Utilization of mathematical processing of retinal images with use of adaptive contrast control (ACC) method to detect quantity of vascular endings

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PURPOSE. *The authors investigated whether the method of mathematical processing of retinal images with the use of a computer can be used to evaluate ocular background figures of patients with physiologic retinal findings. This method is based on identification of vascular endings in an examined retinal area. When the authors mention vascular endings, they do not refer to factual endings, but recognizable vascular endings; there are no endings in a vascular system.*
METHODS. *Adaptive contrast control (ACC) method was used to determine a number of vascular endings. The method is based on mathematical processing of a digitized retina picture with the use of a computer. On a digitized retinal picture, the vascular system is identified with the use of the conditional erosion methodology, and the number of vascular endings is then determined. The ACC method was used to process a file of retinal pictures of 38 patients (76 eyes) with physiologic retinal findings.*
RESULTS. *Based on the results of statistical analysis, the authors detected that the number of vascular endings showed a normal curve (Gaussian distribution, p=0.05). A tight correlation between quantities of vascular endings in the right and the left eyes was also detected, which means that the quantity of vascular endings in the right and the left eyes is in a very close correlation (p=0.05).*
CONCLUSIONS. *The authors highlight that the curve of the number of vascular endings of patients with physiologic retinal findings shows a Gaussian distribution. (Eur J Ophthalmol 2005; 15: 782-6)*

KEY WORDS. *Adaptive contrast control, Mathematical processing of retinal images, Physiologic retinal finding, Quantity of vascular endings*

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INTRODUCTION

The aim of this study was to verify whether the method of mathematical processing of digitized retinal pictures can be used for determination of the number of vascular endings in eyes with physiologic retinal findings. When speaking about vascular endings, we do not mean factual endings, but recognizable vascular endings, as there are no endings in the vascular system.

We also aimed to verify that the quantity of vascular endings of patients with physiologic retinal findings shows a normal curve (Gaussian distribution) and to prove a close correlation between the quantity of vascular

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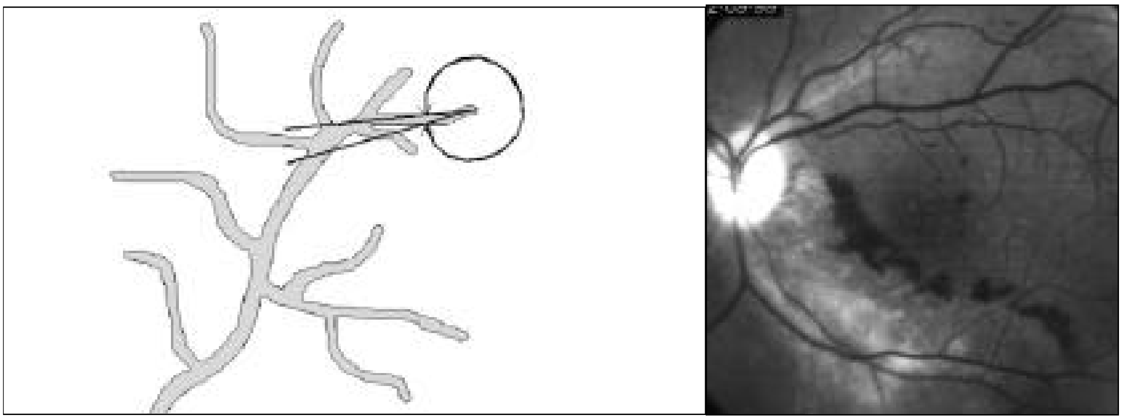

Fig. 1 - *Principle of vessel ending identification. By changing the size of the circle radius and the magnitude of the angle, it is possible to influence the size and sharpness of an ending.*

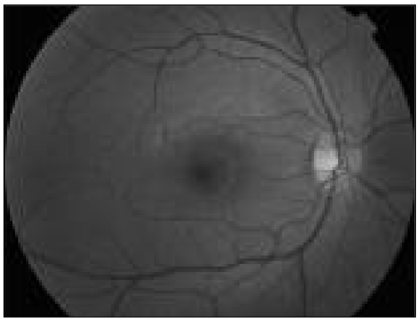

Fig. 2 - *Retinal image before processing.*

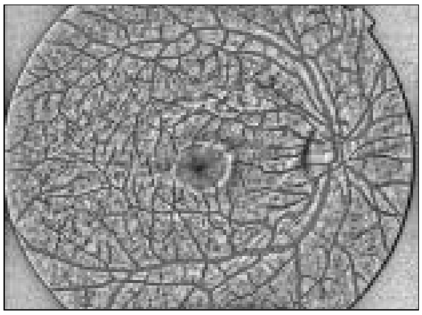

Fig. 3 - *Retinal image after processing using adaptive contrast control method.*

endings in the right and the left eyes (eyes with physiologic retinal findings).

