Sensitivity and kappa statistics was determined for retinopathy and macular oedema grading.

FINDINGS: Mean age of the study participants was 52.4 years ± 9.8 years and 78% were men. Of 120 images captured using SFI, 90% were centred-gradable, 8% were decentred-gradable and 2% were ungradable. 82% patients captured the image within a minute (majority by 31–45 s). The sensitivity of SFI to detect diabetic retinopathy was 88.39%. Agreement between SFI grading and standard fundus photograph grading was 85.86% with substantial kappa (0.77). For the detection of diabetic macular oedema, the agreement between SFI images and standard images was 93.67, with almost perfect kappa (0.91).

CONCLUSION: Fundus images were captured by patients using SFI without major difficulty and were comparable to images taken by trained specialist. With greater penetrance, advances, and availability of mobile photographic technology, we believe that SFI would positively impact the success of diabetic retinopathy screening programs by breaking the barriers of availability, accessibility, and affordability. SFI could ensure continuation of screening schedules for diabetic retinopathy, even in the face a highly contagious pandemic.

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INTRODUCTION

Nine percent of the global adult population suffers from diabetes mellitus [1]. By 2030, this would increase to 366 million and the most vulnerable population would be from low-middle income countries [2]. With increasing duration of the disease, microvascular and macrovascular sequelae begin to manifest. Health-related economic burden, due to expenditure on control and treatment of the disease and its complications, as well as working hours lost in the process is substantial. Diabetic retinopathy is one of the three major microvascular complications of diabetes mellitus. In its natural history, diabetic retinopathy develops after a period of latency and progresses slowly but relentlessly, from a stage of mild severity to an advanced stage and to blindness. The disease remains asymptomatic not only in its early stages but also when it has reached a stage of impending vision loss. Regular screening for retinopathy and timely intervention has the potential to reduce diabetes-related blindness by almost 90% [2].

Diabetic retinopathy, being an important public health problem, the presence of an asymptomatic stage and the availability of effective treatment, mandates measures to improve regular screening of patients as recommended by international guidelines [3]. Unfortunately, only 50% to 65% of the total diabetic population undergoes annual DR screening as recommended by the American Academy of Ophthalmology [4]. Barriers to achieving targets for retinopathy screening, other than the disease being asymptomatic, include poor patient education, lack of access and affordability and dependency on technicians or specialists. The global COVID 19 pandemic has further compounded problems for diabetic retinopathy screening, for both patients and retinal physicians due to prolonged lockdown measures.

Available methods for diabetic retinopathy screening include ophthalmoscopy, biomicroscopy and/or fundus photography [5]. The gold standard for detection and grading of diabetic retinopathy is by capturing seven field 30° stereoscopic photographic images of the fundus [6]. Fundus photography has a sensitivity and specificity that is superior to ophthalmoscopic methods [7, 8]. Over the past few decades, fundus photography using desktop analogue and digital cameras has been supplanted by handheld digital and smartphone-based cameras [9]. Some of these newer devices have also gained acceptance from national agencies as acceptable tools for regular diabetic retinopathy screening. However, all these devices still necessitate a trained technician to capture the retinal photographs.

Recently, in a small pilot study of 3 patients, we reported our initial observations on the ability of diabetic patients to capture images of their retina, themselves [10, 11]. We designated this innovative approach to capturing retinal images as Selfie Fundus.
Imaging (SFI). During the ongoing lockdown restrictions due to COVID-19 and the increased need for precautions to be taken by physicians and technicians while interacting with patients, we studied the utility of SFI in a larger cohort of patients with diabetes. Our observations indicate that images obtained by SFI are non-inferior to those captured using standard fundus camera and has the potential to complement traditional methods of retinal screening being currently practiced. In difficult periods, like the ongoing pandemic, SFI would enable continued success of retinopathy screening programs without increasing the risk of disease spread. With further advances in smartphone image capture capabilities and its integration with machine learning, we contemplate that SFI may be able to significantly enhance current approaches to diabetic retinopathy screening.

**METHODS**

This prospective, comparative study was initiated after obtaining due ethical clearance (IECPG-646/19/12/2018) from the institutional ethics committee and followed the tenets of the Helsinki Declaration. Written informed consent was taken from all patients stating their voluntary participation in the study [after reading the patient information sheet provided to each participant]. 60 diabetic patients with clear ocular media were recruited. Inclusion criteria were diabetic patients above 18 years of age, clear ocular media, good visual acuity and fixation and willing to provide informed consent. One eyed patients and those with other ocular conditions like cataract, ocular hypertension, and retinal pathology other than diabetic retinopathy were not considered for study enrolment.

