AVRDB: Annotated Dataset for Vessel Segmentation and Calculation of Arteriovenous Ratio

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***Abstract*— Hypertension is a syndrome that causes multiple adverse effects on the human eye such as retinopathy, optic neuropathy and choroidopathy. Hypertensive retinopathy (HR) is a pathological condition of human retina that arises due to the elevated blood pressure. Increased blood pressure causes narrowing of retinal arteries and veins that may lead to retinal hemorrhages, arteriovenous nipping, cotton wool spots and even papilledema. HR is one of those syndromes that have no apparent symptoms and can cause severe damage to the vision or even death (due to the presence of severe papilledema). HR is classified into different grades or categories depending upon its severity. There are different eye testing techniques that can be used to detect HR. Some commonly used techniques are ophthalmoscopy, fundus photography and fundus fluorescein angiography (FFA). Different researchers are working on developing fully automated decision support systems to diagnose HR. But in order to verify their efficiency, they need to test them on standardized and publicly available datasets. Therefore, this paper proposes a dataset that contains 100 high quality digital retinal images for the automated diagnosis and grading of HR. The dataset has been acquired by Armed Forces Institute of Ophthalmology (AFIO) and it has been annotated by multiple expert ophthalmologists. The proposed dataset is first of its kind to provide researchers with the segmented arteriolar and venule patterns along with the clinically calculated arteriovenous ratios (AVR), optic nerve head (ONH), hard exudates (HE) and cotton wool spots annotations. Apart from this, the proposed dataset has been thoroughly compared with the well-known publicly available datasets where the proposed dataset outmatched other datasets by allowing different researchers to automatically diagnose different complications of retinal pathology.**

Keywords—Hypertensive Retinopathy (HR), Papilledema, Fundus Photography, Arteriovenous Ratio (AVR)

I. INTRODUCTION

Sense of sight in humans is due to the vision formed by human eyes [1]. Human eye(s) is composed of three layers. The outer layer is known as sclera which protects the eyeball [2]. Underneath sclera, lies choroid which contains blood vessels and provide nourishment to the whole eyeball. The innermost and vision forming layer of an eyeball is retina [2]. The vision, after passing through pupil and biconvex lens, falls on retina. This vision is formed as a scaled and inverted image on fovea [2]. Fovea contains rod and cones cells surrounded by macular region with approximate diameter of 5500 microns. Figure 1 shows the complete anatomical structure of a human eye.

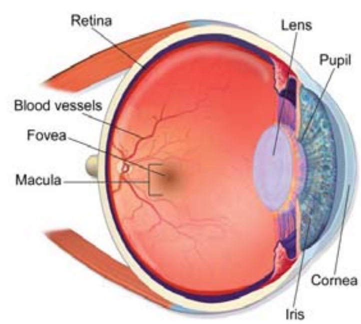

Figure 1: Anatomy of human eye [3]

There are many eye disorders that are associated with retina and HR is one of the most common and deadliest disease. HR occurs because of excessive blood pressure during hypertension. Increased blood pressure causes narrowing of retinal arteries and veins that may lead to retinal hemorrhages, arteriovenous nipping and even papilledema. HR is one of those syndromes that have no apparent symptoms and can cause severe damage to the vision or even death (due to the presence of severe papilledema). HR is classified into different grades or categories depending upon its severity. HR severity is usually shown on a scale of 1 to 4. This scale is known as Keith–Wagener–Barker classification system. The detailed complications of HR at each stage are characterized below:

- Grade 1 is related to the mild narrowing of retinal arteriolar patterns.

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- Grade 2 is related to the severe shrinking of retinal arteries. This stage is known as arteriovenous (AV) nipping. Plus signs of grade 1

- Grade 3 is a more advanced stage in which hard exudates, cotton wool spots, microaneurysms and retinal hemorrhages appears on the fundus of the retina. Plus signs of grade 2

- Grade 4 indicates the last stage of HR which includes swelling and blurring of the optic disc (OD), indicating the presence of papilledema. People having grade 4 HR are at a very higher risk of having strokes and cardiovascular diseases. Plus signs of grade 3

