ORIGINAL ARTICLE

Optical Coherence Tomography Image Analysis to Segment the Choroid by a New Method: Selection of Ranges by Color Tonality

Aldo Antonio Escobar Duran[1], Paola Castillo Juarez[2], Luis Niño-de-Rivera[1,3]

[1]Artificial Vision Lab. ESIME, UPC del Instituto Politécnico Nacional, 011430, CDMX, México, [2]Escuela Nacional de Ciencias Biológicas, Instituto Politécnico Nacional, 11340, CDMX, México, [3]Microstimulation Research Unit, APEC, Hospital Luis Sánchez Bulnes, 04030, CDMX, México

ABSTRACT

The choroid is a vascular tissue that carries oxygen and nutrients to the retina, extending from the ora serrata to the optic nerve and attaches to the sclera through connective tissue. The choroid has a key role in the functioning of the retina; its analysis in retinal diseases has acquired clinical relevance. Degenerative diseases such as diabetic retinopathy or age-related macular degeneration, require a deeper understanding about the physiopathology of the choroid and its morphological changes during medication, among others physicians require to follow the alteration of the flow through the retinal pigmented epitelium and Bruch's membrane or relative ischemia due to malfunction of the Bruch-choriocapillaris complex. However, the choroid region from optical coherence tomography (OCT) spectral domain image is not well enough defined to appreciate small changes in the choroidal structure, mainly by its gray level regularity, making a difficult task to identify the differences of the layers that make up the choroid, even by specialists in retina. **Methods:** To mark as different the vascular structure of the choroid, we propose a new method to segment the choroids from OCT image described in this paper as segmentation by selection of ranges by color tonality. The objective of this proposal is to show more clearly the zone of the vasculature of the choroid to evaluate diabetic retinopathy evolution. This algorithm is easily install in a desktop computer following its description reported. **Results:** We show that the segmentation method proposed let an important improvement to appreciate the structure of the choroid from conventional OCT SD images distinguishing clearly: The choriocapillaris (Ruysch layer), the middle choroidal layer (Sattler layer), and the great vessel layer (Haller layer). This article presents new results that are compared it with the method reported in the literature by Sonoda.

Key words: Binarization images, Bruch-choriocapillaris complex, chorioretinal blood flow, choroid, choroid layers, choroidal structure, image segmentation, optical coherence tomography-spectral domain

INTRODUCTION

The choroid is a vascular tissue that carries oxygen and nutrients to the retina, extending from the ora serrata to the optic nerve and attaches to the sclera through connective tissue. The choroid varies in thickness from 0.1 to 0.2 mm. The choroid has a key role in the functioning of the retina. In recent times, its analysis in connection with patients with retinal diseases has acquired clinical relevance.[1,2] Degenerative diseases such as diabetic retinopathy or age-related macular degeneration (AMD), require a deeper understanding about the physiopathology of the choroid and its morphological changes during medication, among others physicians require to follow the alteration of the flow through the retinal pigmented epitelium (RPE) and Bruch's membrane or relative ischemia due to malfunction of the Bruch-choriocapillaris complex.[3] OCT-SD is an amply procedure for diagnosis and treatment. However, OCT SD images show images with low choroids differentiation among their layers. In addition to the above, it requires knowing, numerically the area of the choroid layers.

Address for correspondence:
Luis Niño de Rivera, Artificial Vision Lab. ESIME, UPC del Instituto Politécnico Nacional, 011430, CDMX, México.
E-mail: Luisninoderivera@gmail.com

God efforts to understand the morphological and vascular description of this tissue as well as its thickness are reported in Wang *et al*.,[3] Shahlaee *et al.,*[4] Caio *et al*.,[5] and Hua *et al.*[6] Those papers help to evaluate the structure of the choroid and give us an approach to the calculation of the stromal area within the vascular layers of the choroid. Sonodas *et al.*[2] proposed binarizing conventional OCT-SD images to find the vascular area and the interstitial space of the choroid tissue in healthy patients. However, additional efforts require improving the choroid layers differentiation. We talk in this paper about a new approach to evaluate the morphological and vascular description of this tissue and its thickness with advantages and additional facilities to separate the layers of the choroid by a new segmentation method that let to see each layer of the choroid clearly. This procedure assigns to each layer a color that let it differentiate from the other layers, even from non-experts.

