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Comparison of Central Light Reflex Width-to-Retinal Vessel Diameter Ratio between Glaucoma and Normal Eyes by Using Edge Detection Technique

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***Abstract*—**Glaucoma is a disease that causes visual loss in adults. Glaucoma causes damage to the optic nerve and its overall pathophysiology is still not fully understood. Vasculopathy may be one of the possible causes of nerve damage. Photographic imaging of retinal vessels by fundus camera during eye examination may complement clinical management. This paper presents an innovation for measuring central light reflex width-to-retinal vessel diameter ratio (CRR) from digital retinal photographs. Using our edge detection technique, CRRs from glaucoma and normal eyes were compared to examine differences and associations. CRRs were evaluated on fundus photographs of participants from Mettapracharak (Wat Raikhing) Hospital in Nakhon Pathom, Thailand. Fifty-five photographs from normal eyes and twenty-one photographs from glaucoma eyes were included. Participants with hypertension were excluded. In each photograph, CRRs from four retinal vessels, including arteries and veins in the inferotemporal and superotemporal regions, were quantified using edge detection technique. From our finding, mean CRRs of all four retinal arteries and veins were significantly higher in persons with glaucoma than in those without glaucoma (0.34 *vs.* 0.32, $p < 0.05$ for inferotemporal vein, 0.33 *vs.* 0.30, $p < 0.01$ for inferotemporal artery, 0.34 *vs.* 0.31, $p < 0.01$ for superotemporal vein, and 0.33 *vs.* 0.30, $p < 0.05$ for superotemporal artery). From these results, an increase in CRRs of retinal vessels, as quantitatively measured from fundus photographs, could be associated with glaucoma.

***Keywords*—**Glaucoma, retinal vessel, central light reflex, image processing, fundus photograph, edge detection.

I. Introduction

GLAUCOMA is an eye disease that is a leading cause of vision loss and irreversible blindness worldwide. Glaucoma causes degeneration of the optic nerve. Intraocular pressure (IOP) is recognized as the main risk factor for glaucoma, but not all patients with glaucoma have elevated IOP. It is possible that glaucoma causes vascular insufficiency and/or vascular degeneration that, in turn, damages the optic nerve. A number of studies have reported association between glaucoma and retinal arteriolar narrowing using visualization by standard fundus camera during eye examination [1], [2]. However, the standard fundus camera is limited in its ability to produce images from which actual scaling of blood vessels can be determined. Central light reflex (CR) is the appearance of a centralized light reflection from the surface of retinal vessels (Fig. 1). This term has several variations in clinical practice, to include arteriolar light streak, blood vessel wall reflection, copper-wiring, and silver-wiring [3]. Several previous studies suggested association between CR and systemic vascular diseases, such as hypertension [4]–[6]. Quantitative measurement of CR can provide information for identifying any association diseases, so CR can be used for identifying glaucoma if there is association between them.

This article presents and describes an innovative technique for quantitative measurement of central light reflex width-to-retinal vessel diameter ratio (CRR) from digital retinal photographs. This ratio may be helpful in overcoming limitations associated with the use of standard fundus camera and, further, may help to establish association between CRR and glaucoma.

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II. Related Works

Brinchmann-Hansen et al. measured width of central light reflex of retinal arteries and veins in hypertensive patients using half-height of vascular intensity profile from retinal photographs [5]. The intensity of central light reflex is significantly reduced and both widths of the blood column and light reflex increases in hypertensive patients. Bhuiyan et al. described the methodology and assessed the reliability of software that quantifies retinal arteriolar central light [7]. Canny detection technique with gradient pattern detection was used to measure the ratio between width of retinal arteriolar central light reflex and vessel diameter. This measurement is referred to as central light reflex width-to-retinal vessel diameter ratio (CRR). From a total of 150 retinal photographs used in [7], intraclass correlations for intergrader and intragrader CRR measurements were 0.76 and 0.86, respectively. In multivariate analysis, a higher CRR is associated with higher arterial blood pressure. These reported findings allow us to conclude that CRR measurement is a reliable tool for the study of retinal arteriolar abnormalities in patients with systemic diseases.

