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Retinal images benchmark for the detection of diabetic retinopathy and clinically significant macular edema (CSME)

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Abstract: Diabetes mellitus is an enduring disease related with significant morbidity and mortality. The main pathogenesis behind this disease is its numerous micro- and macrovascular complications. In developing countries, diabetic retinopathy (DR) is one of the major sources of vision impairment in working age population. DR has been classified into two categories: proliferative diabetic retinopathy (PDR) and non-proliferative diabetic retinopathy (NPDR). NPDR is further classified into mild, moderate and severe, while PDR is further classified into early PDR, high risk PDR and advanced diabetic eye disease. DR is a disease caused due to high blood glucose levels which result in vision loss or permanent blindness. High-level advancements in the field of bio-medical image processing have speeded up the automated process of disease diagnoses and analysis. Much research has been conducted and computerized systems have been designed to detect and analyze retinal diseases through image processing. Similarly, a number of algorithms have been designed to detect and grade DR by analyzing different symptoms including microaneurysms, soft exudates, hard exudates, cotton wool spots, fibrotic bands, neovascularization on disc (NVD), neovascularization elsewhere (NVE), hemorrhages and tractional bands. The visual examination of the retina is a vital test to diagnose DR-related complications. However, all the DR computer-aided diagnostic systems require a standard dataset for the estimation of their efficiency, performance and accuracy. This research presents a benchmark for the evaluation of computer-based DR diagnostic systems. The existing DR benchmarks are small in size and do not cover all the DR stages and categories. The dataset contains 1445 high-quality fundus photographs of retinal images, acquired over 2 years from the records of the patients who presented to the Department of Ophthalmology, Holy Family Hospital, Rawalpindi. This benchmark provides an evaluation platform for medical image analysis researchers. Furthermore, it provides evaluation data for all the stages of DR.

Keywords: benchmark dataset; classification; computer-assisted diagnosis; diabetic retinopathy; digital image processing; fundus photographs.

OCIS codes: diabetic retinopathy; classification; fundus photographs; benchmark dataset; (100.2000) digital image processing; (100.3008) image recognition; -algorithms; (110.2970) image detection systems.

Introduction

Diabetes mellitus is a chronic metabolic disease related to impaired glucose metabolism. It is associated with significant morbidity and mortality throughout the world. The main pathogenesis factor related to diabetes mellitus is its numerous micro and macrovascular complications. Diabetes mellitus has reached the magnitude of an epidemic with the utmost impact in third world countries. In developing countries, it is considered one of the most common underdiagnosed, uninvestigated and untreated diseases [1]. The widespread increase in the prevalence of diabetes mellitus poses major public health and socioeconomic threats. The different types of complications related to diabetes mellitus affect various organs of the body.

Diabetic retinopathy (DR) is one of the most common and serious complications of diabetes mellitus. Both insulin-dependent and non-insulin-dependent diabetes mellitus can be associated with diabetic eye diseases. DR is considered one of the most dangerous of all the complications of diabetic mellitus because it is one of the most common causes of secondary blindness. Different studies have shown differences in prevalence of DR in various parts of the world ranging from 15.3% to 42.4% [2].

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The human eye is the most sensitive and vital organ of the body. The retina is the innermost, light sensitive layer of the eye. It is a critical part of the eye as it creates an inverted image of the object in the visual field. There are many diseases associated with the retina such as DR, hypertensive retinopathy, macular edema (ME), macular scar, vascular occlusion, retinal detachment and retinitis [1]. Our study is primarily associated with the screening and diagnosis of DR.

DR is a disease categorized by retinal ischemia, hyperpermeability, neovascularization and ME due to microvascular changes in the retinal vasculature [3]. Numerous risk factors for DR have been recognized which can be classified into modifiable risk factors and non-modifiable risk factors. Modifiable risk factors include serum lipids, blood glucose levels, blood pressure and smoking. Non-modifiable risk factors include duration of disease, age, genetic predisposition and ethnicity [4, 5]. Severe visual loss will occur in patients with DR if timely diagnosis and treatment are not initiated. In developing countries, DR is one of the major causes of vision loss in working age population.

Based on the Early Treatment Diabetic Retinopathy Study (ETDRS), DR has been classified into two categories: proliferative diabetic retinopathy (PDR) and non-proliferative diabetic retinopathy (NPDR) [6]. NPDR is further classified into mild, moderate and severe, while PDR is classified into early PDR, high-risk PDR and advanced diabetic eye disease [7]. The organogram in Figure 1 illustrates the relationship between the different stages of DR.

Table 1 adapted from ETDRS elaborates the different stages of DR, their symptoms and pathologies of each class.

Furthermore, diabetic macular edema (DME) is one of the most common causes of decrease in vision in diabetic patients. In addition, advanced PDR with vitreous hemorrhage (VH) and tractional retinal detachment (TRD) are also important causes of severe visual loss and blindness in patients with DR. Table 2 adapted from ETDRS explains the different stages of DME [8].

