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Retinal artery and venular caliber grading: A semi-automated evaluation tool

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ABSTRACT

Retinal imaging can facilitate the measurement and quantification of subtle variations and abnormalities in retinal vasculature. Retinal vascular imaging may thus offer potential as a noninvasive research tool to probe the role and pathophysiology of the microvasculature, and as a cardiovascular risk prediction tool. In order to perform this, an accurate method must be provided that is statistically sound and repeatable. This paper presents the methodology of such a system that assists physicians in measuring vessel caliber (i.e., diameters or width) from digitized fundus photographs. The system involves texture and edge information to measure and quantify vessel caliber. The graphical user interfaces are developed to allow retinal image graders to select individual vessel area that automatically returns the vessel calibers for noisy images. The accuracy of the method is validated using the measured caliber from graders and an existing method. The system provides very high accuracy vessel caliber measurement which is also reproducible with high consistency.

1. Introduction

Cardiovascular diseases (CVD) such as coronary heart disease (CHD) and stroke cause the highest morbi-mortality in developed countries. Early identification of people at risk of these vascular diseases is important as it allows better design and implementation of preventative strategies. Recent research suggests that retinal vascular caliber is closely associated with clinical and subclinical cerebrovascular, cardiovascular and metabolic outcomes. For example, retinal arteriolar narrowing is a predictive factor for coronary heart disease and stroke [1–3]. Retinal vascular imaging can thus offer potential as a non-invasive research tool to predict cardiovascular risk for an individual person [4].

1.1. Definitions of retinal vascular features

Vessel caliber: Vessel caliber refers to the width of a particular vessel cross-section. Fig. 1 shows the calibers of some vessel cross-sections, i.e., length of each line refers to the caliber of the cross-section.

Vessel central reflex: Retinal central light reflection from the surface or outer wall of retinal arterioles or venules which is a bright strip running down the center of a vessel (Fig. 1).

Central retinal arterial equivalent (*CRAE*): Central Retinal Arterial Equivalent is an overall caliber value (i.e., a single scalar value) of big six arteries in width which is derived using the Knudtson formulae as follows [5]:

$$CRAE = 0.88*(w_i^2 + w_j^2) \quad (1)$$

where (i,j) is the largest and the smallest artery pair from the top six arteries. An iterative procedure of pairing up the largest vessel with the smallest is used until a single value for CRAE is reached.

Central retinal vein equivalent (*CRVE*): Similar to CRAE, Central Retinal Vein Equivalent (CRVE) is an overall caliber value for big six veins measured using the Knudtson formulae as follows [5]:

$$CRVE = 0.95*(w_i^2 + w_j^2) \quad (2)$$

where (i,j) is the largest and the smallest vein pair from the top six veins. An iterative procedure of pairing up the largest vessel with the smallest is used until a single value for CRVE is reached.

A measurement through quantification of caliber is to quantify retinal arteriolar and venular caliber as the Central Retinal Artery Equivalent (CRAE) and Central Retinal Vein Equivalent (CRVE), respectively [1].

However, the most challenging issues are to quantify the CRAE and CRVE accurately and to maintain consistency and repeatability in the

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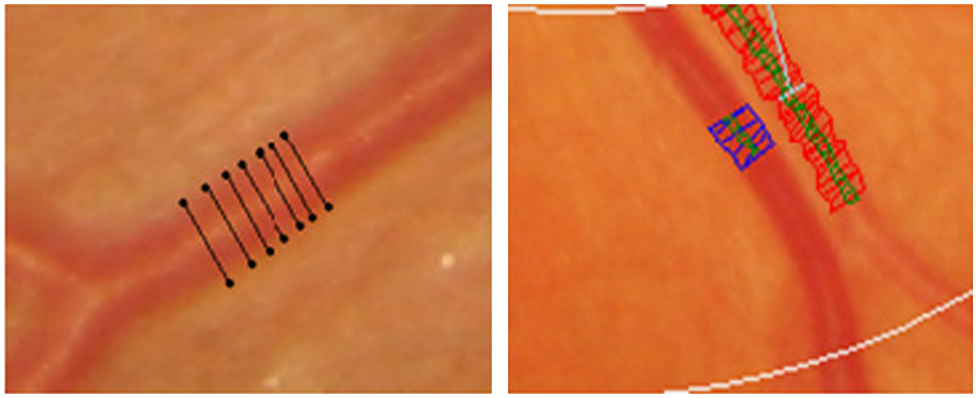