There are multiple eye testing techniques that are used to detect HR. Some common techniques are ophthalmoscopy, fundus photography and FFA. Fundus imagery is the most preferred way of diagnosing HR because its non-invasive and gives objective visualization of retinal vascular pathology [4]. In literature, there have been several HR case studies carried out from medical perspective, where HR was found along with presence of some life-threatening diseases such as papilledema. Also, there are no apparent symptoms of HR especially in earlier stages. Therefore, it is recommended that every patient of HR should be treated very carefully. A thorough history must be taken and a complete physical examination must be done. Many researchers have proposed fully automated decision support systems to diagnose HR based on calculating AVR in [5, 6, 7, 8, 9, 10] and they have tested their proposed system on publicly available datasets such as STARE, INSPIRE-AVR and VICAVR etc. In addition to these databases, we propose a new dataset that contains 100 high quality digital retinal images showing different pathological conditions of HR. Apart from this, the dataset is first of its kind in which different arteriolar and venular pathologies have been annotated along with AVR by multiple expert ophthalmologists. The dataset has been acquired by AFIO, Rawalpindi. Figure 2 shows one of the randomly selected healthy retinal image from the proposed dataset depicting the retinal pathology. Apart from this, this paper is organized in such a way that section II describes the state of the art publicly available datasets, section III depicts the detailed description of proposed dataset and section IV concludes the paper.

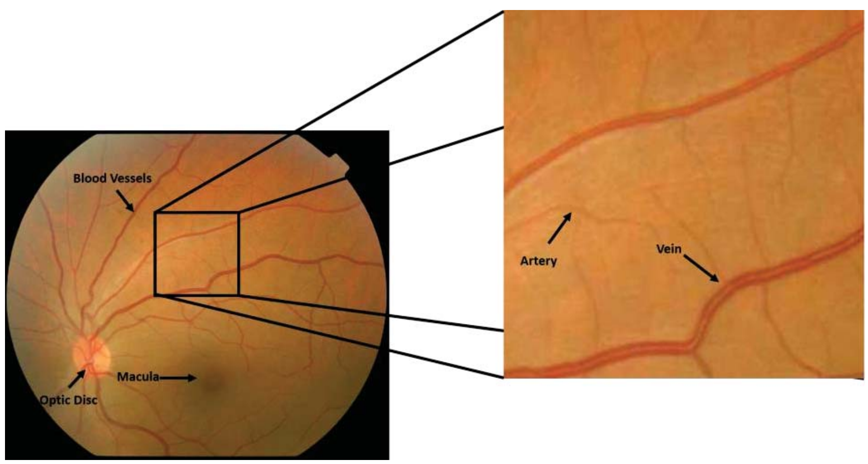


Figure 2: Fundus scan of a healthy left eye showing retinal pathology

II. Related Publicly Available Datasets

In order to develop and test fully automated decision support systems, different research groups have published their annotated image databases for screening various complication of retinal pathology. These datasets are publicly available for researchers to test their proposed systems. Some of the well-known datasets are INSPIRE-AVR, STARE, VICAVR, DRIVE, HRF and MESSIDOR, with a large number of annotations present for vessel segmentation, vessel width measurements and for the detection of different macular and ocular syndromes. The detailed description of each dataset is presented below.

A. INSPIRE-AVR

Iowa normative set for processing images of the retina-arteriovenous ratio (INSPIRE-AVR) is one of the publicly available dataset that contains 40 retinal images indicating annotated vascular pathology, OD region and AVR. This dataset is mainly used to classify and grade different complications of HR. The annotations in this dataset were carried out by two expert ophthalmologists through a semi-automated software developed by University of Wisconsin, Madison, WI, USA [11].

B. VICAVR

The VICAVR is also a publicly available dataset that contains fundus images for analyzing various pathological symptoms of HR. The dataset contains 58 digital retinal images which contains annotated vascular patterns. These annotations have been marked by three expert ophthalmologists. The images contained in this dataset have been acquired using TOPCON NW-100 non-mydriatic fundus camera. All the images contained in the VICAVR are OD centered. The dataset also includes a measurement of arteriovenous pathology at different radii from OD [12].

C. STARE

Structured analysis of the retina (STARE) is a most commonly used database that contained images showing different complication of macular and ocular pathology. STARE contains around 400 images including 50 labeled images of vascular patterns, 80 images showing ground truth for optic nerve detection [13]. All the images in the dataset was captured with the resolution of 605 x 700 pixels with a 24-bits color space, using a TOPCON TRV-50 fundus camera that has 35-degree field of view (FOV).

D. HRF

High resolution fundus (HRF) imaging database was produced by collaborative research groups. The aim of producing this dataset is to support the development of clinical decision support systems for the automated diagnosis of retinal abnormalities. The dataset is publicly available at [14]. It contains 45 retinal images comprising of 15 healthy, 15 glaucomatous and 15 diabetic retinopathy (DR) subjects. These images are acquired at the resolution of 3504 x 2336 pixels with 24-bits per pixel (BPP) from CANON CF-60 UVi camera with a 60-degree FOV. The dataset contains the annotated vascular patterns. These annotations are performed by the group of expert ophthalmologists. The dataset also contains the localization information about the macular and ocular region.