METHODS

Choroid segmentation

Recently, new alternative like transcorneal electrical stimulation (TES) has emerged to treat a degenerative illness such as retinosis (RP) or open-angle glaucoma.[7-10] This pushes us to develop alternative tools to analyze the effects of this incoming treatment to follow its effects in our patients under TES.[7,8] To recognize and evaluate the performance of the three main layers of the vascular structure of the choroid, after TES, we propose to segment the choroidal region of a subfoveal OCT-SD image assigning to each layer a specific color that let separate the layers properly.

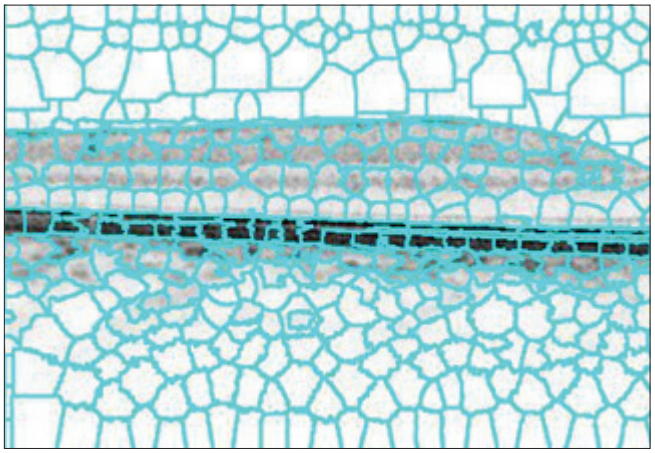

Figure 1: Clusters in the optical coherence tomography image

This method consists in selecting a region of the image, whose gray-tone values correspond to a specific region Rn, where R1>Rn>R2. Each selected Rn region is assigned a default color value Cn. The range of variation of Rn was selected by means of the statistical study of the average of the tonality of the pixels that exist in an OCT image. For this study, 50 OCT images of healthy patients were taken, from which the R1>Rn>R2 region was arbitrarily selected. Within that region, the minimum and maximum average values were determined. The Rn region can be subdivided as many times as desired in clusters Fn, as described in the previous lines until it is possible to assign Cn regions.

Preprocessing stage

As a preprocessing stage, a technique called "super pixels" let determine the grey tonality in the pixels contained in the OCT to define a homogeneous region. As shown in Figure 1, this technique allows an envelope of the segment chosen in a space. Subsequently, the image was divided into clusters (small groups of pixels) for its particular analysis, adapting them to the shape of the tissues and thus determining the average tonality of the pixels contained in each of the clusters. Once each cluster is defined, we select a few of them with minimum differences to assign a color tone, thus achieving a uniform distribution of color tones in those clusters with minimum differences previously defined.

A key point on the selection of the region of the image under analysis is to notice the variety of tones between the pixels at each border, as shown in Figure 2. Then, we define the limits of each layer within the retina taking as a reference the RPE; we established the tonality ranges below and up to the sclera.

Selection of layers by color tonality

The method we call selection by color tonality consists of selecting a region of the image, defined in a grayscale tone

