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A novel computer aided quantification method of focal arteriolar narrowing using colour retinal image

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ABSTRACT

We present a novel method for the quantification of focal arteriolar narrowing (FAN) in human retina, a precursor for hypertension, stroke and other cardiovascular diseases. A reliable and robust arteriolar boundary mapping method is proposed where intensity, gradient and spatial prior knowledge about the arteriolar shape is incorporated into a graph based optimization method to obtain the arteriolar boundary. Following the mapping of the arteriolar boundaries, arteriolar widths are analysed to quantify the severity of focal arteriolar narrowing (FAN). We evaluate our proposed method on a dataset of 116 retinal arteriolar segments which are manually graded by two expert graders. The experimental results indicate a strong correlation between the quantified FAN measurement scores provided by our method and two experts graded FAN severity levels. Our proposed FAN measurement score: percent narrowing (PN) shows high correlation (Spearman correlation coefficient of 0.82 ($p < 0.0001$) for grader-1 and 0.84 ($p < 0.0001$) for grade-2) with the manually graded FAN severity levels provided by two expert graders. In addition to that, the proposed method shows better reproducibility (Spearman correlation coefficient $\rho = 0.92$ ($p < 0.0001$)) compared to two expert graders ($\rho_{grader_1} = 0.81$ ($p < 0.0001$) and $\rho_{grader_2} = 0.75 (p < 0.0001)$) in two successive sessions. The quantitative measurements provided by the proposed method can help us to establish a more reliable link between FAN and known systemic and eye diseases.

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1. Introduction

Attenuation or narrowing of the retinal arteriole is known as focal arteriolar narrowing (FAN), which is the sudden narrowing of the arteriolar width in the retina [1] as shown in Fig. 1.

Focal arteriolar narrowing (FAN) is an indication of arteriosclerosis. It is a systemic disease. The presence of FAN in the retinal arterioles affects the entire circulatory system [2]. Previous researches have shown that FAN has a significant correlation with cerebral thrombosis or coronary thrombosis [3–6]. Currently, the assessment of FAN is performed by a human grader in a qualitative manner. The grader examines retinal photographs and compares the detected abnormalities with standard photographs to assess their presence and severity. This results in a 2-scale (absent or present) or 4-scale (absent, questionable, mild and severe) grading system. This grading process, however, depends heavily on the grader's expertise and thus, its accuracy and reproducibility are of concerns. Therefore a computer aided reliable and reproducible FAN quantification method is a necessity for the large scale and longitudinal studies.

Pedersen et al. [7] have presented a semi-automated method for the detection of FAN. They trace the artery from the user given start and end point using Dijkstra's shortest path algorithm. After tracing the artery they have used full width half maxima (FWHM) method to compute the arteriolar width. Then normalized accumulated gradient (NAG) and coefficient of variance (CV) of the arteriolar widths are used to detect the presence of FAN. In [7] only intensity information is used to trace the arteries which might not work for the arteries having low contrast and high central reflex. In Roy et al. [8] an automatic method is presented for detecting the presence of FAN in an arteriolar segment, where retinal vessels are first classified into artery and vein. Then arteries are divided into segments using the position of the branch and crossover points. Following this, the width of each artery segment is analysed to detect the presence of FAN. Automated FAN

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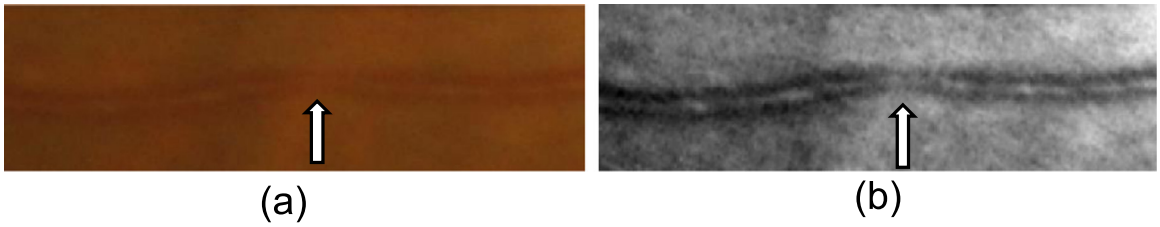

Fig. 1. An arteriolar vessel segment with focal arteriolar narrowing in (a) RGB channel and in (b) green channel.

detection is extremely difficult in pathological retinal images because pathological retinal images contain arteries with poor contrast and high arterial central reflex [4] which makes classification of artery and vein very difficult. In addition, poor contrast of arteries affects the detection of branch and crossover points which is mandatory for fragmenting the arteries into small candidate segments. Thus automatic detection of candidate arteriolar segment is very challenging in pathological retinal images. In this paper we mainly focus on the quantification of the FAN, which provides more detail information regarding the FAN severity. Therefore we propose a semi-automatic method that uses little manual intervention to select the candidate arteriolar segment. Following that a novel arteriolar boundary mapping method is proposed to accurately map arteriolar boundary which is a necessity for accurate arteriolar width measurement.