E. DIARETDB0

Standard diabetic retinopathy database calibration level 0 (DIARETDB0) is another publicly available fundus imagery database [15] for analyzing diabetic retinopathy patients. It contains 130 color fundus photographs from which 20 are of healthy subjects and remaining contains abnormal DR pathology such as hard exudates, soft exudates, microaneurysms, hemorrhages and neovascularization. These images are acquired from Kuopio university hospital with the fundus camera of 50-degree FOV. The images are stored in a PNG format along with a text file that contains the detected diabetic lesion type. Apart from this, the dataset contains variety of undesired parameters such as acquisition noise, camera geometry and optical aberrations.

F. DIARETDB1

Standard diabetic retinopathy database calibration level 1 (DIARETDB1) is also a publicly available database [16] that comprises of 89 images from which 84 images contains DR pathology and 5 images are of healthy subjects. These images are acquired by the fundus camera of 50-degree FOV. The dataset have been annotated by four expert ophthalmologists by highlighting exudates and bright lesions on the respective fundus scan.

G. DRIONS

Digital retinal images for optic nerve segmentation (DRIONS) is another publicly available database specifically designed to test fully automated system for ONH segmentation. The dataset is available at [17] and it contains 110 OD centered fundus photographs. These images were acquired using an analog fundus camera and are scanned using HP-PhotoSmart-S20 scanner. The images have the dimension of 600x400 pixels where each pixel is represented by 8 bits. The dataset has been annotated for ONH segmentation by 2 expert ophthalmologists.

H. MESSIDOR

Methods to evaluate segmentation and indexing techniques in the field of retinal ophthalmology (MESSIDOR) is an online free database [18] which contains around 1200 fundus scans. These images are acquired using a TOPCON TRC NW6 non-mydriatic 3CCD camera that has a FOV of 45-degrees. Dataset is categorized into 3 groups where group contains 400 images. Each group is annotated by different expert ophthalmologist. All the images in the dataset are captured at the resolution of 1440 x 960, 2240 x 1488 and 2304 x 1536 where each pixel is comprised of 8-BPP. The dataset has been annotated to analyze various complications and severity levels of DR and ME.

I. DRIVE

Digital retinal images for vessel extraction (DRIVE) is also a famous online dataset [19] that contains 40 fundus scans depicting vascular patterns and different complications of DR. These images are captured with the resolution of 768 x 584 pixels, 8-BPP, using Canon CR5 non-mydriatic 3CCD camera with FOV of 45-degrees. Out of 40 images in the dataset 33 contains the healthy retinal pathology while 7 of them show mild complications of DR. Apart from this, all the vascular patterns have been annotated in the dataset by expert ophthalmologists which helps in vessel segmentation.

Table 1: Dataset Comparison

Dataset	**AVR***	**VA***	**ONA***	**GA***	**HE***	**GT***	**NI***
INSPIRE-AVR	✔	✔				2	40
VICAVR	✔	✔				2	58
STARE		✔	✔				400
DIARETDB0					✔		130
DIARETDB1					✔	4	89

HRF		✔	✔	✔			45
DRIONS			✔			2	110
PROPOSED	✔	✔	✔	✔	✔	**4**	**100**

*AVR: Arteriovenous Ratio; VA: Vascular Annotations; ONA: Optic Nerve Annotations; GA: Glaucoma Annotations; HE: Hard Exudates; GT: Experts in Ground Truth; NI: Number of images in dataset

Table 1 summarizes different pathological conditions of human retina which can be characterized using the publicly available datasets and they are also compared with the proposed dataset. For HR, there are only three datasets that are being used which gives the calculated AVR for the characterization of HR. But apart from AVR, the proposed dataset also provides the annotated arteriolar and venule pathology which can be used to test the efficiency of the automated self-diagnosis system to extract and characterize vascular patterns. In addition to that, the proposed dataset can be used to identify other types of retinal pathologies as well such as macular edema (ME), papilledema and proliferative diabetic retinopathy (PDR) etc. as shown in Table 1.

III. Proposed Dataset Description

The dataset is primarily focused on testing the efficiency of fully automated clinical decision support systems that aim to diagnose various complication of HR. For that purpose, the proposed dataset contains annotated vascular pathology which is further characterized into arteriolar and venule patterns. Apart from this, the proposed system can also be used to diagnose other retinal syndromes like ME, papilledema and PDR etc.