Preliminary visual acuity measurement, anterior segment evaluation and dilated indirect ophthalmoscopy were undertaken for all patients. Demographic history and pertinent details regarding diabetes were also recorded. Patients who fulfilled the inclusion and exclusion criteria were given instructions about the approach to SFI. Instructions on obtaining images using SFI was provided using a tutorial video created for the purpose. The study [supplementary material 1] and reinforced by a mock demonstration. Once the patient indicated that they had comprehended the instructions, they were given the camera and asked to perform SFI. During the same hospital visit, fundus images of each patient were then also captured by a trained technician using two additional approaches, first, with the same handheld smartphone camera and second, using standard digital tabletop fundus camera (gold standard). All 360 images (2 images of both eyes of each participant, using three different approaches) were then graded for severity of retinopathy and diabetic macular oedema by a retina specialist/trained ophthalmologist. Treatment was offered as necessitated, based on severity and as per recommended guidelines.

**Retinal photography**

Eyes were dilated with eyedrop Tropicamide 1%, one drop, three times at 10 min intervals. A short video training session, ranging from two to five minutes, was carried out where it was demonstrated to the patients, how to hold the camera, align it and move it slowly towards the eye. This was followed by a live, mock demonstration. Patients were taught to hold the camera firmly with both the hands at the distal and proximal end with the eyepiece facing them and positioned approximately 4 inches away from the eye to be imaged. They were to then move in the camera slowly, whence, upon sensing the red retinal reflex, the camera automatically begins image capture. While the image is being captured, a snap sound is produced with every click from the device and the patient is advised to hold the camera steady at this point of time. Hence, multiple images get captured with every click from the device and the patient is advised to produce informed consent. One eyed patients and those with other ocular conditions like cataract, ocular hypertension, and retinal pathology other than diabetic retinopathy were not considered for study enrolment.

In brief, three levels of retinal photographic images (50 degree field of view) of both eyes was captured-

1. By patient (after appropriate instruction and training videos) using handheld smartphone based single field camera. (Volk iNview, USA) (Fig. 1)
2. By trained technician using the same handheld smartphone based single field camera. (Volk iNview, USA)
3. By technician using standard digital desktop camera that is usually considered as gold standard (Zeiss, FF450 Visupac, Germany)

Image quality was first noted as gradable-centred, gradable-not centred and ungradable. Retinopathy severity was then categorized by a retina specialist/ trained ophthalmologist according to the International Council of Ophthalmology (ICO) classification [12]. The categories were no DR, mild NPDR, moderate NPDR, severe NPDR and PDR. Diabetic macular oedema was classified as no DMO, non-central involved DMO or central involved DMO. Determination of sensitivity and kappa statistics for the level of agreement between the three different methods of image capture, was calculated using STATA 12.1 software. Analysis considered the quality of images obtained and severity of diabetic retinopathy and diabetic macular oedema.

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MEAN AGE OF THE STUDY PARTICIPANTS WAS 52.4 YEARS ± 9.8 YEARS AND 78% WERE MEN. USING IMAGES CAPTURED USING STANDARD DESKTOP DIGITAL CAMERA (GOLD STANDARD), SEVERITY GRADING OF DIABETIC RETINOPATHY AS NO DR, MILD NPDR, MODERATE NPDR, SEVERE NPDR AND PDR WAS 2%, 6%, 55%, 18% AND 16% RESPECTIVELY. 3% OF IMAGES WERE UNGRADABLE. SEVERITY GRADING BASED ON IMAGES CLICKED ON SMARTPHONE HANDHELD DEVICE BY THE TRAINED TECHNICIAN WAS 3.3% WITH NO DR, 5.8% WITH MILD NPDR, 58.3% WITH MODERATE NPDR, 13.3% WITH SEVERE NPDR AND 15%, PDR. 4.1% OF THESE IMAGES WERE UNGRADABLE.

Seven ungradable images on SFI were excluded from sensitivity analysis. Of the remaining 113 images, 99 images were comparable for correct grading of diabetic retinopathy severity to images taken on the standard photographs (true positive), while 13 images failed to show the lesions that were picked up on the standard fundus photography (false negative). Seventy-four images were comparable and correctly identified DMO (true positive). Thirty-nine eyes had no DMO in both SFI and standard images (true negative). Hence, the sensitivity of SFI to detect diabetic macular oedema was found to be 93.7%. The accuracy of the classification was almost perfect, as shown by positive kappa coefficient (0.91). In a similar manner, it was found that agreement between SFI images and that captured by the technician using the same handheld camera was much higher at 98.3% with a perfect kappa coefficient (0.97).