The main clinical application of our results consists of the possibility to compare the number of vascular endings of patients with various retinal vascular diseases with the relevant numbers found for eyes of patients with physiologic retinal findings. Another clinical aspect of our study is represented by the possibility to determine the degree of severity of a clinical finding for particular retinal pathologies.

METHODS

To determine the quantity of vascular endings, the adaptive contrast control (ACC) method was used. The ACC method was developed and primarily practiced at the Institute of Mathematics, Department of Mechanical Engineering, Technical Engineering College Brno, in collaboration with the authors, from the Eye Clinic of University Hospital Brno, and the Institute of Pathological Physiology, Medical Faculty of Masaryk University Brno (1).

The ACC method is a software method that enables the user to identify vascular endings and determine their quantity in a monitored retinal area. Its advantages consist of the possibility to process data acquired by means of various media (retinal images from digital pictures, color, black and white photographs, slides), and the possibility to archive the results and compare the results of a particular patient in time (verification of progression or regression of findings).

Methods used for structural parameters estimation

The ACC method makes the defined structures distinct. Most suitable for processing by this method seems to be the images acquired in the red-free mode. In this mode, the green part of the color spectrum is most distinct. This part of a color spectrum gives the best image of the vascular system, as the difference between the red color (representing blood vessels) and the orange color (representing retina) consists of the content of the green part of the spectrum. The acquired good contrast picture is apt for further processing. Modification of the adaptive contrast change method consists of the fact that the luminance part is not defined as a weighted average of individual parts, but it is determined that the luminance picture is consistent with the intensity of the green part of the original colored image.

It is possible to proceed to segmentation of an image, and thus start identification of the vascular system. First, it is useful to choose particular attributes of pixels. These attributes are represented by brightness, intensity of particular color parts, and especially by the pixel color. It is possible to identify the whole vascular system, having the vessels highlighted on their background.

Using the conditional erosion method, we draft a one-pixel line called G-curve through the center of the vascular system. The number of vascular endings is identified by drafting a circle of a selected radius on both ends of the G-curve. It is also possible to select an interval. After drawing a circle, we measure the maximum outer angle for the selected radii.

By the outer angle we mean the angle of a selected radius sector, which does not intersect the blood vessel area. If this angle falls within the required preselected range of values, the G-curve ending will be designated as a vascular ending (Fig. 1).

By changing the size of the circle radius and the magnitude of the angle, it is possible to influence the size and sharpness of an ending. Figure 2 illustrates a retinal image before processing.

Figure 3 illustrates retinal image after processing with the use of ACC method, with identified vascular endings. If we take a closer look, however, we will see that the endings near the picture edges are caused by artificial discontinuity of a vessel system due to picture edge. Although all the vessels continue farther, we can neglect this matter and count all the identified endings.