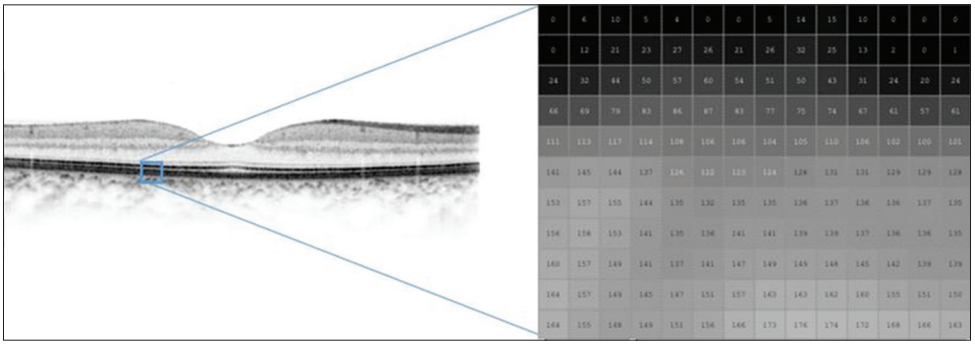

Figure 2: The limits of each layer within the retina take as a reference the retinal pigmented epithelium

corresponding to a specific region R, where R1> Rn> R2, R1, and R2 are the set of values that identify the region Rn. In the choroid case under study, we define a region R from each of the three main layers of the choroid, R1, R2, and R3. Each selected Rn region is assigned a default color value Cn. The range of variation of Rn is selected by means of the statistical study of the average of the totality of the pixels that are in a 50 OCT images from healthy patients.

Once each of the three sub-regions of the choroid (SRNC) was determined, the range of the gray levels of each region SRIC, SRIIC, and SRIIIC is defined. In turn, each of the regions is binarized independently, to clearly delineate each of these regions, as shown in Figure 3. With the help of an artificial vision algorithm, it was possible to eliminate areas or pixels that they are outside the choroid region. Once each layer of the choroid is segmented, we are in the position to calculate the area of the layers.

Once segmented, each SRNC region we assign a different color to each layer. The color selection criterion was determined so that each vascular section had to be differentiated from the interstitial zone; a base color of the RGB color space was assigned. Choroid segmentation can be done with the tools proposed in this article for any of the image slices provided by the OCT.

RESULTS

The results show clearly the area of the choriocapillaris as shown in Figure 4 in dark blue color. The vascular and interstitial area of the middle choroid layer is clearly separated as indicated in Figure 5 in red and yellow, respectively, as well as the vascular and interstitial area of the layer of large vessels as shown in Figure 6 in cyan and green, respectively.

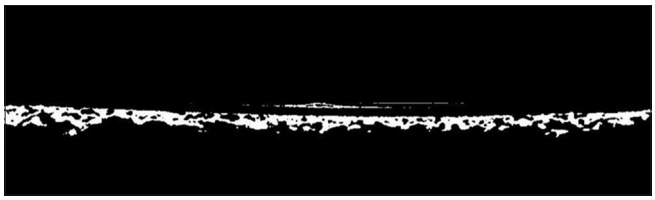

Figure 3: Separation of the choroid structure from the optical coherence tomography image

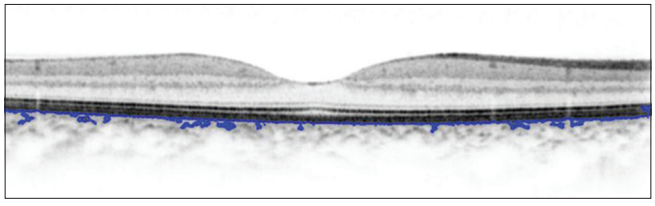

Figure 4: Choriocapillaris (Ruysch layer). From conventional optical coherence tomography, spectral domain does not let to see clearly the fine differences among the layers of the choriocapillaris

We show in Figure 7 the set of layers segmented by this method within the subfoveal OCT image and Table 1 shows the calculated area of each of the layers shown in Figure 7. It is worth mentioning that this method was also tested in OCT images of different cuts along the retina, managing to segment the same layers mentioned above and be able to measure the area of each of these.

We show in Figures 8 and 9, the different cuts of the whole OCT image that includes the segmentation of choroid using the proposed method where the differences among the layers of the choroid are clearly distinguished. Tables 2 and 3, respectively, contain the area obtained for each cut.