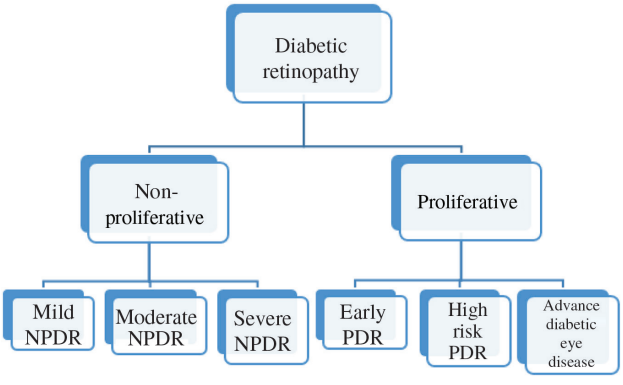

Figure 1: Organogram of DR.

Different signs and symptoms associated with DR are as follows: hard exudates can be defined as the collection of extracellular lipid that has leaked from abnormal leaky retinal capillaries. They are small waxy or glistening whitish/yellowish lesions. They are located in the outer plexiform layer of the retina usually at the junction of the normal and abnormal retina [9]. Cotton wool spots or soft exudates can be defined as confined superficial white, pale yellow-white or grayish-white lesions in the nerve fiber layer which develop secondary to retinal ischemia. They are round or oval in shape and have ill-defined (feathery) edges, frequently with striations parallel to the nerve fibers [10]. Retinal hemorrhage can be defined as bleeding from the blood vessels within the retina, which can be pre-retinal, intra-retinal or sub-retinal. Hemorrhage from the retinal vessels can leak into the vitreous leading to VH. Microaneurysms are small outpouchings or bulges that develop in the wall of small blood vessels. These small lesions may allow blood to leak into nearby tissue. People with diabetes may develop microaneurysms in the retina which are one of the signs of NPDR [11]. Neovascularization on the disc (NVD) is one of the signs of PDR. It is characterized by the formation of variable-sized new vessels which form secondary to retinal ischemia. They can grow over normal retinal vessels, because they grow anterior to the plane on the retina. Due to their abnormal architecture, these vessels leak profusely on angiography. They can be defined as neovascularization over the optic nerve head or within 1500 μm from the edge of the optic nerve. Neovascularization elsewhere (NVE) can be defined as the presence of neo-vessels which are 1 disc diameter away from the disc. They are also formed secondary to retinal ischemia and grow anterior to the retinal plane. They are one of the signs of PDR [12].

In recent years, a huge amount of work has been carried out in automated DR disease diagnostic systems, automated decision support systems, computer-aided diagnostic systems or automated detection of DR at initial stages. There are also a number of research works on the detection or segmentation of clinical symptoms related to DR in retinal images. These research works are based on the detection of clinical signs of DR like microaneurysms [11], soft exudates, hard exudates [9], cotton wool spots [10, 13], fibrotic bands, NVDs, NVEs [12, 14, 15], hemorrhages [11] and tractional bands. In most of the research works, the researchers tested their algorithms on publicly available datasets. Most of the publicly available state-of-the-art

Table 1: ETDRS chart.

Disease severity level	Findings observable upon dilated ophthalmoscopy
Mild NPDR	Early diabetic changes, i.e. microaneurysms, retinal hemorrhages, exudates and cotton wool spots which does not fulfill the criteria of moderate NPDR
Moderate NPDR	Patients in whom the following non-proliferative diabetic changes are present Retinal hemorrhages which are seen in quadrants 1–3 having size more than 2A standard ETDRS photograph Mild IRMA (intra-retinal microvascular abnormalities) Venous changes like beading which are only present in one quadrant Scattered cotton wool spots
Severe NPDR	Retinal hemorrhages seen in all four quadrants Venous changes like beading seen in more than one quadrant IRMA moderate in size seen in any quadrant
Early PDR	Proliferative diabetic changes like NVD and NVE which do not fulfill the criteria of high-risk PDR
High-risk PDR (i.e. proliferative diabetic retinopathy)	Patients in whom the following proliferative diabetic changes are present: NVDs present which are greater than one-third diameter of the disc Presence of vitreous or pre-retinal hemorrhage with NVD Presence of vitreous or pre-retinal hemorrhage with NVE which are greater than half of the disc area
Advanced diabetic eye disease	Presence of one or more of the following Vitreous hemorrhage Retrohyloid hemorrhage Tractional retinal detachment Rubeosis iridis

Diabetic retinopathy classification [7].

Table 2: DME chart.