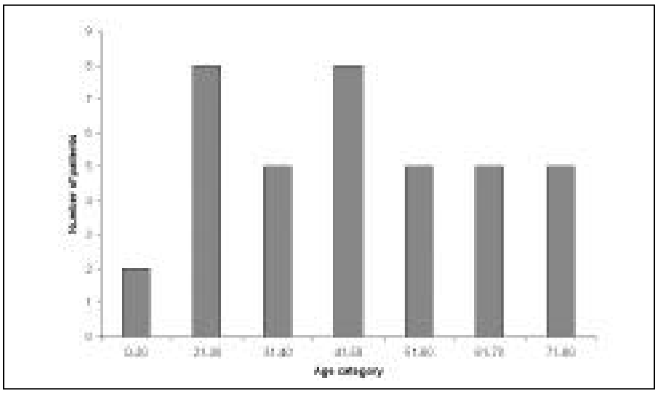

Fig. 4 - *Age distribution in the group of patients.*

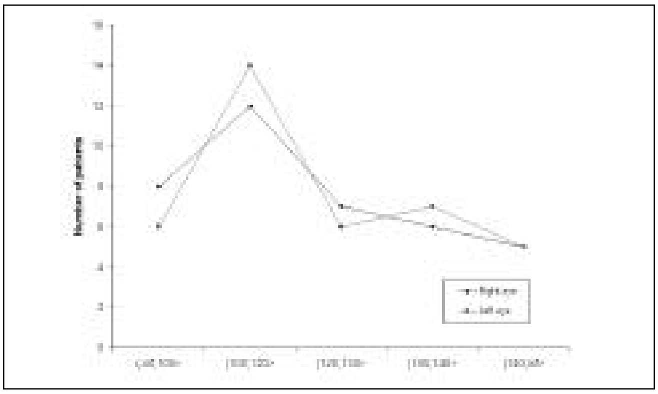

Fig. 5 - *Distribution in number of vascular endings in right and left eyes.*

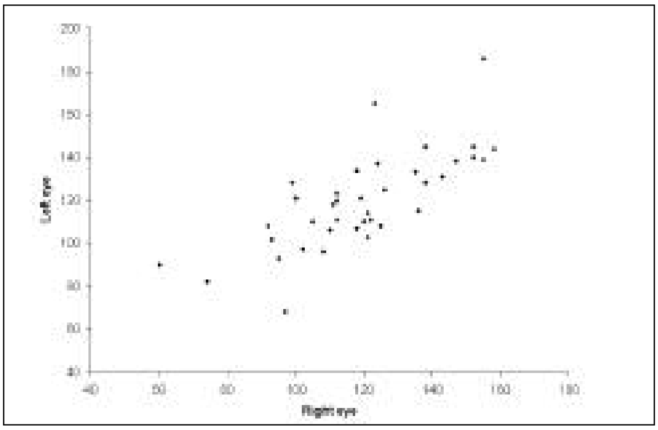

Fig. 6 - *Correlation in number of vascular endings in right and left eyes.*

Image format used for mathematical processing

Almost any retinal image is applicable for evaluation by mathematical analysis. This means that we can use any good quality color or black and white picture, as well as a slide, that can be scanned and further processed (2). It is also possible to use retinal images in a digital form, acquired with the use of any digital imaging system (3, 4).

In our case, we use digitized noncompressed retinal images in a tiff format that can be further processed without the need of scanning. It is crucially important to use noncompressed retinal images. Any image compression leads to deformation of digitized images that become inapplicable for processing.

Image quality is fundamentally important, which is mainly influenced by transparency of optical media of an eye. Generally, every retinal image with a well visible vascular system can be processed.

Image angle selection and image position on fundus

For retinal photography, we use Topcon TRC 50 IX fundus camera combined with the digital imaging system Imagenet (Topcon). It is important to choose the angle size and place the center of an image to a specific retinal area (5). For our set of images, we used the image angle magnitude of 50 degrees, with its center in the center of a macula.

RESULTS

For our set of images, we used pictures of 76 eyes of 38 healthy individuals: 23 men and 15 women with physiologic retinal findings. These patients presented for a regular preventive ophthalmic examination, during which no eye pathology was diagnosed. The age range of patients was 18 to 80 years (average 46 years), as shown in Figure 4.

We used the chi square formula to determine whether the quantity of vascular endings on the left and the right eyes of healthy individuals shows a normal distribution.

For the right eye, we calculated an average value of vascular endings (119.16) and standard deviation from normal Gaussian distribution (s=22.47). We do not dismiss the hypothesis on normal Gaussian distribution of vascular endings even on the significance level of p=0.05. For the left eye, we calculated the average value of vascular endings (119.79) and standard deviation from normal Gaussian distribution (s=22.54). Similarly as for the right eye, we do not dismiss the hypothesis on normal Gaussian distribution of vascular endings even on the significance level of p=0.05. Distribution of values for vascular ending numbers in the left and the right eyes is shown in Figure 5.

The next task was to examine whether correlation exists between the number of vascular endings in the right and the left eyes. As we have not dismissed both hypotheses on a normal (Gaussian) distribution of vascular endings, we can now determine the correlation coefficient r between the numbers of vascular endings in the left and the right eyes. In our case, the correlation coefficient r=0.747163.

