ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

DOI: 10.5336/ophthal.2021-84780

Evaluation of Choroidal and Retinal Vascular Alterations in Macular Region of Eyes with Exfoliation Glaucoma: A Cross-Sectional Study

Eksfoliasyon Glokomlu Gözlerde Makulada Koroidal ve Retinal Vasküler Değişikliklerin Değerlendirilmesi: Kesitsel Çalışma

Gözde HONDUR[a], Emine ŞEN[a], Mevlüt YILMAZ[a], Serdar BAYRAKTAR[a], Ufuk ELGİN[a]

[a]Clinic of Ophthalmology, University of Health Sciences Ulucanlar Eye Training and Research Hospital, Ankara, Türkiye

ABSTRACT Objective: To characterize the alterations in the vasculature of the retina and choroid in eyes with exfoliation glaucoma (XFG) with the enhanced depth imaging (EDI) modality of an optical coherence tomography (OCT) and OCT angiography (OCTA). **Material and Methods:** In this cross-sectional observational study, the choroidal vascularity index (CVI) values were assessed with EDI OCT and macula vessel density (VD) in the superficial capillary plexus (SCP) values were assessed with OCTA compared among 35 XFG cases (15 eyes with early stage and 20 eyes with moderate to advanced stage) and 32 healthy controls, which were age and sex matched. **Results:** The eyes with XFG had significantly lower global (whole image) macula VDs compared with the control eyes (p<0.001). The eyes with moderate to advanced stage XFG had also lower mean CVI values compared with the control eyes (p=0.01). The mean CVI values of the XFG eyes had a moderate correlation with the visual field MD values (r=0.398, p=0.01), while choroidal thickness values of the XFG eyes did not demonstrate such an association with the visual field MD values (r=0.035, p=0.84). Mean macula VD values in the SCP demonstrated a strong correlation with the visual field MD values (r=0.698, p<0.00001). **Conclusion:** The lower CVI and macula VD of XFG eyes compared with healthy controls and its significant correlation with the severity of glaucoma imply the role of retinal and choroidal vascularity in XFG pathogenesis.

Keywords: Choroidal vascularity index; enhanced depth imaging; optical coherence tomography angiography; vessel density

ÖZET Amaç: Bu çalışmanın amacı, eksfoliasyon glokomlu (EG) gözlerde retina ve koroid vaskülaritesindeki değişiklikleri, optik koherens tomografi (OKT) artırılmış derinlik görüntüleme (ADG) modu ve OKT anjiyografisi (OKTA) ile karakterize etmektir. **Gereç ve Yöntemler:** Bu kesitsel gözlemsel çalışmada, koroid vaskülarite indeksi (KVİ) ADG mod OKT ile ve makula yüzeyel kapiller pleksus (YKP) damar dansitesi (DD) OKTA ile değerlendirildi; EG vakaları (n=35, 15 erken evre göz ve 20 orta ileri evre göz) ile yaş-cinsiyet uyumlu sağlıklı kontrol grubu (n=32) arasında karşılaştırıldı. **Bulgular:** EG'li gözlerde, kontrol grubuna göre daha düşük global makula DD değerleri saptandı (p<0,001). Ayrıca orta ileri evre EG'li gözlerde, kontrol grubuna göre daha düşük ortalama KVİ değerleri saptandı (p=0,01). EG'li gözlerin ortalama KVİ değeri, görme alanı ortalama sapma değeri ile orta derecede korelasyon gösterirken (r=0,398, p=0,01); ortalama koroid kalınlığı değeri, görme alanı ortalama sapma değeri ile anlamlı korelasyon göstermedi (r=0,035, p=0,84). Makuladaki ortalama YKP DD değeri ise görme alanı ortalama sapma değeri ile güçlü bir korelasyon gösterdi (r=0,698, p<0,00001). **Sonuç:** Sağlıklı kontrollerle karşılaştırıldığında EG'li gözlerin düşük KVİ ve makula DD'sine sahip olması ve bunların glokomun şiddeti ile anlamlı derecede korele olması, EG patogenezinde retinal ve koroidal vaskülaritenin rolüne işaret etmektedir.