A. Image Acquisition

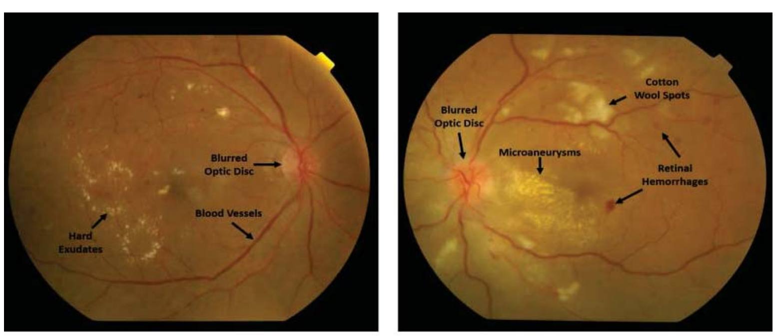
The proposed dataset has been acquired from AFIO, Rawalpindi, Pakistan. Observed patients were selected by ophthalmologists based on their clinical history. The criteria for patient selection was the medical examination done by expert ophthalmologists. Patients with normal examination results are categorized as healthy and images acquired from them are labeled as normal. The nominal age limit for the candidates were 25 to 80 years where the ratio of males and females were proportionally balanced.

Image acquisition is done using TOPCON TRC-NW8 by proper dilation of eye to get a good quality image of internal retina using the following specifications: Centered on optic disc and macular regions, with dimensions of 1504 x 1000. JPEG uncompressed images are used with 30-degrees of FOV. Images with poor illumination, unclear information and improper capture were discarded. Table 2 summarizes the proposed dataset [20].

Table 2: Dataset Summary

Dataset	**Healthy**	**Diseased**
Resolution	1504 x 1000 pixels	1504 x 1000 pixels
Maculae Centered	10	76
OD Centered	10	4
Presence of Exudates		12
Presence of Hemorrhages		7
Papilledema		4
HR		45
Cotton Wool Spots		8

The dataset contains 86 maculae centered and 14 OD centered fundus scans. Out of these 86 scans, 76 contain the disease patterns. The major types of syndromes that can be tested by the proposed dataset are HR, ME, papilledema and PDR. Figure 3 shows the randomly selected scans from the proposed dataset showing each type of abnormal syndrome indicated by the presence of hard exudates, retinal hemorrhages, cotton wool spots, mircroaneurysms, blurry OD region and arteriovenous pathology.



(a) (b)

Figure 3: Abnormal pathological symptoms reflecting different types of retinal syndromes

The dataset is specifically targeted for the analysis of HR. For that purpose, the retinal blood vessels have been annotated which are further classified into arteriolar and venule patterns as shown in Figure 4. The vascular patterns are used to compute AVR from which HR can be diagnosed. Apart from the annotated arteriovenous pathology, the proposed dataset also contains annotations about the HR affected scans and healthy scans.