Disease severity level	Findings observable upon dilated ophthalmoscopy
Diabetic macular edema apparently absent	Macula normal with no edema or thickening
Diabetic macular edema apparently present	1. Increase in thickness of retina present within 1 disc diameter from the center of the macula 2. Presence of hard exudates having size more than standard photograph 3* in a standard 30° photographic field centered in the macula (field 2) 3. Some hard exudates within 1 disc diameter of the center of the macula
Clinically significant macular edema	1. Increase in retinal thickening at or within 500 μm of the center of the macula 2. Hard exudates at or within 500 μm of the center of the macula 3. If associated with the thickness of the surrounding retina. a zone or zones of retinal thickness 1 disc area in size at least part of which was within 1 disc diameter of the center

Diabetic macular edema classification [8].

datasets are small in size; moreover, the image quality and resolution are not standardized. There is no specific dataset available which assist and covers all stages of DR and most datasets only contain healthy images. All these issues can influence the performance of algorithms; therefore, to overcome these problems, we proposed a dataset having 1445 high-resolution images which are specific to DR. Moreover, this dataset can also be used for research related to vessel segmentation and biometric identification. The proposed dataset was acquired from the Department of Ophthalmology of Rawalpindi Medical University (RMU), Rawalpindi. It contains 1445 ultra-high-resolution retinal images of both healthy and diseased subjects captured using a non-mydriatic fundus camera. The fundus photograph test is the most widely used screening test for DR due to its clear visualization and ease to analyze the retina. The rest of the paper is structured as follows: section "Related work" presents research related to the proposed dataset. In section "Existing datasets", we discuss and theoretically analyze the publicly available state-of-the-art datasets. In section "The proposed benchmark for the detection of diabetic retinopathy", we discuss in detail the proposed dataset and present a comparison of the proposed dataset with other state-of-the-art datasets. Section "Conclusion and future work" presents the conclusion, scope of future work and enhancement of the dataset.

Related work

There are a number of research works related to retinal pathologies. But much of these have focused on small datasets or datasets that were less relevant to the addressed problem. Leontidis [16] proposed a novel unified framework for an efficient and robust extraction of vessel features for the analysis of anomalies. In order to track vascular changes, the author studied the registered retina for years to find the vascular progression from no-DR to DR. The framework used various algorithms for various steps: for vessel segmentation, an active contour model was used; two distinct approaches, regularized random forest and an elastic-net, were used for feature selection. For the final phase, logistic regression and random forest were used for classification. Akram et al. [13] designed a novel hybrid classifier technique to detect microaneurysms, hemorrhages, hard exudates, cotton wool spots or any other type of lesion in retinal images. To improve the performance of the proposed technique and accuracy in classification, the authors combined the m-mediods with the Gaussian mixture model. Standard fundus image databases were used to assess the proposed technique. The proposed system graded the retinal image into one of the three categories of NPDR based on the number, type and location of lesion occurrence. This technique achieved the best results compared to all the previous methods practiced and proposed for the automated detection of DR. The overall performance/accuracy was good in all previous techniques but the research was focused only on the early stage detection of DR which included bright (cotton wool spots, exudates) and dark lesions (hemorrhages, microaneurysms). On the basis of these dark and bright lesions without identifying the size and quantity of their occurrences on the retina, we can only detect the presence of DR without knowing its type [17]. Welikala et al. [14] developed an approach to detect the neovascularization in order to classify PDR using a novel modified line operator and a standard line operator. The support vector machine was used to perform the final classification on each set of features. In this technique, the results were obtained using a small database of 60 images only. Waheed et al. [18] presented a method using a hybrid feature set based on mediods classification for retinal blood vessel segmentation. The researchers used a novel region-based hybrid feature set to distinguish the normal blood vessels and the false blood vessels which grow as a result of diabetes. Zhang et al. [19] conducted research on color retinal images for the detection of exudates in order to detect DR. E-ophtha EX, a new clinical database, was used to determine the performance of this technique. This dataset contained contoured exudates. This proposed method for the detection of exudates was developed for complex problems like determining the growth of the disease between two different examinations of the same patient. The preprocessing step is based on denoising, normalization and detection of artifacts in the image which may lead to false detection of exudates. The candidate segmentation technique was introduced based on mathematical morphology which used the classical and contextual features. As a final step, the random forest algorithm was applied to segment the exudates. Sidra and Shagufta [20] also conducted research on the automated detection of exudates from fundus images using fuzzy C-means (FCM) clustering in combination with morphological methods. In this research, the blood vessels and the optic disc were first eliminated from the fundus image. Then, the feature vector was extracted from the processed image for the detection of exudates. FCM was implemented and tested on 500 images obtained from publicly available datasets; most images were from the Diabetic Retinopathy Database (DIARETDB0). Huiqi and Chutatape [21] used edge detection techniques in the proposed technique for the extraction and segmentation of exudates. Principal component analysis (PCA) was used to detect the optic disc and the shape of the optic disc was detected using a modified active shape model. Both Sidra and Huiqi developed a method to detect hard exudates (a symptom of DR) which can be used as a feature for DR classification.