RESULTS

Mean age of the study participants was 52.4 years ± 9.8 years and 78% were men. Using images captured using standard desktop digital camera (gold standard), severity grading of diabetic retinopathy as no DR, mild NPDR, moderate NPDR, severe NPDR and PDR was 2%, 6%, 55%, 18% and 16% respectively. 3% of images were ungradable. Corresponding severity grading using SFI and PDR was 2%, 6%, 55%, 18% and 16% respectively. 3% of retinopathy as no DR, mild NPDR, moderate NPDR, severe NPDR and PDR. 4.1% of these images were ungradable. Of the remaining 113 images, 79 images were gradable, 4 images were ungradable and 7 images were excluded from sensitivity analysis. Of the remaining 111 images, 99 images were comparable for correct grading of diabetic retinopathy severity to images taken on the standard photographs (true positive), while 13 images failed to show the lesions that were picked up on the standard fundus photography (false negative). Seventy-four images were comparable and correctly identified DMO (true positive). Thirty-nine eyes had no DMO in both SFI and standard images (true negative). Hence, the sensitivity of SFI to detect diabetic macular oedema was found to be 93.7%. The accuracy of the classification was almost perfect, as shown by positive kappa coefficient (0.91). In a similar manner, it was found that agreement between SFI images and that captured by the technician using the same handheld camera was much higher at 98.3% with a perfect kappa coefficient (0.97).

Table 1. Comparison of diabetic retinopathy severity grading and diabetic macular oedema grading using selfie imaging of the retina by the patient, trained technician using the same handheld fundus camera and images obtained using standard (desktop) fundus photography (N = 120).

| DR severity grading | Sefie Imaging by patient using handheld fundus camera | Imaging by technician using handheld fundus camera | Standard desktop fundus camera imaging |
|---------------------|------------------------------------------------------|--------------------------------------------------|--------------------------------------|
| No DR               | 4                                                    | 4                                                | 2                                    |
| Mild NPDR           | 7                                                    | 7                                                | 7                                    |
| Moderate NPDR       | 68                                                   | 70                                               | 66                                   |
| Severe NPDR         | 16                                                   | 16                                               | 22                                   |
| PDR                 | 18                                                   | 18                                               | 19                                   |
| Not gradable        | 7                                                    | 5                                                | 4                                    |
| DME grading         |                                                      |                                                  |                                       |
| No DMO              | 39                                                   | 39                                               | 39                                   |
| Non-centre DMO      | 29                                                   | 30                                               | 30                                   |
| Centre involved DMO | 45                                                   | 46                                               | 47                                   |
| Not gradable        | 7                                                    | 5                                                | 4                                    |

DISCUSSION

Diabetic retinopathy is a severe sight threatening complication of diabetes mellitus and has become the most common cause of blindness in middle aged adults, in several countries [13]. There is a significant lead time between onset of diabetes and the development of retinopathy, and in addition, highly efficacious therapy to prevent visual disability is available. The focus of screening is to detect retinopathy before it has progressed to a stage wherein therapy becomes ineffective or less efficacious. Reports suggest that 90% of blindness resulting from diabetic retinopathy is entirely preventable if major success is achieved in implementing internationally accepted screening guidelines. A high percentage of success in screening translates to lower visual morbidity and hence to reduced health costs and improved health economics. Unfortunately, more than 40% of diabetic patients currently fail to report for recommended screening even in developed nations. The situation is even more alarming in low-middle income countries [14–16].

Several approaches to diabetic retinopathy screening have been explored and used in practice [17]. Broadly, these can be categorized into methods based on ophthalmoscopy and those based on photography. The former methods are subjective and so
have a wide margin of specificity and sensitivity based on the amount of training. The latter is objective, has high sensitivity and specificity but is technology and cost intensive. Despite these limitations, grading of images captured using fundus cameras is considered the most efficient method for the management of diabetic retinopathy. Since the patient must be at the facility (clinic/telemedicine), screening by fundus photography is limited by the significant drawbacks of accessibility, affordability, and availability [18]. In this background, an important question that has remained unexplored is “Can screening be taken to the patients themselves?” With SFI, we explored this possibility.

