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Measuring the Branching Angle for the Diagnosis of Hypertensive Retinopathy

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Abstract

The sizes and changes in the retinal arteries branching angles are an important characteristic for diagnose of hypertension, and also used as a preliminary index of the future location of the branch. An algorithm that can automatically calculate the branching angle which is defined according to vascular blood flow dynamics is presented. The result shows that the theoretical prediction and manual measurement have good agreement.

Keywords*: retinal, branching angle, blood flow dynamic*

1. Introduction

Hypertensive retinopathy (HR) is a common cardiovascular disease. Arteriolar stricture in retinal images is considered as an important sign of hypertension. Because of precise quantitative analysis the vessel stenosis is extremely difficult, so the arteriolar to venular diameter ratio (AVR) at the intersection is used to study the disease of hypertension [1-2]. But the dilatation of veins and some eye diseases such as high myopia, uveitis and retinal dystrophy will lead to the narrowing of the retinal vessels, so AVR is not suitable as a separate reference standard to diagnose of hypertension.

Another useful sign of hypertension is the angles change of the big arterial branches, especially in the 2nd or 3rd branches. The higher the blood pressure is, the greater the angles of the branches. The branching angles of arteries 45°~60° means mild hypertension, 60°~90° means moderate hypertension, and greater than 90° severe hypertension [3].

In ophthalmic clinical, diagnosis of hypertension is relying on ophthalmoscope and experienced ophthalmologist. But it is difficult to observe the changes of small vessels. Quantification research of the branching angles helps to diagnose hypertension patients through integrated with the history and control of hypertension and according to the situation of funds changes, and provides a scientific basis for judgment the degree of hypertension.

2. Definition of Bifurcation Angle

The consumption of energy is concerned to the shape of blood vessels, and researchers have found that the branching angles of an animal's vascular are almost fixed [3-4]. Therefore, a hypothesis is proposed. That is, the geometry of blood vessels turns to the structure of minimum energy consumption in the process of biological evolution. In evolutionary terms, the formation of morphological structure of vascular is a result of natural selection. It is also the winner who is the most compatible with the environment, which means that it meets the optimized structure and function. Based on this, Diao [4]

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considers that the optimum principle hold true to the vascular system, and quantitative analysis of the vascular branches. Take the structure of least metabolic energy consumption as the best structure to construct an objective function so that the whole branches structure has minimum energy consumption. The value of vascular branching angle in the principle of minimum energy consumption is analyzed below.

Let an arterial bifurcation is specified in terms of the vessel segment AB, BC and BD of the parent vessel, the larger branch, and the two smaller branches respectively as shown in Figure 1. If the entire vascular system meets the optimality conditions, the bifurcation as part of the system also meets. The objectives function is defined by the next equation [5]:

$$P = \frac{3\pi K}{2}(r_0^2 L_0 + r_1^2 L_1 + r_2^2 L_2) \tag{1}$$

Where K is the scaling factor which is relate to the energy needed per unit time of the vascular tissue and blood metabolic. Let $r0$ and L_0 be the radius and length of the parent vascular segments AB; and the $r1$, $r2$ and L_1, L_2 be the radius and length of the two branches segments, respectively. The $a1$ and $a2$ will be used to denote the angles of the two branches vessel BC and BD make with the direction of parent vessel AB as shown in Figure 1.

The design criterion for the algorithm is to minimize the objectives function P.

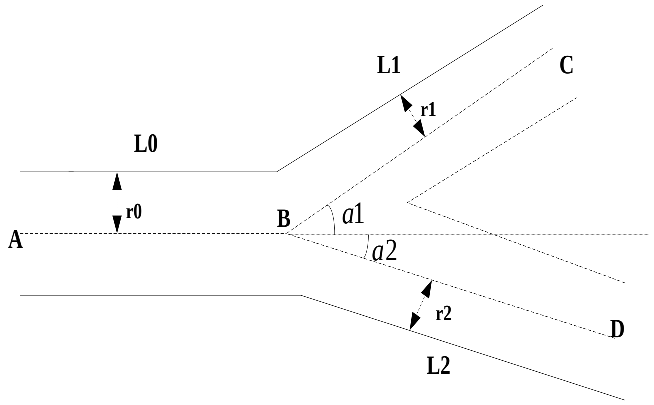


Figure 1. Vascular Branches Model

The virtual displacement principle will be used, and set the radius remains invariability. When there is a shift δ by extend the line AB, the change of $L_i (i = 0,1,2)$ and P is δL_i and δP respectively as shown in Figure 2. Then:

$$\begin{cases} \delta L_0 = \delta \\ \delta L_1 = -\delta \cos(a1) \\ \delta L_2 = -\delta \cos(a2) \end{cases} \tag{2}$$

