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Retinal artery–vein caliber grading using color fundus imaging

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ABSTRACT

Recent research suggests that retinal vessel caliber (or cross-sectional width) measured from retinal photographs is an important feature for predicting cardiovascular diseases (CVDs). One of the most utilized measures is to quantify retinal arteriolar and venular caliber as the Central Retinal Artery Equivalent (CRAE) and Central Retinal Vein Equivalent (CRVE). However, current computer tools utilize manual or semi-automatic grading methods to estimate CRAE and CRVE. These methods involve a significant amount of grader's time and can add a significant level of inaccuracy due to repetitive nature of grading and intragrader distances. An automatic and time efficient grading of the vessel caliber with highly repeatable measurement is essential, but is technically challenging due to a substantial variation of the retinal blood vessels' properties. In this paper, we propose a new technique to measure the retinal vessel caliber, which is an "edge-based" vessel tracking method. We measured CRAE and CRVE from each of the vessel types. We achieve very high accuracy (average 96.23%) for each of the cross-sectional width measurement compared to manually graded width. For overall vessel caliber measurement accuracy of CRAE and CRVE, we compared the results with an existing semi-automatic method which showed high correlation of 0.85 and 0.92, respectively. The intra-grader reproducibility of our method was high, with the correlation coefficient of 0.881 for CRAE and 0.875 for CRVE.

1. Introduction

Cardiovascular diseases (CVDs) such as coronary heart disease and stroke, are the leading causes of death in developed and developing countries; claiming 17.1 million lives a year [1]. This figure is expected to increase due to the ageing population and cardiovascular risk factors such as diabetes and obesity. Early identification of people at risk of CVDs is important as it allows for better designs and implementation of preventative strategies.

Recent studies have shown that retinal vessel caliber changes (arteriolar narrowing and venular widening) can be a predictive marker for CVDs such as coronary heart disease and stroke [2,3]. A quantification of retinal vessel caliber (i.e., cross-sectional width), summarized as the CRAE and CRVE has been utilized to assess microvascular health in vivo [4]. This may contribute to early diagnosis and prevention of the mortality

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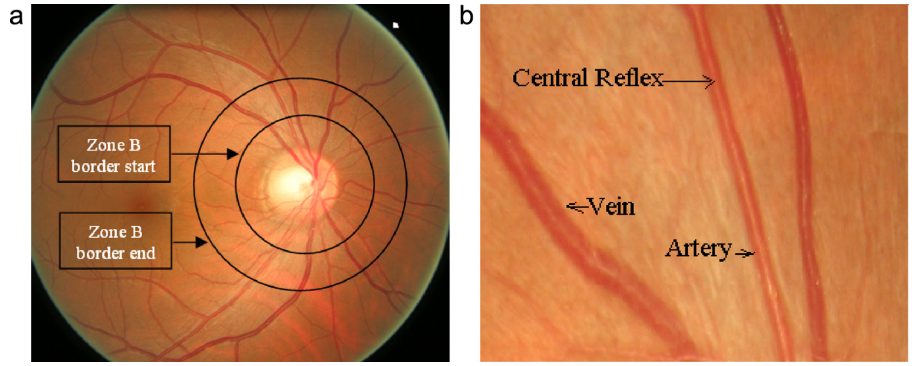

Fig. 1 – A retinal image showing zone B area (a) and cropped image showing the retinal artery, vein and the central reflex (b).

and morbidity associated with CVDs, and eventually reduce the burden of CVDs which is the aim of the work described in this paper.

The most widely utilized grading processes for retinal vessel caliber are manual and semi-automatic methods where a human grader determines a vessel as an arteriole or venule [5,6]. The vessel cross-sectional width is then measured to represent the vessel caliber. This process is time consuming, costly, and has high inter-grader variability [7]. Reproducibility is another major issue. So, an automatic and accurate grading process is a necessity for retinal vessel caliber measurement.

A number of vessel caliber measurement techniques have been proposed [8–11] which mainly models vessel cross-sectional profile to measure the vessel caliber. The models have been designed for profiling blood vessels using various patterns, such as regular, triangular, elliptical and Gaussian. A 2D vessel width measurement model has been proposed [8,9] which assumes image intensity as a function of distance across the vessel as a single Gaussian form. Gao et al. [10] have proposed a model for the intensity profiles over vessel cross sections using twin Gaussian functions which can overcome a central reflex problem and acquire vessel width. Huiqi et al. [11] have proposed a method which is based on matched Gaussian filter and Kalman filter for measurement of vascular width in zone B area. Zone B is the circular region (Fig. 1) which starts at 1× Optic-Disc-diameter and ends at 1.5× Optic-Disc-diameter from the Optic-Disc-center in the retinal image [12].

Existing techniques have limitations, such as intensity distribution curves are not always of single or twin Gaussian form and can be random in the vessel orientation. In particular, the central reflex which is a bright strip running down the center of a vessel causes a complicated intensity cross-section for two parallel or side-by-side vessels [13]. Locally, this is hard to distinguish from two side-by-side vessels with central reflex [14,15]. Individual vessel width needs to be computed to identify the true vessel(s).

In this paper, we describe a new method to compute vessel caliber as CRAE and CRVE. The proposed method tracks the retinal blood vessels and measures caliber. Our method can be described as further improvement of dual Gaussian model that identifies individual vessel width to overcome the limitation of merging two side-by-side vessels as single vessel and detection of vessel central reflex.

2. The proposed method

The proposed method focuses on efficient and accurate vessel caliber measurement, thus it tracks vessel edge and computes the width for each of the cross-sections of a vessel. For vessel tracking and caliber measurement, we consider the zone B area to follow the established Knudtson protocol for CRAE and CRVE computation [5]. Therefore, the main focus of our method is to identify individual vessel segment's edge and measure its caliber.

We note that there are existing edge tracking based methods [8,11] for retinal vessel detection and width measurement. However, the methods regularly fail on high resolution images which has the property such as central reflex; they also fail to detect two side-by-side parallel vessels (Fig. 2). Our method offers further improvement of this existing vessel edge tracking based methods as we consider edge profiling (i.e., measure intensity level on both side of edge within specific direction) to define the first edge or second edge of a vessel based on direction (Section 3.1) and vessel actual width in microns through image calibration and microns/pixels computation. We also consider central reflex pattern which provides accurate detection of vessel for two side by side vessels including vessel with central reflex. Fig. 2 shows the results on vessel edge tracking by parallel edge or single and twin Gaussian and the vessel tracked by our method.

Therefore, our contribution in the paper is vessel caliber measurement by tracking or identifying individual vessel edges. The novelty of our method can be stated as:

- Provide a method for enhanced feature extraction, i.e., edge profiling for individual vessel edge tracking.
- Retinal vessel central reflex pattern identification.
- Utilize retinal blood vessel physiological properties to improve the accuracy of vessel caliber measurement.

3. Methodology

First, all edges are detected from the image and then each of the edges is identified individually from the zone B area. To compute zone B area, we obtain the optic disc (OD) center and radius [16]. Edge profiling is subsequently performed