Anahtar Kelimeler: Koroid vaskülarite indeksi; artırılmış derinlik görüntüleme; optik koherens tomografi anjiyografi; damar dansitesi

Exfoliation syndrome (XFS) is an age-related systemic disease in which an anomalous extracellular material is synthesized and accumulates in intraocular tissues as well as non-ocular tissues.[1] It is the most frequent detectable cause of secondary open angle glaucoma worldwide.[2] Exfoliation glaucoma (XFG)

Correspondence: Gözde HONDUR
Sağlık Bilimleri Üniversitesi Ulucanlar Göz Eğitim ve Araştırma Hastanesi, Göz Hastalıkları Kliniği, Ankara, Türkiye
E-mail: gozdealtiparmak@yahoo.com

Peer review under responsibility of Turkiye Klinikleri Journal of Ophthalmology.

Received: 03 Jun 2021 ***Received in revised form:*** 01 Jan 2022 ***Accepted:*** 29 Jan 2022 ***Available online:*** 02 Feb 2022

is recognized for a more aggressive clinical course with more episodes of high pressure, wider intraocular pressure (IOP) fluctuations, poorer response to medical treatment than primary open angle glaucoma (POAG).[3,4] The more aggressive clinical course of XFG compared to POAG may be related to its relatively stronger association with vascular impairment.[5]

The improvement in ocular imaging technologies has provided clinicians with new methods to evaluate the structural and vascular characteristics of the retina and choroid with greater detail. Optical coherence tomographic angiography (OCTA) is a new modality providing imaging of the microvasculature of the optic disc and retina.[6] Also, the enhanced depth imaging (EDI) mode of the optical coherence tomography (OCT) has become a widely used method for imaging the choroid.[7] Choroidal vascularity index (CVI) has also been introduced as a new method to assess choroidal vascular status.[8]

Previous OCTA studies have shown the diminished microvasculature of the peripapillary region and the macula of eyes with XFG.[9,10] The peripapillary and macular choroidal alterations in POAG were also studied based on CVI in only a few previous reports.[11,12] However, none of these studies evaluated the association between the CVI and XFG.

The macula is the retinal region with the highest concentration of retinal ganglion cells, hence the macula is a strategic region for assessment of glaucomatous alterations.[13,14] Since the present study is aimed at investigating the macular retinal and choroidal vasculature in eyes with XFG versus that of healthy controls and comparing the correlation between retinal and choroidal vascular parameters and severity of glaucomatous damage in XFG eyes.

MATERIAL AND METHODS

STUDY PARTICIPANTS

The OCT and OCTA images were obtained from glaucoma patients and healthy subjects who accepted to contribute the study. The study was approved by the Ankara Training and Research Hospital Institutional Ethics Committee (date: December 30, 2020, number: E-20-414) and conducted in accordance with the ethical principles of the Declaration of Helsinki. A written informed consent was obtained from all the participants.

A detailed anamnesis was obtained from all the participants and also a full ophthalmological examination and retinal nerve fiber layer (RNFL) analysis on OCT and visual field analysis (Humphrey Visual Field Analyzer, Carl Zeiss Meditec Inc., Dublin, CA, USA) were performed. Also, the central corneal thickness and axial length parameters (Lenstar LS 900, Hagg-Streit AG, Koeniz, Switzerland) were evaluated. All EDI OCT and OCTA measurements were done by the same physician in the morning (between 9 and 12 am) to avoid diurnal fluctuations.

The inclusion criteria for healthy subjects were a best corrected visual acuity of 20/30 or better, a spherical refractive error within +5 to -5 diopters (D), <3 D of astigmatism, normal clinical ocular findings with no evidence of retinal or optic nerve head pathologies, IOP of less than 21 mmHg, open iridocorneal angles, intact RNFL, and normal visual field results.