A detailed analysis of the automated DR detection algorithms reveals that there is a lot of scope for research in this area to make it reliable and authentic for implementation in daily clinical practice. Moreover, there is a huge requirement for a benchmark dataset for DR, which would include the subtypes of DR and their classification according to the severity level of the disease. Comprehensive and reliable ground truth details are also required. To overcome this problem, we propose a benchmark dataset with ample ground truth details including the different symptoms of DR, its types and the severity level of the disease.

Existing datasets

There are many eye/ophthalmic/retinal datasets publicly available for research. Some of them are very common among researchers and are considered as standard benchmark datasets for retinal prognosis. These datasets are mainly used for testing purpose of computer-aided systems, their efficiency and reliability assessment, automated decision support assessment and for disease diagnosis and classification. These datasets are also used for

research problems related to vessel segmentation, biometric identification systems (person identification using vessel pattern) [22] and other research problems in which retinal images are involved. This section of the paper includes the list of the state-of-the-art publicly available datasets with a brief analysis.

DRIVE

Digital Retinal Images for Vessel Extraction (DRIVE) is a famous dataset which was published publicly in 2004 [23]. The main motive for designing this dataset was to test segmentation algorithms for detection of vessels. The dataset contains only 40 images distributed between train and test sets. Only six images contain DR complications with very mild changes, and ground truth is also not available. The images were taken using a Canon non-mydriatic CR-5 fundus photograph camera. The dataset contains 24-bit color images with 565×584 pixel resolution. Although many DR classification and detection related research works have been tested on this dataset, for instance [8, 13, 15, 18, 22], it is not very suitable for testing such research.

STARE

The Structured Analysis of the Retina (STARE) project was initiated in 1975 at the University of California [24]. The STARE dataset was designed during1996–2004. The motive was to construct a system that would automatically detect diseases of the eye. This dataset contains 400 raw images of 24-bit color space with 605×700 pixel resolution of the retina including images of different eye diseases. The TopCon TRV-50 fundus photograph machine was used for capturing retinal images. The dataset is not specific for DR disease as it contains less than 40 images of DR but is general and small in size.

DIARETDB0

Diabetic Retinopathy Database (DIARETDB0) [25] consists of 130 retinal images. The dataset is small in size, some images are of very poor quality and it contains only three images of PDR stage. Twenty images are normal and healthy retinal images and the remaining 107 images contain mild to moderate symptoms of different stages of DR. The images contain different clinical signs of DR like hard exudates, soft exudates, microaneurysms, hemorrhages and neovascularization. The images were captured using a digital fundus camera of a 50° field of view with 24-bit color space [red-green-blue (RGB)] and 1500×1152 pixel resolution. This dataset is referred to as the "calibration level 0 fundus images". The dataset also contains the ground truth value of each image and evaluation script for Matlab.

DIARETDB1

Diabetic Retinopathy Database (DIARETDB1) [26, 27] [26] consists of 89, 24-bit color space retinal images with 1500×1152 pixel resolution. The images are in ".png" format. Four independent medical experts provided ground truth and validated it. This dataset is referred to as the "calibration level 1 fundus images". Of the images, 84 images contain mild to moderate changes of DR and five are healthy images.

HRF

High-Resolution Fundus (HRF) [28], a digital retinal database, is a joint venture of a research group established for research on automated segmentation of retinal images. It is a small dataset divided into three categories: healthy images, glaucomatous images and DR affected fundus images. Each category contains 15 images. The images were acquired using a CANON CF-60 fundus camera with a 45° field of view. The resolution of each image is 3504×2336 pixels with 24-bit color space and in JPEG format. The database is publicly available [28].

RIDB

Retina Identification Database (RIDB) [29] comprises 100 healthy retinal images. The main aim of this dataset was to design a person identification system. None of the DR and other retinal infected disease images are included in this dataset. The images were taken using a TopCon 50EX digital fundus camera with a resolution of 1504×1000 pixels and 24-bit (RGB) color space.

MESSIDOR

Methods to evaluate segmentation and indexing techniques in the field of retinal ophthalmology (MESSIDOR), a publicly available dataset, contains about 1200 images with a division of 400 images in three sets. Each set of 400 images was obtained from different ophthalmology

Table 3: Publicly available state-of-the-art retinal datasets.

