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Assessing the possibility of using portable and stationary non-mydriatic fundus cameras for diabetic retinopathy screening assisted by an artificial intelligence-based software platform in primary care

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Purpose: *To assess the possibility of using portable and stationary non-mydriatic (NM) fundus cameras for diabetic retinopathy (DR) screening assisted by the artificial intelligence (AI)-based Retina-AI CheckEye© software platform in primary care.*
Material and Methods: *In this prospective, open-label study, 609 subjects (1218 eyes) with either diagnosed diabetes mellitus (DM) or risk factors for DM were divided into two groups depending on whether the fundus camera was stationary or portable. NM single-field fundus photography was performed with a stationary fundus camera in group 1 and a portable camera in group 2. The AI-based Retina-AI CheckEye© software platform was used for the analysis of digital color fundus photographs of subject eyes for signs of DR. The numbers of poor-quality fundus images and the presence or absence of DR were noted, and the stage of DR was assessed.*
Results: *In group 1 and group 2, there were 37 eyes and 339 eyes, respectively, whose images could not be processed by the neural network. DR was found in 15 subjects (5.17%) in group 1 and 8 subjects (2.51%) in group 2. Previously undiagnosed DM complicated by DR was discovered in 13 (4.5%) of the subjects included in group 1 versus 7 (2%) of the subjects included in group 2.*
Conclusion: *Digital color fundus images taken with stationary and portable NM fundus cameras through non-dilated pupils and analyzed by the AI-based Retina-AI CheckEye© software platform provided DR detection and grading by stages among subjects with diagnosed DM as well those with undiagnosed DM. The percentage of poor-quality photographs can be reduced and the effectiveness of DR screening with the use of the AI-based Retina-AI CheckEye© software platform can be improved through the involvement of an experienced operator and better adherence to protocol for uploading fundus images to the cloud storage.*

Introduction

The global diabetes prevalence in 20–79 year olds in 2021 was estimated to be 10.5% (536.6 million people), rising to 12.2% (783.2 million) in 2045 [1]. In 2021, almost one in two adults (20-79 years old) with diabetes were unaware of their diabetes status [2]. Further advancements in diabetes surveillance systems, as well as the implementation of mechanisms to detect undiagnosed diabetes at the population level, are required. Therefore, it is prudent to advocate early screening protocols for individuals identified as having an augmented susceptibility to diabetes [3].

An increase in the global diabetes prevalence has resulted in increased rates of diabetic complications, particularly diabetic retinopathy (DR) [4]. The number of adults worldwide with DR in 2020 was estimated to be 103.12 million, rising to 160.50 million in 2045 [5]. Broad, system-wide strategies are needed to tackle this global challenge: (1) evolving understanding of the epidemiology, risk factors, and public health challenges in DR, (2) evolving strategies to develop effective biomarkers in DR, and (3) evolving screening strategies for DR, leveraging technologies, such as telemedicine and artificial intelligence (AI) [4, 6, 7].

Recently, there have been numerous reports on the efficacy of DR screening applications using various fundus structure imaging devices, approaches for retinal image taking and analysis, and AI-based data processing tools [9, 10, 11, 12]. We have previously found 93% sensitivity and 86% specificity for the DR detection based on color fundus imaging assisted by the software Retina-AI CheckEye© [6]. It is, however, noteworthy that, currently, there is no

consensus on the standardized procedure for obtaining fundus images for AI-assisted DR screening.

The purpose of this study was to assess the possibility of using portable and stationary non-mydriatic fundus cameras for diabetic retinopathy screening assisted by the artificial intelligence (AI)-based Retina-AI CheckEye© software platform in primary care.

Material and Methods

Study design and subjects

This prospective, open-label study was conducted in the Community Interest Company "Irpin Town Primary Care Polyclinic" (Irpin Town Council, Kyiv Oblast) in collaboration with State Institution (SI) "The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine", and included 609 subjects (1218 eyes), who underwent Retina-AI CheckEye-assisted DR screening from January 2, 2024 to March 17, 2024. All procedures performed in the study were in accordance with the ethical standards of the Helsinki declaration. The study was approved by the bioethics committee of SI "The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine" (committee minutes dated February 5, 2024), and informed consent was obtained from subjects.

Individuals were included if aged > 18 years and either diagnosed with type 1 or 2 DM or had any risk factor (RF) for DM (age, family history, excessive body mass index and/or high blood pressure).

Exclusion criteria were (1) age < 18 years, (2) a history of eye disease like age-related macular degeneration, retinal vessel occlusion, retinal detachment, chorioretinitis, vasculitis, anterior or posterior segment neoplasm, etc., (3) history of eye surgery (including laser intervention), and (4) reported history of non-transparent optical media (mature or immature cataract or apparent vitreous haze).

Subjects were randomly divided into two groups based on the type of fundus camera used for obtaining digital color fundus images.