The inclusion criteria for XFG were defined as a glaucomatous optic nerve appearance with the presence of exfoliation material being noticeable on the anterior chamber structures, a gonioscopically open angle, glaucomatous RNFL thinning, and a glaucomatous visual field defect or an abnormal glaucoma hemifield test result. The stage of glaucoma was classified as early [24-2 visual field mean deviation (MD) ≥-6 dB] or moderate-to-advanced [24-2 visual field MD<-6 dB] in XFG eyes based on Hodapp-Parrish-Anderson criteria. One eye of each subject was enrolled in the study. The involved eye was selected in unilateral cases and one eye was selected at random when both eyes were eligible.

We eliminated the patients who had a previous ocular trauma or posterior segment intraocular surgery, nonglaucomatous optic neuropathies, any retinal disease that may affect macular thickness, systemic diseases such as diabetes mellitus or hypertension.

EDI OCT IMAGE ACQUISITION AND CVI ASSESSMENT

All the participants underwent OCT imaging with the Spectralis OCT (Heidelberg Engineering, Heidelberg, Germany) using the EDI mode. After mydriasis was attained and the patient appropriately positioned, the EDI OCT scan of the foveal center was acquired.

The choroidal thickness was calculated from retinal pigment epithelium to the outer border of the choroid at the subfoveal area using the calipers provided in the software.

EDI OCT images were analyzed with the ImageJ software (Version 1.47, National Health Institute, Bethesda, MA) using the binarization protocol described by Agrawal et al.[8] After converting the image into 8 bit, the Niblack autolocal threshold tool was applied, which allows the demarcation of the choroidal stroma and its total vascular lumen (Figure 1). The binarized image was then transformed to the RGB format, and luminal areas were highlighted with the color thresholding tool. The total choroidal, luminal and stromal areas were then calculated within the central 1,500 µm. The fraction of the luminal area to the total choroidal area yielded the CVI. All the CVI analysis and measurements were performed separately by 2 blinded investigators.

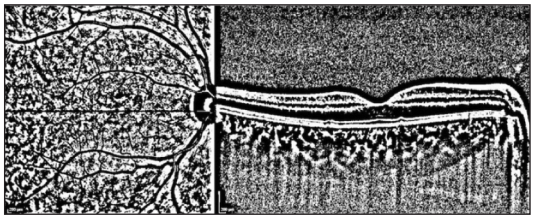

FIGURE 1: The enhanced depth imaging optical coherence tomography scan passing through the foveal center of each eye was selected. Total choroidal area, lumen area and stromal area were calculated in the central 1,500 µm. The image was converted to 8 bits and thresholding was applied.

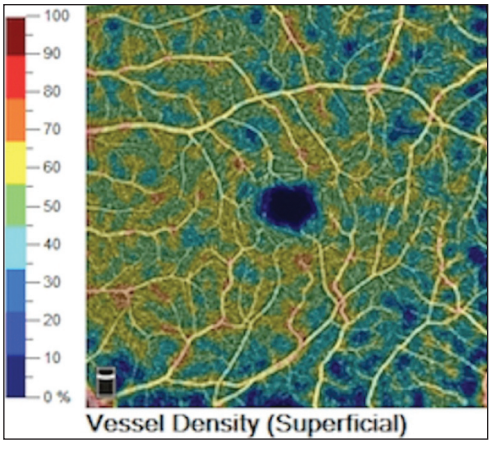

FIGURE 2: Macula vessel density map provided by the 6-mm angio retina scan.

OCTA IMAGING

OCTA images were acquired by the initial experienced physician with the AngioVue Imaging System (Optovue XR Avanti, Optovue, 2017.1.0.151). The vessel density (VD) values of the macular region was obtained over a 6x6 mm region centered on the foveal avascular zone.