Datasets	DRA	HE	NVD & NVE	CSME	GT	TNI
DRIVE	–	–	–	–	–	40
STARE	–	–	–	–	–	400
DIA RETDB0	Y	–	–	–	Y	130
DIA RETDB1	Y	Y	–	–	Y	89
HRF	–	–	–	–	–	45
RIDB	–	–	–	–	Y	100
Proposed dataset	Y	Y	Y	Y	Y	1445

DRA, Diabetic retinopathy annotation; HE, hard exudates; NVD/NVE, neovascularization on disc/elsewhere; CSME, clinically significant macular edema; GT, ground truth; TNI, total number of images.

departments. Eight hundred images are of dilated pupil and 400 images of non-dilated pupil. The images in MESSIDOR [30] were acquired from three different eye departments using a non-mydriatic TopCon NW6 fundus camera with a 45° field of view. Each set of 400 digital retinal images is opinioned and analyzed by various professional ophthalmologists. The images were captured using 24-bit color plane at 1440×960, 2240×1488 or 2304×1536 pixel resolution.

Table 3 presents the complete comparison between the proposed dataset and other state-of-the-art datasets with attributes related to DR.

After a comprehensive analysis of the famous retinal datasets, we can conclude that there is a need to develop a benchmark dataset of retinal images with the target of automated detection of DR and its subclasses specifically with the disease severity level. It would help researchers to conduct research specific to computer-aided DR diagnosis and classification systems.

The proposed benchmark for the detection of diabetic retinopathy

The prime objective of the proposed dataset is to provide a platform for researchers working on retinal diseases, specifically for DR. It can also be utilized for other retinal diseases such as hypertensive retinopathy (HR), ME, papilledema and for person identification systems. The proposed digital retinal database will work as a benchmark dataset to testify the performance, reliability and authenticity of fully/semi-automated disease diagnostic systems and person identification systems related to retinal images. The proposed benchmark for the detection of DR is publicly available for research purposes. For acquisition of benchmark, please contact the first author.

Fundus image acquisition

All the digital retinal images of the proposed dataset were acquired from the Department of Ophthalmology, RMU. Image acquisition was done under the supervision of an ophthalmologist panel comprising five expert ophthalmologists. Patients whose records are included in the proposed dataset have a history of diabetes of 1 or more years, are aged between 35 and 80 years, have blood glucose level fluctuations, can be insulin-dependent or non-insulin-dependent and may have a history of hypertension. The gender ratio is 60% female and 40% male patients.

The fundus photograph test was taken from an NIDEK non-mydriatic AFC-330 auto fundus camera which autofocuses the center of the retina. Patients with constricted pupil are dilated before the fundus test to attain the best standard quality retinal images for the proposed dataset. For other patients, the fundus test is accomplished without dilatation due to the non-mydriatic functionality of the AFC-330 camera. For pupils as small as 3.3 mm, the fundus test is performed with a 33° field of view and for normal pupils of 4 mm, the test is performed with a 45° field of view. Each image in the proposed dataset have a high resolution of 2976×2976 pixels with RGB 8-bit color space. The image format is JPEG with a 33–45° field of view. The exclusion criteria for images in the proposed dataset are blur or faded surface, poor or low brightness, poor resolution and unclear margins or low clinical information due to cataract or blurred view, etc. Figures 2–10 display some retinal images randomly selected from the proposed benchmark for the detection of DR with different clinical pathologies.

In Figure 2, the healthy images of the retina are illustrated showing no clinical signs of retinal disease. Patients are declared as healthy or normal if disease pathologies are not found on retina after the initial clinical screening by a technologist and a detailed clinical or slit lamp examination by a consultant ophthalmologist. These

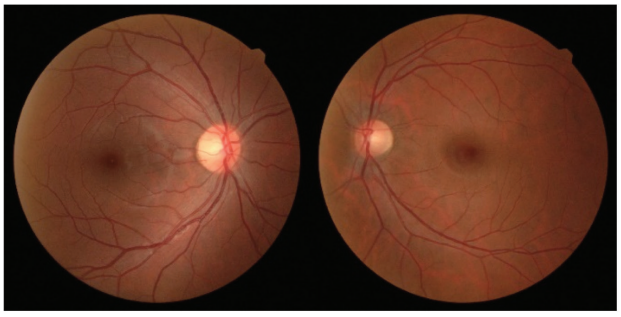

Figure 2: Healthy retinal images.