Subjects in group 1 had their fundus images taken with an NM stationary fundus camera (NFC-700, Crystalvue Medical Corporation, Taoyuan, Taiwan; field of view, 45°; minimum pupil size, 4 mm; resolution, 5 megapixels (MP)), and subjects in group 2 had their fundus images taken with an NM portable fundus camera (Aurora, Optomed, Oulu, Finland; field of view, 50°; minimum pupil size, 3.1 mm; resolution, 5 MP).

Study procedure

Prior to enrollment, subjects were informed of the study purpose and procedure, and informed consent was obtained. Fundus photographs were taken in a dark room, with the patient sitting up, using a standard technique. The operator tried to obtain photographs for both eyes. No mydriatic was used. A central 45°- or 50°-degree field involving the macula and optic disc was captured, and images were centered in the macula.

The images were submitted to the cloud for analysis. The AI-based Retina-AI CheckEye© software platform was used for the analysis of digital color fundus photographs of subject eyes for signs of DR.

The neural network made decisions on the (1) presence or absence of DR and (2) DR stage using a five-stage disease severity classification for DR [13].

Fundus images obtained were classified into one of the five categories (no DR, mild non-proliferative DR (NPDR); moderate NPDR; severe NPDR or poor-quality image) (Table 1).

Statistical analysis

Data were analyzed using JASP ver. 0.19.1 (JASP Team, Amsterdam, the Netherlands). Pearson's chi-square test was used for testing the association between the risk of obtaining a poor (class 5) image and the type of fundus camera. A p-value of < 0.05 was considered statistically significant.

Results

Group 1 (the stationary camera-related group) included 290 subjects (580 eyes). Images for both eyes in 9 subjects (18 eyes) and one eye in 19 subjects (19 eyes, including 4 eyes whose images were not unloaded to the cloud) of these 290 subjects were classified as poor-quality (class 5).

Table 1. Classification of fundus images depending on the pathological changes detected

Image class	Image characteristics
Class 0	No DR detected
Class 1	Mild non-proliferative DR
Class 2	Moderate non-proliferative DR
Class 3	Severe non-proliferative DR
Class 4	Proliferative DR
Class 5	Poor-quality image

Note: DR, diabetic retinopathy

Therefore, in group 1, there were 37/580 eyes (6%) whose images could not be processed by the neural network.

Consequently, in group 1, the results were calculated for 281 patients (543 eyes), including 90 patients with DM (180 eyes). Poor-quality images of both eyes and single eye were obtained for 8 and 17 of these patients, respectively. Among group 1 patients, 82 patients with DM (147 eyes) were included in the analysis. The rest 200 patients (400 eyes) had not been previously diagnosed with DM and were referred for screening due to the presence of RF. Poor-quality images of both eyes and single eye were obtained for one and two of these patients, respectively. Among group 1 patients, 199 (398 eyes) with RF were included in the analysis.

Group 2 (the portable camera-related group) included 319 subjects (638 eyes). Images for both eyes in 105 subjects (210 eyes) and one eye in 129 subjects (129 eyes, including 14 eyes whose images were not unloaded to the cloud) of these 319 subjects were classified as poor-quality (class 5). Therefore, in group 2, there were 339/638 eyes (53%) whose images could not be processed by the neural network.

Consequently, in group 2, the results were calculated for 214 patients (299 eyes), including 58 patients with DM (116 eyes). Poor-quality images of both eyes and single eye were obtained for 41 and 15 of these patients, respectively. Among group 2 patients, 17 patients with DM (19 eyes) were included in the analysis. The rest 261 patients (522 eyes) had not been previously diagnosed with DM and were referred for screening due to the presence of RF. Poor-quality images of both eyes and single eye were obtained for 64 and 114 of these patients, respectively. Among group 2 patients, 197 (280 eyes) with RF were included in the analysis (Table 2).

DR was found in 15 patients (22 eyes; 5.17% of the subjects included in this group) in group 1, and 8 patients (9 eyes; 2.51% of the subjects included in this group) in group 2.

It was found that 13 patients (4.5% of the subjects included in this group) in group 1 and 7 patients (2% of the subjects included in this group) in group 2 had previously undiagnosed DM complicated by DR. The percentage of poor-quality fundus images was significantly higher for the portable fundus camera (53% of the eyes included in group 1) than for the stationary fundus camera (6% of the eyes included in group 2; $p < 0.001$).

Discussion

In terms of pupil dilation, there is no international consensus on the optimal approach to DR screening [14]. Various authors noted that NM fundus photography can provide a reliable DR screening solution [15]. In the current study, retinal photographs were taken through nondilated pupils using an NM fundus camera in a dark room. On the one hand, in very narrow pupils, this approach (NM fundus photography) can increase the proportion of ungradable photographs and worsen both the sensitivity and specificity of DR detection compared with dilated photography [14]. On the other hand, NM fundus photography reduces the time required for screening, is convenient for the patient, and excludes the risks of complications of mydriatics (allergic reactions and an increased intraocular pressure).