In this study, the superficial VD values were measured over a 6x6 mm region centered on the foveal avascular zone (Figure 2). The foveal zone was designated to the central 1 mm circle, the parafoveal zone was designated to the second 3 mm circle, and the perifoveal zone was designated to the outermost 6 mm circle. The zones were also automatically separated into 4 sectors of 90° each (superior, inferior, temporal, and nasal). The whole image (WI) macula VD (mVD) was measured in the entire 6x6-mm image. The superficial capillary plexus (SCP) was made up of the capillaries between the inner limiting membrane and the posterior inner plexiform layer margin. OCTA scans with low quality were disregarded in the incidence of one or more of the listed conditions: inadequate signal strength index (less than 6 on a 10-point scale), incidence of blink artifacts, motion artifacts, media opacities interfering with the vessel signals, or any segmentation errors.

STATISTICAL ANALYSIS

The SPSS software (SPSS for Windows Version 20.0; SPSS Inc., Chicago, IL, USA) was used for analysis. Categorical variables were compared by means of the chi-squared test. One-way ANOVA was used for the analysis of the differences between the three groups in those with normal distribution and post hoc analysis was achieved with the Bonferroni test. The one-way ANOVA on ranks was used in those without normal distribution and post hoc analy-

sis was achieved with the Dune test. A p value <0.05 was accepted as significant. Correlations between the vascular parameters and the visual field MD values were evaluated using Pearson correlation analyses in XFG patients.

The power of the study was 0.8 based on a sample size of more than 14 eyes in each group and the significance level of 0.05.

RESULTS

Thirty-five eyes with XFG [15 eyes with early stage and 20 eyes with moderate to advanced stage (10 eyes with moderate stage and 10 eyes with advanced stage)], and 32 control eyes were evaluated in this study. There was no difference in terms of sex, age axial length and central corneal thickness values between the groups (p>0.05 for all). The XFG eyes were under treatment with topical hypotensive drops. The IOPs of the XFG group and the control group were similar (p=0.45). Table 1 outlines the clinical features of the participants.

Table 2 demonstrates the retinal and choroidal vascular parameters of the groups in detail. Eyes with XFG (both early and moderate to advanced stage eyes) had significantly lower global (WI) mVDs in the SCP (p<0.001). The mVDs of the 4 sectors are also shown in Table 2 in detail. The moderate to advanced stage XFG eyes had also markedly lower CVI values compared to the control eyes (p=0.01). The XFG eyes also had lower mean subfoveal choroidal thickness compared to the healthy eyes, but the difference was not significant (p=0.28) (Table 2).

The WI mVD values demonstrated a strong correlation with visual field MD values in the XFG group (r=0.698, p<0.00001). The CVI values demonstrated only a moderate correlation with visual field MD values in the XFG group (r=0.398, p=0.01). In addition, the CT values did not demonstrate any correlation with visual field MD values in the same group (r=0.035, p=0.84) (Figure 3) (Table 3).

TABLE 1: Clinical and demographic data of the groups.

	Controls	Early stage XFG	Moderate to advanced stage XFG	p value
Number of eyes	32	15	20	
Gender (F/M)	13/19	7/8	8/12	0.90*
Age (years)	63.93±6.65	62.66±8.06	64.65±7.57	0.72**
Axial length (mm)	23.20±0.94	23.29±0.99	23.54±1.04	0.6***
Central corneal thickness (µm)	549±34	540±25	534±30	0.31**
IOP (mmHg)	15.5±2.0	15.6±2.7	14.5±2.7	0.45***
Mean deviation (dB)	-0.32	-2.57	-14.70	

Statistical significance was calculated with the chi-square test*, the one-way ANOVA** and the one-way ANOVA on ranks test***; Data are presented as mean±standard deviation; XFG: Exfoliation glaucoma; F/M: Female/male; IOP: Intraocular pressure.

TABLE 2: Choroidal and retinal vascular parameters of the study groups.