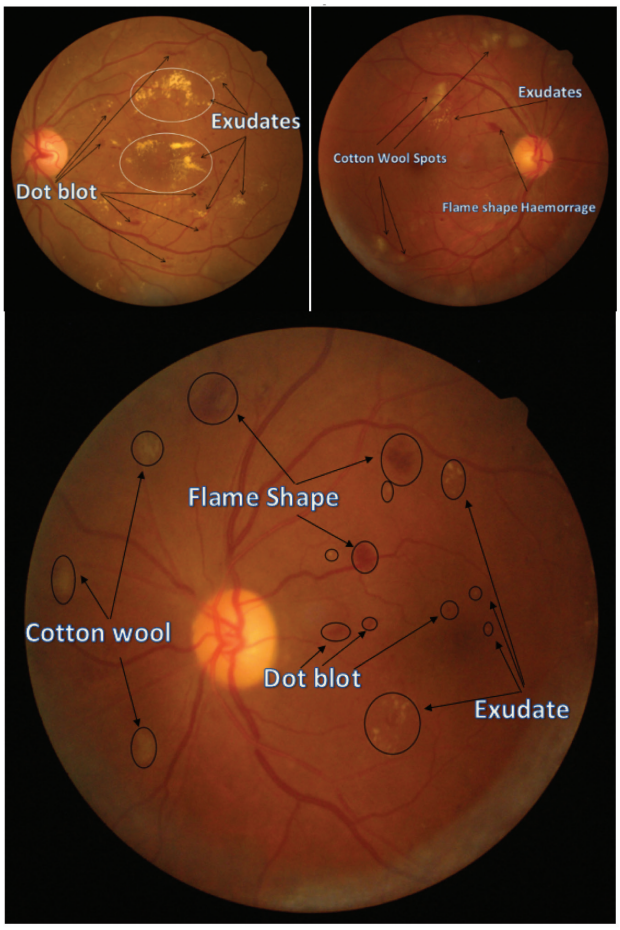

Figure 3: Abnormal retina with different clinical signs of NPDR.

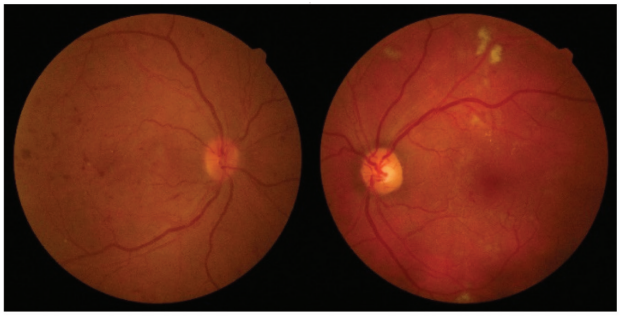

Figure 4: Mild stage of NPDR.

650 normal images can be used for person identification systems which are considered as the most authentic identification systems.

In Figure 3, there are three colored retinal fundus photographs showing different clinical signs of NPDR. In the first image in Figure 3, there are many dot-blot hemorrhages in peripheries and in the macular area. Exudates are also present in the macular area but the disc area is clear.

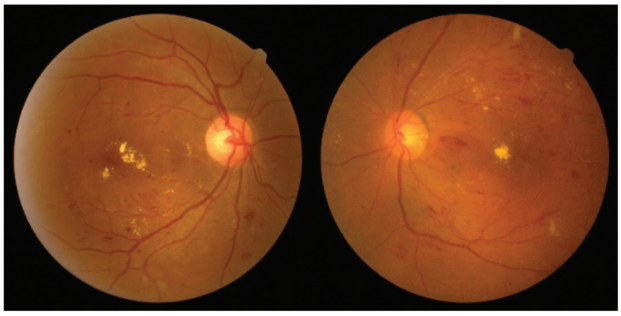

Figure 5: Moderate NPDR stage.

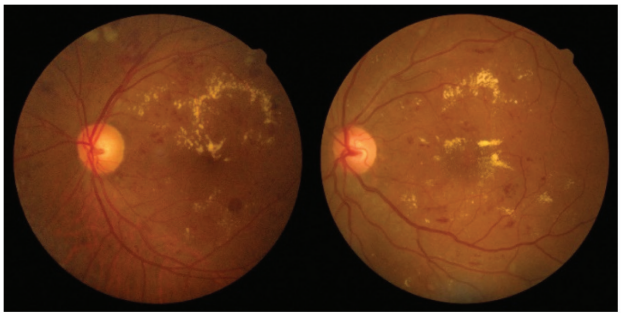

Figure 6: Severe NPDR stage.

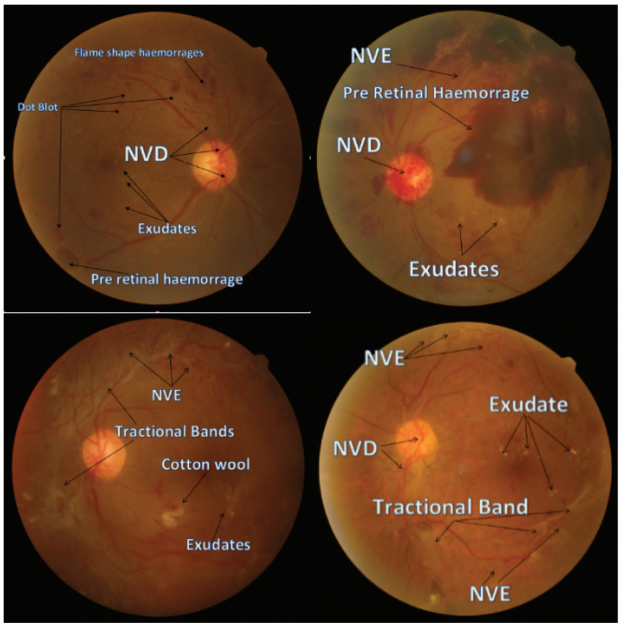

Figure 7: Abnormal retina with different clinical signs of PDR.