So, the change of objectives function is obtained as:

$$\delta P = \frac{3\pi K}{2}(r_0^2 \delta L_0 + r_1^2 \delta L_1 + r_2^2 \delta L_2) = \frac{3\pi K}{2}\delta(r_0^2 - r_1^2 \cos(a1) - r_2^2 \cos(a2))$$

In order to achieve the requirement of the optimal condition δP must be equal to zero. Namely:

$$r_0^2 - r_1^2\cos(a1) - r_2^2\cos(a2) = 0 \tag{3}$$

Considering the small displacement via extend the lines CB and DB separately by the same method and get the corresponding changes of $L_i(i=0,1,2)$ and P. For meeting the optimum conditions, the corresponding equation can be obtained:

$$-r_0^2\cos(a1) + r_1^2 + r_2^2\cos(a1+a2) = 0 \tag{4}$$

$$-r_0^2\cos(a2) + r_1^2\cos(a1+a2) + r_2^2 = 0 \tag{5}$$

The total branching angles $a1+a2$ could be achieved by simultaneous equations (3), (4) and (5).

$$(a1+a2) = \arccos\left(\frac{r0^4 - r1^4 - r2^4}{2\times r1^2 \times r2^2}\right) \tag{6}$$

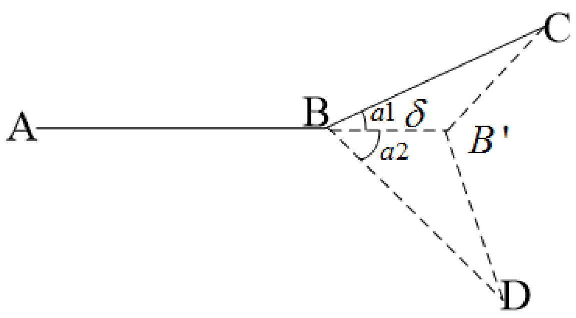


Figure 2. Virtual Displacement Principle

3. Experimental Results

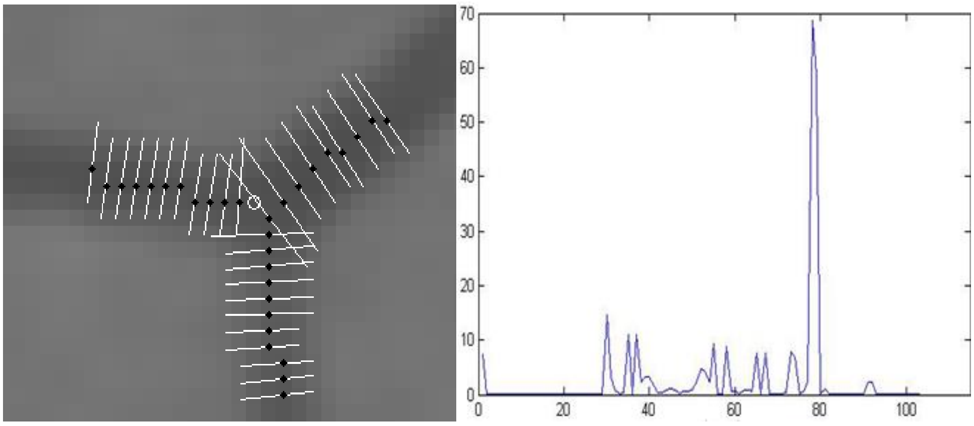
The branching angle measurements are generally carried out by experienced ophthalmologists, who determine the angle by measuring the angle between the inside edge lines or center lines of the two vessel branches. The subjectivity of this manual measurement method is relatively strong, so an automatic method for measure the branching angle is proposed. It is helpful for the clinical diagnosis.

The steps of automatic measurement the branching angle are as follows:

1) First select the area of bifurcation angle, the three branches vessel are denoted as l_0, l_1 and, l_2 and then the center set $C=\{c_1,c_2,\ldots,c_t\}$ of the selected area and the corresponding diameter of each center can be obtained by the method as reference[6-9], as shown in Figure 3.

2) Identify the location of bifurcation point. Although the vessel segments for width and direction of the local area will not change suddenly, the direction of vessel centerline will mutate in the bifurcation point for the bifurcation structure. Therefore, forward difference for the direction vectors of the center points, as shown in Figure 3 (b), and then

the bifurcation point p_0 is determined by identifying the location of the greatest change, the results shown in Figure 3(a) of the hollow round position.