One-field fundus photography is the most convenient, readily available and commonly used method of screening for DR and other fundus diseases [15-18]. Thus, in the current study, NM fundus cameras were used to assess the state of the central retinal field (including the macula and optic disc), which allowed to obtain high-quality retinal photographs without pupil dilation. Others have advocated for the use of 2-, 3-, 5- or 7-field fundus photography for DR screening [9, 14, 19, 20]. Srihatrai and colleagues [21] demonstrated that the sensitivity and specificity of fundus photographs for DR detection by primary care physicians were acceptable. They concluded that 1- and 5-field fundus photography each represent a convenient screening tool with acceptable accuracy.

In the current study, low-quality fundus photographs were caused by a very narrow pupil or unreported history of significant lens opacity (mature or immature cataract). Thus, in group 1 and group 2, there were 37 eyes and 339

Table 2. Numbers of subjects/eyes found to have diabetic retinopathy and their class distribution in groups 1 and 2

Image class	Stationary camera, n = 281 /543			Portable camera, n = 214 /299		
	DM 82/147	RF 199/398	NSE 281/543	DM 17/19	RF 197/280	NSE 214/299
Class 0	71/131	195/390	266/521	10/12	196/278	206/290
Class 1	7/10	4/6	11/16	4/4	1/2	5/6
Class 2	2/3	0/0	2/3	1/1	0/0	1/1
Class 3	0/0	0/0	0/0	1/1	0/0	1/1
Class 4	2/3	0/0	2/3	1/1	0/0	1/1

Note: n, number of subjects/eyes found to have diabetic retinopathy; DM, subgroup of subjects with previously diagnosed diabetes mellitus; RF, subgroup of subjects with risk factors for diabetes mellitus; NSE, number of subjects/patients analyzed or classified with a particular category for the group

eyes, respectively, whose images could not be processed by the neural network. Therefore, the percentage of poor-quality fundus images was significantly higher for the portable fundus camera (53% of the eyes included in group 1) than for the stationary fundus camera (6% of the eyes included in group 2; $p < 0.001$). It is noteworthy that the minimum pupil size required for the operation of the stationary NM fundus camera is larger than that required for the operation of the portable NM camera (4 mm versus 3.1 mm). Portable fundus cameras are relatively difficult to use in a hand-held manner and require high operator expertise, which is another likely cause of a high rate of poor-quality fundus photographs obtained with the portable fundus camera. Many programs employ NM photography, with mydriasis being reserved for cases where ungradable images are obtained [14].

In the present study, DR was found in 15 subjects in group 1 versus just 8 subjects in group 2. Of note is that the field of view was smaller for the stationary fundus camera than for the portable fundus camera (45° versus 50°). DR was found in 5% of the subjects enrolled in group 1 (with photographs taken with a stationary fundus camera) versus 2.5% of the subjects enrolled in group 2 (with photographs taken with a portable fundus camera), which may be associated with a higher rate of high-quality images obtained in group 1. Previously undiagnosed DM complicated by DR was discovered in 4.5% of the subjects included in group 1 versus just 2% of the subjects included in group 2. Therefore, the effectiveness of detection of DR by screening can be improved through (1) a reduction in the percentage of poor-quality fundus photographs and (2) the adherence to protocol for uploading fundus images to the cloud storage. This is especially related to the use of portable fundus cameras which require high operator expertise.

Two limitations of the study should be noted. First, the study sample was relatively small because the study was based on patients attending just one medical facility. Second, the study had no controls having dilated multifield fundus photography; this limitation will be improved in future research in the field. Despite the above limitations, the results of this study demonstrate that the use of non-mydriatic single-field fundus photography with stationary and portable fundus cameras for Retina-AI CheckEye-assisted DR screening provides DR detection and grading by stages among subjects with diagnosed DM as well as subjects with risk factors for DM.

Conclusion

Non-mydriatic single-field fundus photography provides images of adequate quality for DR detection and grading by stages in the course of Retina-AI CheckEye-assisted DR screening in primary healthcare. Digital color fundus images taken with stationary and portable nonmydriatic fundus cameras through non-dilated pupils and analyzed by the AI-based Retina-AI CheckEye© software platform provided DR detection and grading by stages among subjects with diagnosed DM as well as subjects with risk factors for DM. The percentage of poor-quality photographs can be reduced and the effectiveness of DR screening with the use of a portable NM fundus camera can be improved through the involvement of an experienced operator and better adherence to protocol for uploading fundus images to the cloud.

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Abbreviations: *AI, artificial intelligence; DM, diabetes mellitus; DR, diabetic retinopathy*