This image is classified as NPDR with clinically significant macular edema (CSME) and falls into the sight threatening diabetic retinopathy (STDR) category. The second image in Figure 3 includes the clinical signs of DR, for instance, cotton wool spots in macular peripheries and in

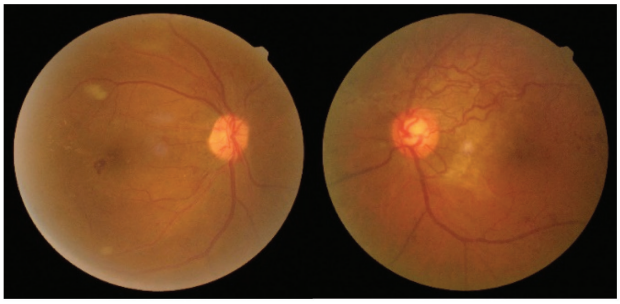

Figure 8: Early PDR stage.

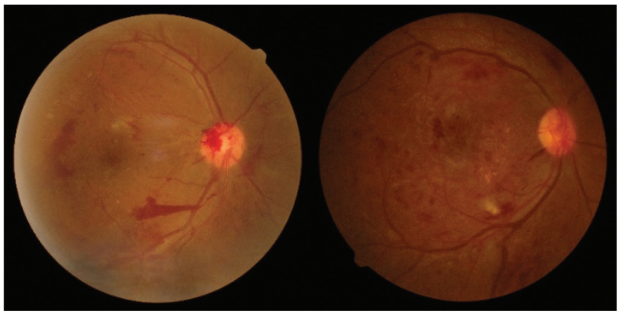

Figure 9: High-risk PDR.

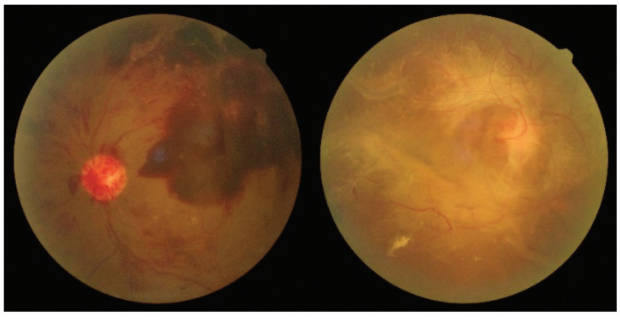

Figure 10: Advanced diabetic eye disease.

the marginal area of the retina, flame-shaped hemorrhages in the peripapillary area and exudates along the superior vascular arcade. This image is classified as NPDR. Image 3 contains soft and hard exudates, cotton wool spots, dot-blot and flame-shaped hemorrhages with very mild CSME, which is classified as NPDR. Figure 4 shows the images of mild NPDR stage; the left image contains exudates in the macular area as well as in the peripheries. Hemorrhages are present in the macular area and in its peripheries as well as in the peripapillary area. The right image contains early DR changes, i.e. cotton wool spots are present in two quadrants of the retina, exudates are present in the macular area in small amounts and microaneurysms exist in various areas of the retina in small quantities.

Figure 5 shows moderate NPDR. The left image contains exudates present in quadrants 1–3 of the retina including peripheries as well as the macular area which indicates the presence of ME according to the ETDRS classification explained in Table 2. Moreover, hemorrhages exist in quadrants 1–2 of the retina whereas microaneurysms are present in quadrants 2–3. The right image contains cotton wool spots in peripheries and exudates in quadrants 1–3. Exudates are present in peripheries as well as in the macular area which is considered as CSME. Microaneurysms are spotted in various areas of the retina.

Figure 6 shows a fundus photograph of severe NPDR. The left image contains exudates in quadrants 2–3 of the retina. Cotton wool spots are present in peripheries of the retina, whereas hemorrhages including dot-blot or flame-shaped are present in all four quadrants of the retina. Microaneurysms can also be seen in all quadrants. The right image contains both hard and soft exudates in quadrants 3–4. The presence of exudates in the macular area in high numbers indicates CSME. Flame-shaped or dot-blot hemorrhages are present in quadrants 3–4 of the retina whereas microaneurysms are also present in various areas.

These clinical signs are initially identified through retinal screening by the technologist as normal or abnormal and after the screening, the consultant considers the clinical signs and defines the images as normal or abnormal. If the fundus image is declared as abnormal, then the consultant ophthalmologist decides on an appropriate intervention to be done according to the international practice standards based on diabetes mellitus and other conditions of the patient. Figure 7 includes the images containing PDR pathologies like NVD, NVE, pre-retinal hemorrhages and tractional bands.