Our main contribution is the proposal of a novel arterial boundary mapping method. Rather than using only intensity information, we incorporate gradient information into our segmentation framework. In addition, spatial prior information of the arteriolar shape is also incorporated into the segmentation framework using a graph based optimization approach. Arteriolar widths are computed after mapping the arteriolar boundaries and following that a set of FAN measurement scores is computed. Proposed method is evaluated on 116 artery segments of ENVISion retinal image dataset [9]. We select ENVISion dataset because it contains pathological retinal images with low contrast and high central reflex affected arteries taken from elderly people (age $\geq$60) having hypertensive retinopathy. Our method quantifies the focal narrowing by analysing the arteriolar widths which shows high correlation with the manually graded FAN severity level given by two expert graders. Following that, we compare the accuracy of FAN quantification, using the proposed artery segmentation method and a state-of-the-art vessel segmentation method. Then, we compare the reproducibility of our method with two expert graders.

The rest of this paper is organized as follows. In Section 2, description of the dataset is given. In Section 3, the details of the proposed method are described. The results and discussion which are summarizing the performance of the proposed method are presented in Section 4. Finally, Section 5 concludes the paper.

2. Dataset

The proposed method is evaluated using high resolution retinal images obtained from 54 patients of ENVISion study [9]. Two colour retinal photographs, centred on the optic disc and macula, are taken from each eye of the participant. The photographs are taken after 5 min of dark adaption, without pharmacological pupil dilation, using non-mydriatic (CR-1) Canon EOS 50D[1] (15.1 mega pixel resolution) fundus camera with a field of view of 45°. The resolution of the retinal images are 4752 pixels × 3168 pixels (pixel size = 25.399×10^3 μm).

[1] http://www.canon-europe.com/medical/eye_care/cf-1/

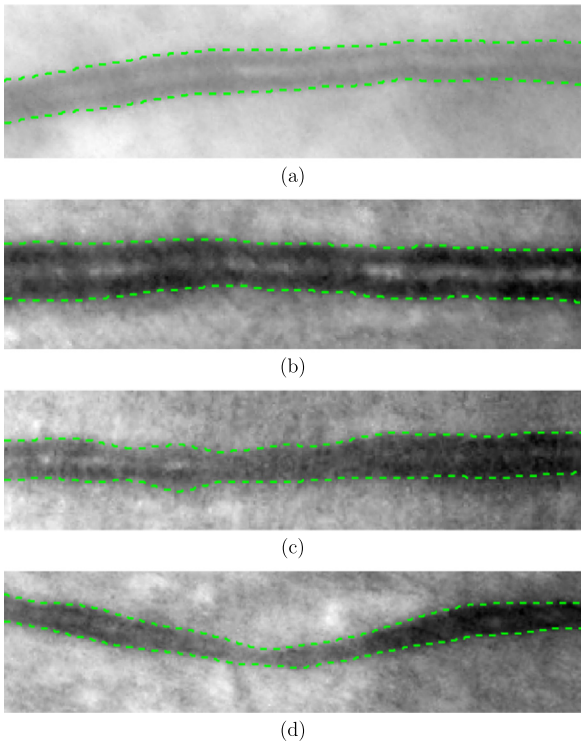

Fig. 2. Automatically segmented arterial boundary for different FAN severity level: (a) absent, (b) questionable, (c) mild and (d) severe.

From these images, 116 arterial segments are arbitrarily selected to evaluate the performance of the proposed method for FAN assessment. The range of the median width of the selected arterial segments are (16.83 ± 3.43) pixels. Each arterial segment is manually graded by two expert graders; one of them is from the Centre for Eye Research Australia (CERA) (Melbourne, Australia) and the other one is from the Department of Computing and Information Systems, University of Melbourne, Australia. A 4-scale grading system (where 0 = normal, 1 = questionable, 2 = mild and 3 = severe) is used to label the severity of FAN. A set of 4 example FAN segment with varying FAN levels is shown in Fig. 2.

3. Methodology

Block diagram of the proposed method is presented in Fig. 3. Our method has seven main steps as follows:

1. Four manually given candidate points are used to crop a rectangular region of interest (ROI) containing the arteriole of interest (AOI).
2. A set of preprocessing operations is performed on the ROI to make the AOI segmentation easier.
3. The candidate arteriolar edge points inside the ROI are obtained by gradient analysis.

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