Fig. 2 Selfie fundus images versus standard images [case example 1]. Comparative photographs of participant 1 showing images captured using selfie fundus imaging (1A, 1B), by technician using the same handheld fundus camera (1C, 1D) and standard desktop fundus camera (1E, 1F).

Ninety of the selfie images obtained by the patients themselves were of good quality and appropriately centred on the retina, disc macula and both the vascular arcades. Though there were some initial challenges, a good proportion of patients (48.3%) could independently accomplish the task and the remaining could do so with minimal assistance. After the tutorial session, when the patients became acquainted with the procedure and the device, the majority of them were able to capture adequate images within 30-45 s. When compared with images captured using a standard fundus camera, SFI had a sensitivity of 88.4% to diagnose the severity of diabetic retinopathy and the kappa coefficient was substantial at 0.77. For the identification of DMO, the sensitivity of SFI was 93.7% and the kappa coefficient was almost perfect (0.90) with 93.3% agreement. The quality of SFI was also highly comparable to the photographs taken by the trained specialist on the same device.

An important necessity with SFI using the currently available smartphone camera is the need for pupillary dilatation. This may bring to question the safety of having diabetic patients themselves dilate their pupils. However, this concern may be acceptable given the benefits of successful screening for diabetic retinopathy and the reported low risk (~1%) of severe intraocular pressure elevation (>25 mmHg) after dilatation with Tropicamide 1% even in eyes with narrow anterior chamber angle [19]. Other minor obstacles to SFI include severe senile ptosis, dermatochalasis, deeply set eyeball, senile tremor, cervical spondylosis, senile fatigue, frozen shoulder, and few others. As anticipated, the presence of hazy media is an impediment to image capture with all cameras and so it is with SFI also. However, the inability to
capture retinal images using SFI should be construed as the presence of significant cataract, posterior capsular opacification, corneal opacity, asteroid hyalosis or even vitreous haemorrhage and urgent ophthalmology consultation becomes inevitable.

Table 2. Image centration pattern and need for providing assistance during selfie fundus imaging (SFI).

| Image quality (n = 120) |          |          |
|------------------------|----------|----------|
| Well centred           | 108      |          |
| Partially decentred    | 9        |          |
| Decentred              | 3        |          |
| Assistance during SFI  |          |          |
| None                   | 29       |          |
| Fixation target        | 16       |          |
| Lid retraction         | 10       |          |
| Hand support           | 5        |          |

So, in this study, we present our observations on SFI, an innovative approach to diabetic retinopathy screening, wherein a patient independently takes a photograph of one’s own retina. The patient can then save the images and tele-consult with the ophthalmologist for further guidance. This approach would overcome barriers like poor access to healthcare, travel cost and distance, busy schedule, lack of caretaker etc. If individuals do not have access to smartphones, SFI may be made available at other public facilities like post offices, banks etc. as it is not heavily dependent on costly infrastructure. It can even be carried by healthcare workers to the patient’s residence. When amalgamated with the burgeoning field of machine learning and AI, we are optimistic that SFI may have the potential to improve the success of diabetic retinopathy screening programmes of all countries. In addition, during situations like a highly contagious and dangerous pandemic, SFI may help to sustain timely screening efforts for diabetic retinopathy. Some limitations of the study include the hospital-based recruitment of participants, limited sample size, evaluation with only one out of the several commercially available fundus cameras, need for initial tutoring of patients using a...
training video and necessity of pupillary dilatation. Though the need for pupillary dilatation seems like a drawback, the benefits of successful screening would outweigh the associated low risk of elevated intraocular pressure [19].

To conclude, the present study highlights the feasibility of bringing SFI to the forefront of diabetic retinopathy screening. To the best of our knowledge, this is the first study undertaken with selfie fundus imaging to screen diabetic patients for retinopathy. With greater penetrance, advances, and availability of mobile technology, including camera resolution and specific health-related apps, we believe that SFI would positively impact success of diabetic retinopathy screening programs, both in normal circumstances as well as situations like the ongoing COVID-19 infection.

**Summary table**

What was known before:

- Fundus imaging by trained specialist was used for grading and screening for diabetic retinopathy.

What this study adds:

- Selfie Fundus Imaging (SFI), which is taking photo of the retina by the patient themselves can improve screening by overcoming the barrier of accessibility and affordability, more so in the era of pandemic.

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**COMPETING INTERESTS**

The authors declare no competing interests.

**ADDITIONAL INFORMATION**

Correspondence and requests for materials should be addressed to Pradeep Venkatesh.

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