	Controls	Early stage XFG	Moderate to advanced stage XFG	p value	Post hoc
Whole image mVD	50.53±3.04	46.65±4.01	36.89±5.01	<0.001	1>2>3
Temporal mVD	47.18±3.92	43.70±4.40	34.96±4.94	<0.001	1>2>3
Superior mVD	50.52±3.20	48.13±4.54	37.77±5.84	<0.001	1=2>3
Nasal mVD	55.18±3.38	52.11±3.94	40.19±7.30	<0.001	1=2>3
Inferior mVD	49.59±4.06	47.36±5.67	36.47±6.47	<0.001	1=2>3
Choroidal thickness	273.65±71.74	265.42±75.06	236.07±74.37	0.28	1>3
Choroidal vascularity index	0.693±0.029	0.686±0.038	0.663±0.034	0.01	1=2

Statistical significance was calculated with the one-way ANOVA test; Data are presented as mean±standard deviation; XFG: Exfoliation glaucoma; mVD: Macula vessel density.

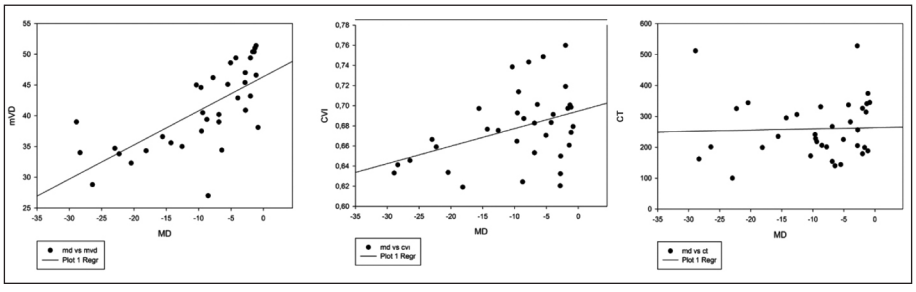

FIGURE 3: Scatter plots illustrating the linear correlation between mVD, CVI, CT and visual field MD in eyes with exfoliation glaucoma. **mVD:** Macula vessel density; **MD:** Mean deviation; **CVI:** Choroidal vascularity index; **CT:** Choroidal thickness.

TABLE 3: Correlation between vascular parameters of the macular area and visual field mean deviation values in XFG eyes.

	Correlation coefficient	p value
Whole image mVD	0.698	<0.00001
Choroidal vascularity index	0.398	0.01
Choroidal thickness	0.035	0.84

XFG: Exfoliation glaucoma; mVD: Macula vessel density.

DISCUSSION

Many studies have stated that vascular factors and reduced ocular blood flow are related with the pathogenesis of glaucoma.[15-18] There are also several studies connected with both ocular and choroidal blood flow in XFS.[19-21] In the present study, we aimed at improving understanding of the potential function of the choroidal and retinal vascular alterations in XFG pathogenesis. Hence, in the present study, we compared both the VDs in the SCP and subfoveal CVI of XFG eyes with age matched healthy control eyes.

XFG group had diminished mVDs in the SCP compared to age matched healthy controls. A significant decrease in the mean VD in the SCP of XFG eyes points toward a prominent role of retinal vascular regression in XFG. Since the SCP is responsible for the nutrition of the inner retina including the ganglion cell bodies.[22,23]

The studies evaluating the OCTA changes in macular region of XFG eyes are limited, and these studies have not reached a common conclusion. Although a previous study detected similar mVDs between POAG and XFG eyes, other important studies reported a lesser mVD in XFG eyes than that of POAG.[9,10,24] To the best of our knowledge, the CVI of XFG eyes has not been evaluated before. We could not include a POAG group in the present study hence we could not evaluate the comparison of POAG and XFG eyes. Instead, we simultaneously evaluated the OCTA parameters and CVI in XFG eyes.