(a) Bifurcation Structure (b) Forward Difference for the Direction Vectors

Figure 3. Branching Angle Measurement

3) Determine the general direction of each branch. If only according to the distance from the center point set C to the bifurcation point to determine a point in which the branch is more difficult. But because of the direction of each vessel segment without mutation, so for each branch, point set C point for the direction of the corresponding the direction of the center does not have a substantial change. Based on this, sort the direction K_C of the center point set C from small to large, and the $K_C^{'} = \{k_1, k_2, ..., k_t\}$ can be got. Find the two largest change location of $K_C^{'}$, denoted by u and v, and there $k_u < k_v$. The general directions of the three branches are:

$$\begin{cases} \psi_0 = \dfrac{k_1 + k_2 + ... + k_u}{u} \\ \psi_1 = \dfrac{k_{u+1} + k_{u+2} + ... + k_v}{v - u} \\ \psi_2 = \dfrac{k_{v+1} + k_{v+2} + ... + k_t}{t - v} \end{cases} \tag{7}$$

4) Classification of the point set C, that is, distinguish the points belonging to which branch segment, set $C0$, $C1$ and $C2$. First calculate the distance between each center from C and the bifurcation point p_0, according to small to large sort of the point C, get the point set C'. On any point of set C', the category can be determined according to the distance between the direction of the point and $\psi_i, i = 0,1,2$.

5) Calculate the vascular branching angles. According to equation (9), if calculate the bifurcation angle, radius of each vessel segment need to be calculated. After several tests, it can be found that the angle of bifurcation is relatively stable when the diameter of each blood vessels segment is measured by the mean diameter of the 6 to 14 center points nearest the bifurcation point, and the fluctuating less than 1°, repeatability. As shown in Figure 4.

Taking into account the corresponding diameter of the center point from each branch which the nearest the bifurcation point has poor reliability, so they are excluded. For example, the corresponding diameters of 10 points of each segment are involved in the calculation, namely second to eleventh point of $C0$, $C1$ and $C2$ respectively as shown in Figure 3(a). Table 1 shows the diameters corresponds to the 10 center points of the three branches. The radius corresponding to the three branches can be got:

$$ri = \frac{1}{20}\sum_{s=2}^{11} Di(s), i = 0,1,2 \tag{8}$$

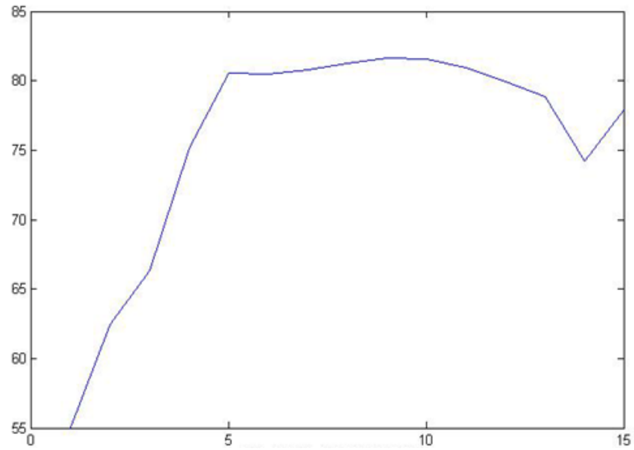


Figure 4. The Change of Branching Angle

The corresponding value in Table 1 are substituted the equation (8), we get $r2$ = 2.7060, $r1$ = 2.5839, $r0$ = 3.1611. It can see that the maximum value $r0$ must correspond to the radius of the main vessel segment, and others correspond to the radius of the two bifurcations of vessels. Inserting $r0$, $r1$ and $r2$ in formula (9), calculated the bifurcation angle $(a1+a2)$ = 89.0280 °, and the entire process takes only about 2 seconds. Using the average value of three times to compare the automatic measurement, considering the subjectivity of manual measurement, and the manual measurement value is about 91.333°.

Table 1. The Diameter of the Three Branches of Measurement

Diameters/ pixel	1	2	3	4	5	6	7	8	9	10
D0	7.5185	6.2497	6.2497	6.2379	6.2379	6.1908	6.1435	6.0884	6.1043	6.2021
D1	6.0749	5.0752	5.0809	5.0592	5.0663	5.0684	5.0664	5.0634	5.0605	5.0631
D2	7.0307	5.0117	5.0026	6.0007	6.0006	5.0017	5.0068	5.0087	5.0240	5.0328

4. Conclusion

We propose an automatic method for measure the branching angle. Although there are some distances in the automatic measurement and manual measurement, in clinical application, the stability and sensitivity of the branching angle is more important than measurement error.

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