To calculate the area of the choroid layer we take as a reference to the distance between the centers of two neighbor pixels. The center of a pixel is the crossing point between two diagonals in the square pixel shown in Figure 10. Each side of our white reference square has a distance L = 0.905896 μm. Then, the pixel area is the product LxL equal to A = 0.1811792 μm^2. The area of the region of interest (ROI) is the product of the number of pixels inside the ROI multiplied by A. The software let the user chose the ROI, and then the software calculates the area of the ROI selected.

CONCLUSIONS

The area and thickness of the choroid vasculature and its area can be obtained numerically, as well as the clear separation of each layer of the choroid from the OCT SD images. The structures of the choriocapillaris, the middle choroid layer, and the great vessel layer are now well defined and clearly separated by different colors letting the physician identify

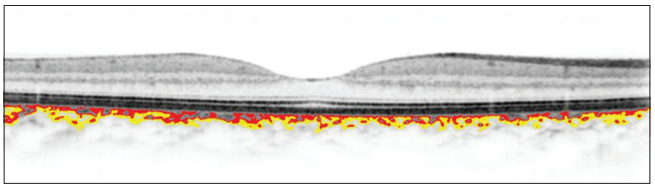

Figure 5: Vascular zone (yellow) and interstitial area (red) of the middle choroid layer (Sattler layer)

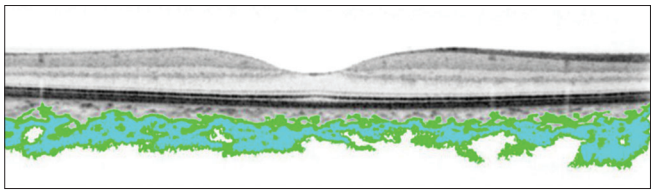

Figure 6: Vascular zone (cyan) and interstitial zone (green) of the great vessel layer (Haller's layer)

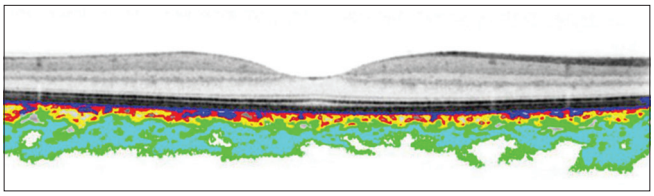

Figure 7: Layers that make up the choroid

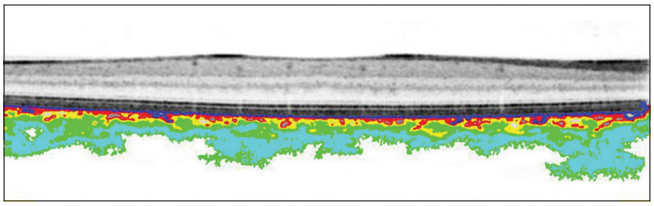

Figure 8: The choroid layers are clearly distinguished among other structures shown in the optical coherence tomography image

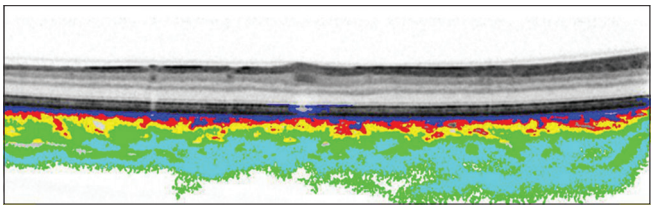

Figure 9: Layers that make up the choroid in Section 2

the evolution of the patient by a simple non-invasive method that can be implemented easily in any desktop computer.

The algorithm proposed in this paper improves the OCT SD facilities, let the physician analyze the layers and vascular zones within the choroid. Results show that in the external zone we can see the division between the sclera and the layer of large vessels, in the internal area, the separation between the choriocapillaris and the EPR can be seen, with the Bruch membrane in the middle. Results suggest new alternatives to study the evolution of this important structure in degenerative pathologies such as RP, Retinosis (RP), Diabetic retinopatia (DR), Age macular degeneration (AMD).