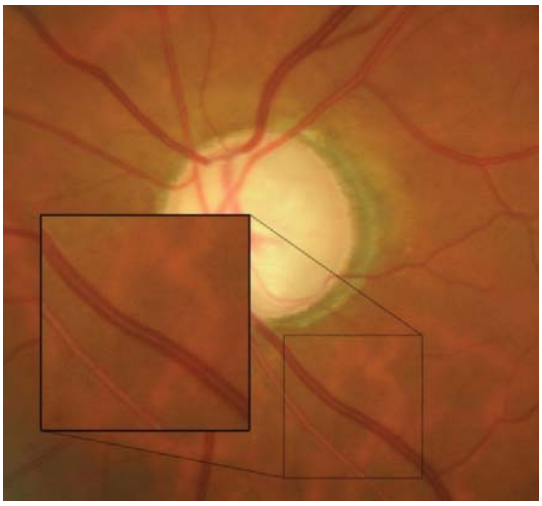

Fig. 1 Central light reflex on retinal artery and vein

III. Material and Method

A. Material

A total of 76 fundus photographs were included from participants aged 20 to 83 years who received treatment at Mettapracharak (Wat Raikhing) Hospital in Nakhon Pathom Thailand. Fifty-five photographs were taken of normal eyes and twenty-one photographs were taken of eyes with glaucoma. All participants with hypertension were excluded. All retinal photographs were taken using a model nonmyd WX^{3D} Kowa Non-Mydriatic Retinal Camera (Kowa Company, Ltd., Nagoya, Japan) in .TIFF format.

B. Define Region of Interest

Optic discs were segmented using active contour and the vertical length of a segment was used as the diameter of the optic disc [8]. Centroid of the segment was considered the center of the region of interest, which is a specified area between two circles of 0.5 and 1 optic disc diameter away from the optic disc margin [9]. An example of the region of interest is shown in Fig. 2.

C. Define Boundary of Vessels

Colored retinal images were converted to monochrome using green channel image because vessels show contrast in the green channel. Pre-processing was performed by applying contrast-limited adaptive histogram equalization [10] and an edge-preserving anisotropic diffusion filter [11]. The outcome of this process was clearer images with more contrast and images with a distinct non-blurry edge.

On pre-processed images, the boundaries of vessels were defined using segmentation technique. Vessel enhancement filter was computed to enhance the contrast of vessels based on eigenvalue analysis of the Hessian matrix [12]. Enhanced images were binarized using Otsu's thresholding [13]. The result was then used as a mask of boundary of vessels for skeletonization and CRRs measurement (Fig. 3).

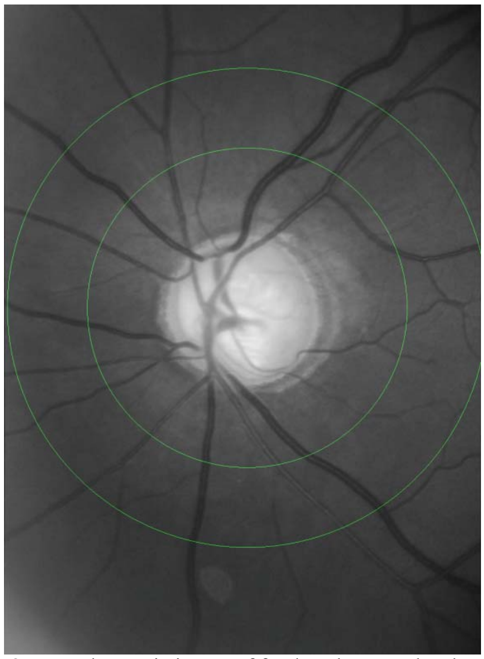

Fig. 2 Monochromatic image of fundus photograph: The area between two green circles is defined as region of interest

Fig. 3 Boundary of vessels

D. Edge Detection

First derivative of Gaussian filter was computed on monochromatic retinal photographs to obtain images of gradient magnitudes [14]. Non-maximum suppression was then computed on the gradient images to preserve all local maxima, while the non-local maxima pixels were deleted. Non-maximum suppression was computed by rounding the gradient direction to the nearest 45◦ axis and comparing the magnitude of the current pixel with the pixels in the positive and negative gradient directions [15]. Only current pixels with large magnitudes were preserved. The edge-pixels that remain after the non-maximum suppression process may still contain noise; therefore and in these cases, double thresholding was used to suppress the noise.