Fig. 1. Lines showing vessel cross-sectional width or caliber (left) and green lines showing vessel central reflex width (right). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

measurement process. This involves retinal blood vessel detection and caliber measurement. A large number of algorithms [6–12] have been proposed for automatic detection of retinal blood vessels. None of these methods can map vessel pixels correctly in the presence of vessel central reflex properties. Although a number of methods [13–16] were proposed for vessel caliber measurement, a significant improvement is still a necessity for vessel with central reflex and existence of parallel and two closely positioned blood vessels (Fig. 2). All these techniques were applied to the high quality images. In addition, for accurate grading of retinal vessel caliber, we have to detect vessels and identify artery and vein with 100% accuracy. Realistically, this goal is almost impossible.

A fully automatic system can be advantageous in efficiency and cost saving image grading but may only be applicable for high-quality images. There are low quality images for which the analysis is most important, because vascular problems occur in the elderly when cataract, miosis or other diseases obscure the ocular media impending to obtain high-quality retinal images. This is why a semiautomatic method is an essential. Fig. 2 depicts some situations where semi-automated method is inevitable. For this reason we developed the system as semi-automatic instead of fully automatic. Our approach is also supported by [17]. A good computer-assisted method for quantification of the signs of retinal vascular damage should have the following characteristics: semi-automated, quick and able to get measures in non-optimal quality images. In this paper, we describe this semi-automated system which aims to quantify retinal arteriolar and venular caliber (CRAE and CRVE respectively) while addressing the above mentioned issues. The CRAE and CRVE values along with other biomarkers such as age, gender, smoking, diabetes and hypertension information can be used for early detection of CVD that will be reported elsewhere.

The main contribution of the paper is the methodology of a grading tool that grades vessel caliber in poor quality images. The system is based on novel methods such as missing vessel region selection, preprocessing and vessel edge detection and vessel identification. The paper focused on the algorithms used for the development of the semi-automated vessel detection and caliber measurement tool, and the evaluation of the software tool which was developed at the Centre for Eye Research Australia. Our aim was to develop a highly accurate and efficient arteriolar and venular caliber measurement system which can also maintain the consistency and repeatability of the grading results.

2. Materials and method

In this paper, we mainly describe the algorithms which are used to develop the semi-automated software. We also provide the analysis of validation of the results. The software interface (Fig. 3) works in the following sequence of steps. First, the color fundas images are loaded using the main interface (Fig. 3a) and processed (compute CRAE and CRVE automatically) them in a batch of images or as an individual image. In this step we automatically detect vessels and measure the individual vessel caliber and compute the CRAE and CRVE and save them in a file. In the second step, we semi-automatically measure the caliber of the undetected or incorrectly graded vessels' caliber and grade the image finally (grading interface in Fig. 3b). We can also select and truncate a vessel which gives us the best caliber measurement accuracy for any artery or vein. The artery or vein is selected by single clicking of a mouse. Once the grading is finished the grader accepts to finalize the grading and the CRAE and CRVE values are saved in the file for the image.

The proposed software system can be presented in two major modules. In the first module we automatically trace vessels and measure caliber using main interface for image loading and processing. In the second module, we use the grading interface to correct the detected calibers by removing part or full vessel, and select the area or region of the missing vessels. In this step, a method determines the vessel edges and measures caliber. Finally, the vessels are selected as artery and vein by a grader to compute CRAE and CRVE. The Knudtson protocol [5] is followed to compute the CRAE and CRVE based on the individual vessels' caliber grading results and automatically saved in the file. The overall system is shown in Fig. 4.

2.1. Automatic vessel detection

As our ultimate focus is on the measurement of vessel caliber which requires vessel edge information, we apply edge based vessel segmentation approach. We use the green channel which has the highest contrast between vessel and background in color the retinal image. To detect vessel edges, we apply the Canny edge detection algorithm [18]. To follow the Knudtson protocol, we aim to trace the vessels from the zone B area only. Zone B is the circular region which starts at 1$*$OD-diameter and ends at 1.5$*$OD-diameter from the OD-center in the retinal image and is the standard use for retinal blood vessel analysis [19]. The grading interface in Fig. 3 shows the zone B area in which the vessel is detected. The zone B area is computed based on OD center and its radius. We have developed an OD detection and center computation method which is reported in [20].

Once we identify the zone B area, we track the individual edges for profiling and filtering to find the actual vessel edges. Within the zone B area, we scan the canny edge detected image and track each of the individual edges and corresponding pixels by region