The proposed segmentation method based on the grayscale tones from OCT SD images let us identify the region of interest ROI and measure the area of the layers that constitute the choroid. This new method turned out to be useful to segment the choroid and its layers in comparison with recent methods described in the literature. The key points are: we analyze the image by regions selecting elements (pixels) with a similar tonality range. Similar tonality creates groups of pixels inside the ROI previously defined. We differentiated the vascular zones from the interstitial zones with colors that stand out from each other. With this, small changes in the morphology were detected. This procedure let us measure area changes within the choroid tissue, assisting the specialists in research, diagnosis and clinical treatment.

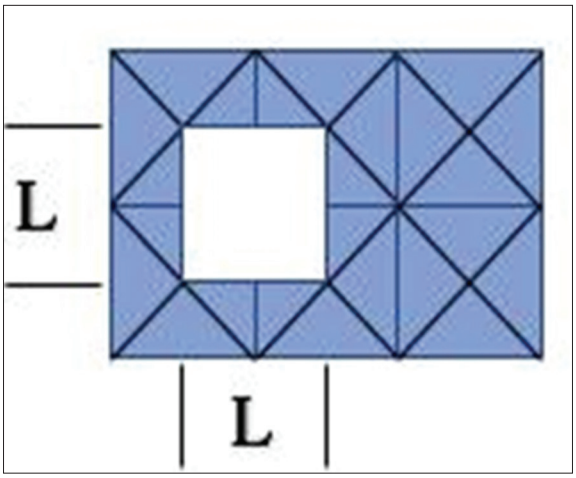

Figure 10: To calculate the area of the choroid layer we take as a reference to the distance between the center of two neighbor pixels. The pixel area is the product LxL equal to A = 0.1811792 μm^2

Table 1: Areas of the choroidal layers in Figure 7

Layer	Zone	Area (μm^2)
Choriocapillaris		47,208
Middle choroidal layer	Interstitial	153,135
	Vascular	85,960
Great vessel layer	Interstitial	541,380
	Vascular	283,455

Table 2: Areas of the choroidal layers in Section 1 in Figure 8

Layer	Zone	Area (μm^2)
Choriocapillaris		37,086
Middle choroidal layer	Interstitial	136,479
	Vascular	73,113
Great vessel layer	Interstitial	482,395
	Vascular	263,057

DISCUSSION

Choroid physiopathology is still unclear. However, Choroid mechanisms are responsible for blood regulation in the retina. OCT SD and segmentation tools offer non-invasive opportunities to investigate the mechanisms of blood flow regulation in ocular degenerative illnesses. A deeper understanding of those Choroid mechanisms requires new techniques for monitoring the choroidal blood flow. Amongst others, we need to study the role of capillaries, astrocytes, and pericytes, which are in charge of regulating blood flow. Choroid morphology and its changes will let us a better approach to understand the retinal and choroidal physiopathology in diabetic retinopathy, age-related

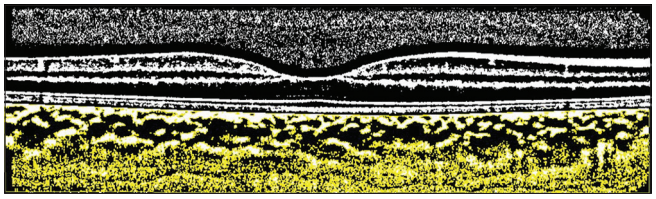

Figure 11: Differences between the color segmentation method proposed in this paper a binarization method used by Sonoda's *et al*

Table 3: Areas of the choroidal layers in Section 2 in Figure 9

Layer	Zone	Area (μm²)
Choriocapillaris		77,803
Middle choroidal layer	Interstitial	210,585
	Vascular	116,402
Great vessel layer	Interstitial	851,336
	Vascular	430,419

Table 4: Areas of the choroid with Sonoda's method

Zone	Area (μm²)
Area interstitial	938,124
Area vascular	494,492

macular degeneration, Glaucoma, and Retinitis Pigmentosa diseases.