Neovascularization is the hallmark of PDR. Images 1, 2 and 4 contain both NVD and NVE whereas image 3 contains only NVE. Images 3 and 4 contain tractional bands which lead to TRD. TRD is a feature of advanced diabetic eye disease. All the images have exudates and dot-blot hemorrhages, while images 1 and 2 contain pre-retinal hemorrhage.

Figure 8 shows the fundus photograph of early-stage PDR. The left image contains NVD in the peripapillary area. Cotton wool spots are present in two quadrants, and exudates exist in the macular area and in its peripheries, which show CSME. Hemorrhages are also present in the macular area. The right image contains bunches of vessels on the disc area which continue to the upper peripheral area of the retina. Hemorrhages are present in quadrants 2–3.

Figure 9 shows the fundus photographs of high-risk PDR. In both pictures, signs of NPDR, i.e. dot-blot

hemorrhages, exudates, microaneurysms, are present. In addition, the image on the left shows NVE with pre-retinal hemorrhage and the image on the right shows neo-vessels on the disc, both of which are signs of high-risk PDR.

Figure 10 shows the features of advanced diabetic eye diseases. The image on the left shows massive pre-retinal hemorrhage and VH which is associated with neo-vessels on the disc and in the retinal periphery. The image on the right shows multiple areas of TRD. Both of these are a feature of advanced diabetic eye disease.

Data annotation

The annotation of each image is done by an ophthalmologist's panel which comprises five senior consultant ophthalmologists from the Department of Ophthalmology of RMU. The proposed dataset contains 1445 high-resolution digital retinal RGB images in JPEG format. Each image has a height and width of 2976×2976 pixels, respectively, with 8-bit color space for each color. The dataset comprises 650 normal or healthy images declared by the panel and 631 images are abnormal (NPDR) with clinical signs and symptoms of DR, specifically NPDR or may be HR including all stages, i.e. mild, moderate and severe, while the remaining 164 images are specifically associated with PDR of different stages.

Dataset summary

The proposed benchmark for the detection of DR comprises 1445 images. The number of healthy or normal images is 650. These images can be utilized for biometric systems also. NPDR type images are 631, while 164 images are of the PDR type. The dataset is divided into two sets: DR and no-DR mainly; the DR set is further divided into two subsets: NPDR and PDR. Each subset contains images of all levels of disease severity (mild, moderate, severe, early, high risk). Table 4 shows the complete summary of the proposed dataset in tabular form.

Table 4 summarizes the different clinical indications of the disease with pathologies of the proposed dataset. The DR annotation includes all signs of both subtypes: NPDR and PDR.

Table 4: Dataset summary.

Properties	Diseased (NPDR)	Diseased (PDR)	Normal
Presence of the optic disc	629	152	646
Presence of macula	628	–	631
HE/SE	552	137	N.A
Hemorrhages	478	156	N.A
Cotton wool spots	173	–	N.A
TB	N.A	62	N.A
NVD	N.A	101	N.A
NVE	N.A	122	N.A
CSME	348	78	N.A

HE/SE, Hard exudates/soft exudates; TB, tractional bands; NVD, neovascularization on disc; NVE, neovascularization elsewhere; HR, hypertensive retinopathy; CSME, clinically significant macular edema.

Evaluation metric

Quantitative analysis is key for the assessment of the performance and efficiency of an automated disease diagnostic system. The following quantitative indicators can be employed for the assessment of diagnostic systems using the proposed benchmark for the detection of DR:

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{1}$$

$$\text{Specificity} = \frac{\text{TN}}{\text{TN} + \text{FN}} \tag{2}$$

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{FN} + \text{TN} + \text{FN}} \tag{3}$$

True positive (TP) signifies the number of images with DR and is correctly identified by the algorithm. Samples which are healthy and identified as unhealthy by the algorithm are false positive (FP). True negative (TN) represents the number of images which are healthy and rightly detected as healthy by the system. Diseased or unhealthy images which are classified as healthy by the system are false negative (FN).

Conclusion and future work

This paper illustrates in detail the proposed dataset and presents all the clinical pathologies of DR. The dataset contains 1445 high-quality digital retinal photographs with ground truth and annotation given manually by a panel of consultant ophthalmologists of RMU for different symptoms and signs for diagnostic and severity level of types of DR (NPDR, PDR). The comparison with other state-of-the-art datasets presented in this article clearly illustrates that the proposed dataset outperformed the rest of the datasets due to attributes like image quality, resolution, ground

truth of all DR disease symptoms and giant dataset. The proposed dataset is specifically designed for research on DR disease, but it can also be used for other retina-associated diseases like CSME, HR and papilledema and for person identification systems using retinal images as it contains 650 healthy retinal images.

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