The presentation of EDI OCT has aided non-invasive, quantitative and detailed evaluation of the choroid.[25] Choroidal thickness has been the first surrogate marker for choroidal structural changes on OCT. However, recent meta-analysis did not find a significant difference in the choroidal thickness between open angle glaucoma patients and controls.[26] It may be due to the insufficiency of the choroidal thickness evaluation in differentiating the alterations between its vascular and stromal components. Hence, more recent studies have concentrated on evaluating the vascular and stromal components of the choroid separately.[27,28] CVI assessment involves an image binarization technique to calculate the relative vascular component of the choroid.[29]

A previous study has reported a lower subfoveal CVI in open angle glaucoma eyes compared to healthy eyes.[11] A far as we know, the importance of CVI has not been studied in eyes with XFG. In the current study, we demonstrated lower subfoveal CVI values in moderate to advanced stage XFG eyes compared to age matched healthy control eyes. However, subfoveal choroidal thickness values did not differ among XFG and control eyes, suggesting the lack of any relationship between the choroidal thickness and XFG. CVI might be more sensitive in representing the vascular impairment in XFG pathogenesis as it specifically analyses the vascular component.

Furthermore, in the present study, both the mVD in the SCP and subfoveal CVI had significant correlations with corresponding visual field MD values, and hence with the disease severity in the XFG eyes, which supports not only diagnostic but also prognostic value of retinal and choroidal vascularity status. On the other hand, the choroidal thickness values did not demonstrate any correlation with the visual field MD values in the same group.

The stronger correlation of the mVD in the SCP (r=0.698) with the glaucoma severity compared to subfoveal CVI (r=0.398) may indicate relatively more importance of the retinal SCP VD compared to choroid in XFG pathogenesis.

As the role of the choroid in the pathogenesis of glaucomatous optic neuropathy is not clear, it is essential to study in greater depth with the advanced imaging technology to understand the real role of the choroid in glaucoma pathogenesis.[26]

The major strength of the present study was the strict matching of the groups for axial length, sex, age, IOP, and central corneal thickness. Age, axial length, central corneal thickness are significantly associated with changes in the choroidal thickness in glaucoma eyes.[30]

The present study is not without limitations. Its cross-sectional design, which precluded the longitudinal follow-up of glaucoma patients and analysis of disease progression, may be considered as the major limitation. In addition, although not validated yet, different IOP-lowering drops may have different effects on the retinal and choroidal vascularity. Another limitation of this study is that the number of patients was relatively small, as was the number in each subgroup, suggesting the need to confirm our findings in larger numbers of patients. We also could not evaluate the moderate and advanced stages separately as the groups are limited to only 10 eyes each. Moreover, POAG patients were not included, which avoided the capability to differentiate changes due to glaucoma versus exfoliation.

CONCLUSION

Our study demonstrated a lower mean mVD and subfoveal CVI values in eyes with XFG versus that of healthy subjects. The results support the role of retinal and choroidal vascular insufficiency in the pathogenesis of XFG. The stronger correlation of SCP density with visual field MD (disease severity) compared to subfoveal CVI may emphasize the relatively more significant role of SCP compared to the choroid in XFG pathogenesis.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Gözde Hondur, Emine Şen, Ufuk Elgin;* ***Design:*** *Gözde Hondur, Emine Şen, Serdar Bayraktar;* ***Control/Supervision:*** *Gözde Hondur, Emine Şen, Ufuk Elgin;* ***Data Collection and/or Processing:*** *Gözde Hondur, Mevlüt Yılmaz, Serdar Bayraktar;* ***Analysis and/or Interpretation:*** *Gözde Hondur, Emine Şen, Ufuk Elgin;* ***Literature Review:*** *Gözde Hondur, Emine Şen, Serdar Bayraktar, Ufuk Elgin;* ***Writing the Article:*** *Gözde Hondur, Emine Şen, Serdar Bayraktar;* ***Critical Review:*** *Gözde Hondur, Emine Şen, Mevlüt Yılmaz, Ufuk Elgin;* ***References and Fundings:*** *Mevlüt Yılmaz, Serdar Bayraktar;* ***Materials:*** *Mevlüt Yılmaz, Serdar Bayraktar.*