E. Skeletonization

Vessel boundary images were skeletonized using morphological operation [16]. Foreground regions were reduced, but the skeletal remnant was preserved representing the extent and connectivity of the vessels. This technique generated a one pixel width line that represented the stem of the vessel (Fig. 4).

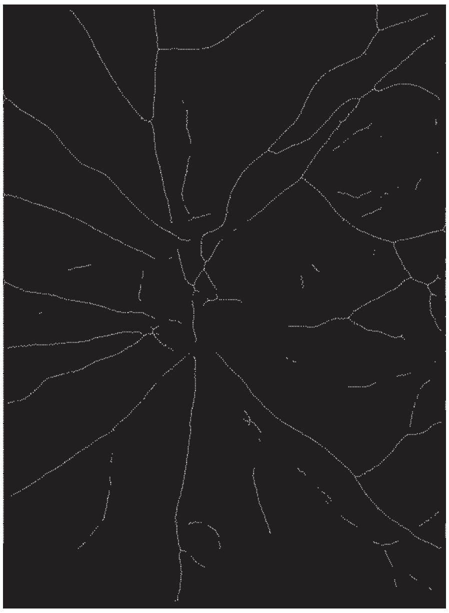

Fig. 4 Skeleton of vessels

F. Measurement of CRRs

Images of the remaining edges were computed using bitwise 'AND' operator with mask of boundary of vessels to obtain vascular borders (Fig. 5). Orthogonal lines of the skeleton were drawn at a spacing of two pixels. The average length along the orthogonal lines between two outermost edge pixels was defined as the width of a blood vessel. The average length between two innermost edge pixels was defined as the width of central light reflex. The mean widths of the vessel and the central light reflex were computed and reported as the CRR.

IV. Result

CRRs from arteries and veins in the inferotemporal and superotemporal disc regions were measured in all 76 photographic images. In a comparison between normal eyes and glaucoma eyes, the average CRRs of the inferotemporal vein ($p < 0.05$), inferotemporal artery ($p < 0.01$), superotemporal vein ($p < 0.01$) and superotemporal artery ($p < 0.05$) were statistically significantly higher in eyes with glaucoma (Table I).

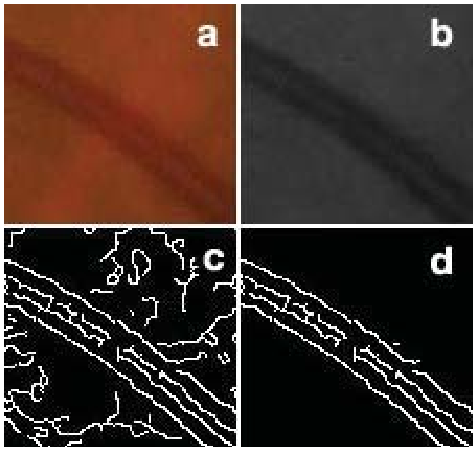

Fig. 5 Illustration of edge detection technique: (a) Original colored image (b) Monochromatic image using green channel of original colored image (c) Edge image from using Canny edge detection (d) Image after using bitwise 'AND' operator with edge image and mask of boundary of vessels

TABLE I
AVERAGE CRRs OF VESSEL IN TEMPORAL DISC REGION

	Infero-temporal vein	Infero-temporal artery	Supero-temporal vein	Supero-temporal artery
Normal eyes	0.32	0.30	0.31	0.30
Glaucoma eyes	0.34	0.33	0.34	0.33

V. Conclusion and Discussion

In this study, we set forth to identify a relationship between CRR and glaucoma. Canny edge detection technique was used to measure vessel diameters and widths of central light reflex. From the results, it can be concluded that CRRs of retinal arteries and veins in fundus photographs are significantly higher in patients with glaucoma than in those without glaucoma.

Our method for CRR measurement and these initial results may provide an alternative tool for glaucoma diagnosis. However, this method has some mentionable limitations. Some fundus photographs with low contrast due to unclear ocular media (especially cataracts) limited our ability to accurately detect vessel borders. The presence and effect of artifacts, background noise, shadows, and lighting conditions can also adversely affect the accurate measurement of vessel borders.

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