We tested the hypothesis that the number of vascular endings in the right eye does not depend on the number of vascular endings in the left eye, and vice versa. On the significance level of p=0.05 we dismiss this hypothesis. Therefore an alternative hypothesis on the number of vascular endings dependence of the right and the left eyes is not refuted. Correlation between vascular ending numbers in both eyes is shown in Figure 6.

By means of statistical analysis, we also aimed to detect whether the number of vascular endings depends on the age of examined persons. For the purpose of this analysis, the whole set was divided into two parts.

The first set comprised 23 individuals (46 eyes) within the age range of 0 to 50 years (Ø=42). An average number of vascular endings was 126.00, with standard deviation of 19.30. The second set comprised 15 individuals within the age range of 51 to 80 years (Ø=71). An average number of vascular endings was 109.47, with standard deviation of 23.32. After processing by statistical analysis with the use of Student's unpaired t-test, a statistically highly significant difference was found between these two sets in numbers of vascular endings (p=0.0012). Based on this statistical analysis, within the age limit of 51 to 80 years, the number of vascular endings is statistically significantly lower than within the age range group of 0 to 50 years.

DISCUSSION

Based on statistical analysis, the number of recognizable vascular endings in healthy eyes features a Gaussian distribution curve. Average values of vascular ending numbers and their standard deviations in both the left and the right eyes are similar and the number of endings in one eye corresponds with the other eye.

These findings represent qualitatively new information. The number of vascular endings in eyes with a physiologic retinal finding seems constant and runs about the value of 120.

It was also found that the number of vascular endings depends on the age of the assessed entity. This is a new finding. It seems possible that the etiologic agent of vascular endings number dependence on age of patients with physiologic retinal findings may be the process of aging of an organism, especially of the vascular system, connected with straightening and obliteration of small retinal vessels due to changes in vessel wall structure. This results in decreasing vascular endings number in retina area under investigation. This can cause numerous retinal age-related pathologic symptoms.

Some pathophysiologic mechanisms affecting the retinal vascular system as well as the aging process may lead to change of number of vascular endings. This is especially true for the process of vascular neogenesis, which eventuates in an increase in vascular endings number. Our assumption needs further investigation, the results of which we will present in future publications.

The basic clinical application of the retinal image mathematical processing method consists of the possibility to timely diagnose the risk of various retinal vascular diseases, whether indicated by a high or a low number of vascular endings, thus enabling the physician to start adequate treatment in a timely fashion.

Another possibility of clinical application consists of monitoring of disease treatment efficiency in time on the basis of repetitive mathematical analysis of retinal images made within a time interval.

This clinical application is mainly applicable in the field of diabetic retinopathy, where we can assume that the number of vascular endings increases with the increasing severity of a retinal finding.

CONCLUSIONS

We found that the number of vascular endings of patients with physiologic retinal findings shows a normal curve (Gaussian distribution). Based on evaluation of data acquired by the method of mathematical processing of retinal images, it is highly probable that the number of vascular endings of patients with physiologic retinal findings is of a practically constant value, which shows only a small value dispersion (1). There is practically no difference in the number of endings in the right and the left eyes (1). These are the first results acquired by the analysis of a relatively small group of patients. Future larger tests are planned.

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REFERENCES

1. Kolar P, Starha P, Hajek D, Vlkova E, Druckmueller M. Importance of mathematical analysis of retinal image in diabetic retinopathy. Cesk Slov Oftalmol 2003; 59: 160-70.
2. Bursell SE, Cavallerano JD, Cavallerano AA, et al. Stereo nonmydriatic digital-video color retinal imaging compared with Early Treatment Diabetic Retinopathy Study seven standard field 35-mm stereo color photos for determining level of diabetic retinopathy. Ophthalmology 2001; 108: 572-85.
3. Eikelboom RH, Yogesan K, Barry CJ, et al. Methods and limits of digital image compression of retinal images for telemedicine. Invest Ophthalmol Vis Sci 2000; 41: 1916-24.
4. Lee MS, Shin DS, Berger JW. Grading, image analysis, and stereopsis of digitally compressed fundus images. Retina 2000; 20: 275-81.
5. Wendt GC, Heikkilae KV, Summanen PA. Detection of retinal neovascularisation using 45° and 60° photographic fields. Diabetes Metabol 2001; 27: 2S3.