We show in Figure 9 each one of the Choroid layers separated by colors. The blue zone corresponds to the Choriocapillaris. Notice the separation between the choriocapillaris and the EPR by Bruch's membrane in the middle. The red area refers to the vascular zones within the choroid. The division between the sclera, shown in white, and the layer of great vessels, shown in light green, are appreciated. With this, we visualize the layers between the choroid through the conventional OCT color tonality method. The proposed algorithm let us analyze each layer by oneself and measure its area changes during medication. We found some differences in the choroid area evaluated between our method and Sonoda's proposal[2]. Even the algorithm for the area evaluation is equal over the very same OCT SD image. The difference in the area found is about 34 percent, which seems to be significant. We attribute this difference to noise-affected pixels mixed with the borders of each layer, as we can see in Figure 11, shown as white tissue. We show in figures 6 to 9 various approaches to choroid segmentation.

We noticed a better resolution among the choroid layers in Figure 9, whereas an evident improvement compared with Sonoda's method is shown in Figure 11.

ACKNOWLEDGMENTS

This research was supported by CONACyT (grant No. 0261660) and The Instituto Politécnico Nacional, (IPN, grant No 20181912).

REFERENCES

1. Lauren AB, Adhi M, Regatieri CV, Nandakumar N, Liu JJ, Laver N, et al. Analysis of choroidal morphology and vasculature in healthy eyes using spectral-domain optical coherence tomography. Ophthalmology 2013;120:1901-1008.
2. Sonoda S, Sakamoto T, Yamashita T, Shirasawa M, Uchino E, Terasaki H, *et al*. Choroidal structure in normal eyes and after photodynamic therapy determined by binarization of optical coherence tomographic images. Invest Ophthalmol Vis Sci 2014;55:3893-9.
3. Wang Q, Chan S, Yang JY, You B, Wang YX, Jonas JB, *et al*. Vascular density in retina and choriocapillaris as measured by optical coherence tomography angiography. Am J Ophthalmol 2016;168:95-109.
4. Shahlaee A, Samara WA, Hsu J, Say EA, Khan MA, Sridhar J, *et al*. *In vivo* assessment of macular vascular density in healthy human eyes using optical coherence tomography angiography. Am J Ophthalmol 2016;165:39-46.
5. Regatieri CD, Branchin L, Carmody J, Fujimoto JG, Duker JS. Choroidal thickness in patients with diabetic retinopathy analyzed by spectral domain optical coherence tomography. Retina 2012;32:563-8.
6. Hua R, Wang H. Dark signals in the choroidal vasculature on optical coherence tomography angiography: An artefact or not? J Ophthalmol 2017;2017:8.
7. Robles-Camarillo D, Niño-de-Rivera L, López-Miranda J, Gil-Carrasco F, Quiroz-Mercado H. The effect of transcorneal electrical stimulation in visualacuity: Retinitis pigmentosa. J Biomed Sci Eng 2013;6:1-7.
8. Gil-Carrasco F, Ochoa-Contrera D, Torres MA, Santiago-Amaya J, Pérez-Tovar FW, Gonzalez-Salinas R, *et al*. Transpalpebral electrical stimulation as a novel therapeutic approach to decrease intraocular pressure in open-angle glaucoma patients. A pilot study. J Ophthalmol 2018;2018:6.
9. Schatz A, Pach J, Gosheva M, Naycheva L, Willmann G, Wilhelm B, *et al*. Transcorneal electrical stimulation for patients with retinitis pigmentosa: A prospective, randomized, sham-controlled follow-up study over 1 year transcorneal electrical stimulation for RP. Invest Opthalmol Vis Sci 2017;58:257-69.
10. Kurimoto T, Oono S, Oku H, Tagami Y, Kashimoto R, Takata M, *et al*. Transcorneal electrical stimulation increases chorioretinal blood flow in normal human subjects. Clin Ophthalmol 2010;4:1441-6.

How to cite this article: Duran AAE, Juarez PC, Nino-de-Rivera L. Optical Coherence Tomography Image Analysis to Segment the Choroid by a New Method: Selection of Ranges by Color Tonality. Clin Res Ophthalmol 2018;1(1):1-5.