REFERENCES

1. Yıldırım N. Psödoeksfoliyatif glokom [Pseudoexfoliative glaucoma]. Glo-Kat. 2011;6:54-9. [Link]
2. Ritch R. Exfoliation syndrome-the most common identifiable cause of open-angle glaucoma. J Glaucoma. 1994;3(2):176-7. [Crossref] [PubMed]
3. Ritch R, Schlötzer-Schrehardt U. Exfoliation syndrome. Surv Ophthalmol. 2001;45(4):265-315. [Crossref] [PubMed]
4. De Moraes CG, Liebmann JM, Liebmann CA, Susanna R Jr, Tello C, Ritch R. Visual field progression outcomes in glaucoma subtypes. Acta Ophthalmol. 2013;91(3):288-93. [Crossref] [PubMed]
5. Galassi F, Giambene B, Menchini U. Ocular perfusion pressure and retrobulbar haemodynamics in pseudoexfoliative glaucoma. Graefes Arch Clin Exp Ophthalmol. 2008;246(3):411-6. [Crossref] [PubMed]
6. Rao HL, Pradhan ZS, Suh MH, Moghimi S, Mansouri K, Weinreb RN. Optical coherence tomography angiography in glaucoma. J Glaucoma. 2020;29(4):312-21. [Crossref] [PubMed] [PMC]
7. Laviers H, Zambarakji H. Enhanced depth imaging-OCT of the choroid: a review of the current literature. Graefes Arch Clin Exp Ophthalmol. 2014;252(12):1871-83. [Crossref] [PubMed]
8. Agrawal R, Gupta P, Tan KA, Cheung CM, Wong TY, Cheng CY. Choroidal vascularity index as a measure of vascular status of the choroid: measurements in healthy eyes from a population-based study. Sci Rep. 2016;6:21090. [Crossref] [PubMed] [PMC]
9. Philip S, Najafi A, Tantraworasin A, Chui TYP, Rosen RB, Ritch R. Macula vessel density and foveal avascular zone parameters in exfoliation glaucoma compared to primary open-angle glaucoma. Invest Ophthalmol Vis Sci. 2019;60(4):1244-53. [Crossref] [PubMed] [PMC]
10. Subasi S, Yuksel N, Basaran E, Pirhan D. Comparison of vessel density in macular and peripapillary regions between primary open-angle glaucoma and pseudoexfoliation glaucoma using OCTA. Int Ophthalmol. 2021;41(1):173-84. [Crossref] [PubMed]
11. Park Y, Cho KJ. Choroidal vascular index in patients with open angle glaucoma and preperimetric glaucoma. PLoS One. 2019;14(3): e0213336. [Crossref] [PubMed] [PMC]
12. Park JW, Suh MH, Agrawal R, Khandelwal N. Peripapillary choroidal vascularity index in glaucoma-a comparison between spectral-domain OCT and OCT angiography. Invest Ophthalmol Vis Sci. 2018;59(8):3694-701. [Crossref] [PubMed]
13. Curcio CA, Allen KA. Topography of ganglion cells in human retina. J Comp Neurol. 1990;300(1):5-25. [Crossref] [PubMed]
14. Hood DC, Raza AS, de Moraes CG, Liebmann JM, Ritch R. Glaucomatous damage of the macula. Prog Retin Eye Res. 2013;32:1-21. [Crossref] [PubMed] [PMC]
15. Michelson G, Langhans MJ, Harazny J, Dichtl A. Visual field defect and perfusion of the juxtapapillary retina and the neuroretinal rim area in primary open-angle glaucoma. Graefes Arch Clin Exp Ophthalmol. 1998;236(2):80-5. [Crossref] [PubMed]
16. O'Brart DP, de Souza Lima M, Bartsch DU, Freeman W, Weinreb RN. Indocyanine green angiography of the peripapillary region in glaucomatous eyes by confocal scanning laser ophthalmoscopy. Am J Ophthalmol. 1997;123(5):657-66. [Crossref] [PubMed]