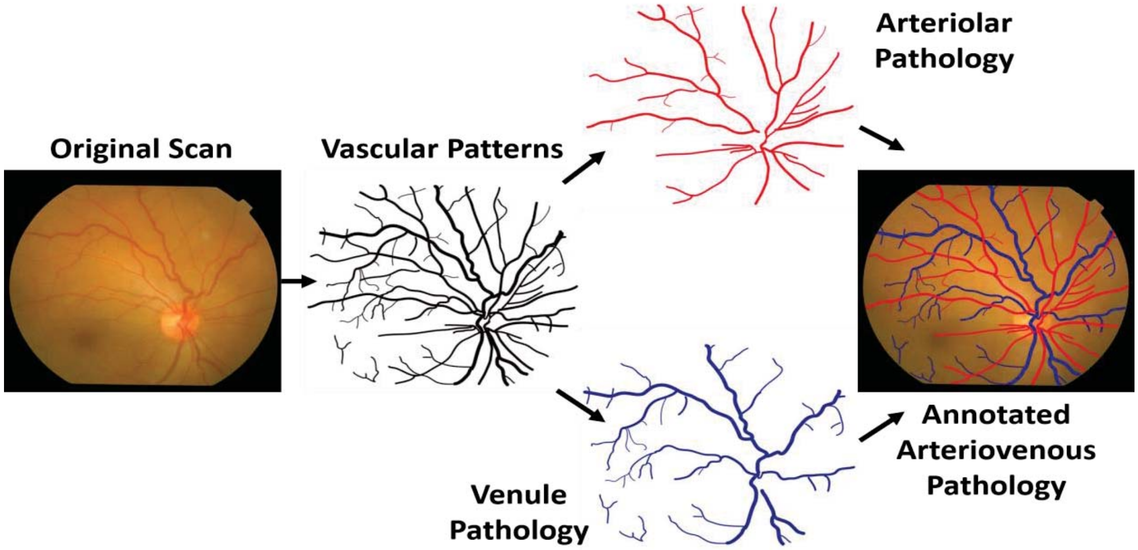


Figure 4: Annotated arteriovenous pathology to identify HR positive candidates

B. Data Annotations

The dataset contains 100 fundus images of both eyes which were annotated by four specialists in AFIO. The annotations include characterization of retinal arteries, veins and a complete vascular pathology. Adobe Illustrator CC is the software which was used by ophthalmologists to mark the observations. Apart from this, the dataset also contains annotated AVR for diagnosing HR. Ground truth of 100 images are also labeled by four expert ophthalmologists. Figure 5 shows three randomly selected retinal images along with their annotated vascular pathology. These annotations are further characterized into arteriolar and venule patterns, and they are also mapped onto the original scan, as shown in Figure 5.

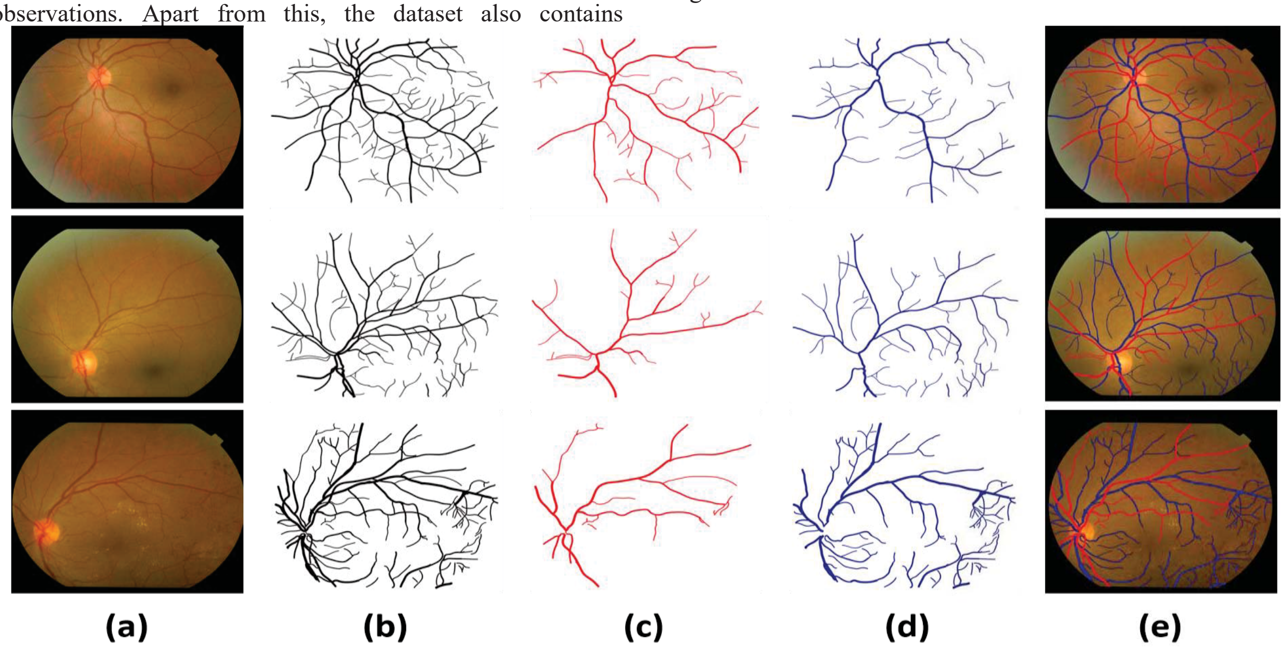


Figure 5: Fundus scans in proposed dataset, (a) original images, (b) annotated blood vessels, (c) annotated arteries, (d) annotated veins, (e) annotated vascular patterns mapped onto the original scan

IV. Conclusion

This paper presents the dataset for analyzing different pathological conditions of HR. The dataset contains 100 retinal scans acquired from AFIO, Rawalpindi, Pakistan. The dataset has been annotated by four different ophthalmologists for diagnosing and measuring different severity of HR. These annotations were carried out through Adobe Illustrator CC. Although the dataset has been primarily designed to analyze HR positive candidates, however it can also be used to diagnose other retinal syndromes like papilledema, ME and PDR etc. The proposed dataset contains annotations of retinal vascular patterns which are further categorized into arteriolar and venule pathologies. These annotated vessels can be used to calculate AVR which can be used as a benchmark to test the efficiency of clinical decision support systems for the automated diagnosis of HR. The proposed dataset has also been compared with other state of the art datasets where it outperformed them by effectively diagnosing different pathological conditions of human retina.

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