17. Huber K, Plange N, Remky A, Arend O. Comparison of colour Doppler imaging and retinal scanning laser fluorescein angiography in healthy volunteers and normal pressure glaucoma patients. Acta Ophthalmol Scand. 2004;82(4):426-31. [Crossref] [PubMed]
18. Tobe LA, Harris A, Hussain RM, Eckert G, Huck A, Park J, et al. The role of retrobulbar and retinal circulation on optic nerve head and retinal nerve fibre layer structure in patients with open-angle glaucoma over an 18-month period. Br J Ophthalmol. 2015;99(5):609-12. [Crossref] [PubMed]
19. Aghsaei Fard M, Safizadeh M, Shaabani A, Kafieh R, Hojati S, Afzali M, et al. Automated evaluation of parapapillary choroidal microvasculature in pseudoexfoliation syndrome and pseudoexfoliation glaucoma. Am J Ophthalmol. 2021;224:178-84. [Crossref] [PubMed]
20. Eroglu FC, Asena L, Simsek C, Kal A, Yılmaz G. Evaluation of choroidal thickness using enhanced depth imaging by spectral-domain optical coherence tomography in patients with pseudoexfoliation syndrome. Eye (Lond). 2015;29(6):791-6. [Crossref] [PubMed] [PMC]
21. Gür Güngör S, Sarigül Sezenöz A, Öztürk C, Gökgöz G, Akman A. Peripapillary and macular vessel density measurement with optical coherence tomography angiography in exfoliation syndrome. J Glaucoma. 2021;30(1):71-7. [Crossref] [PubMed]
22. Provis JM. Development of the primate retinal vasculature. Prog Retin Eye Res. 2001;20(6):799-821. [Crossref] [PubMed]
23. Campbell JP, Zhang M, Hwang TS, Bailey ST, Wilson DJ, Jia Y, et al. Detailed vascular anatomy of the human retina by projection-resolved optical coherence tomography angiography. Sci Rep. 2017;7:42201. [Crossref] [PubMed] [PMC]
24. Jo YH, Sung KR, Shin JW. Peripapillary and macular vessel density measurement by optical coherence tomography angiography in pseudoexfoliation and primary open-angle glaucoma. J Glaucoma. 2020;29(5):381-5. [Crossref] [PubMed]
25. Spaide RF, Koizumi H, Pozzoni MC. Enhanced depth imaging spectral-domain optical coherence tomography. Am J Ophthalmol. 2008;146(4):496-500. Erratum in: Am J Ophthalmol. 2009;148(2):325. Pozonni, Maria C [corrected to Pozzoni, Maria C]. [Crossref] [PubMed]
26. Zhang Z, Yu M, Wang F, Dai Y, Wu Z. Choroidal thickness and open-angle glaucoma: a meta-analysis and systematic review. J Glaucoma. 2016;25(5):e446-54. [Crossref] [PubMed]
27. 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(6):3893-9. Erratum in: Invest Ophthalmol Vis Sci. 2014;55(8):4811-2. [Crossref] [PubMed]
28. Sonoda S, Sakamoto T, Yamashita T, Uchino E, Kawano H, Yoshihara N, et al. Luminal and stromal areas of choroid determined by binarization method of optical coherence tomographic images. Am J Ophthalmol. 2015;159(6):1123-31.e1. [Crossref] [PubMed]
29. Agrawal R, Salman M, Tan KA, Karampelas M, Sim DA, Keane PA, et al. Choroidal Vascularity Index (CVI)--a novel optical coherence tomography parameter for monitoring patients with panuveitis? PLoS One. 2016;11(1):e0146344. [Crossref] [PubMed] [PMC]
30. Maul EA, Friedman DS, Chang DS, Boland MV, Ramulu PY, Jampel HD, et al. Choroidal thickness measured by spectral domain optical coherence tomography: factors affecting thickness in glaucoma patients. Ophthalmology. 2011;118(8):1571-9. [Crossref] [PubMed] [PMC]