Peripapillary and Macular Microcirculation in Glaucoma Patients of African and European Descent Using Optical Coherence Tomography Angiography

Logan Taylor, BS, BA,* Karine D. Bojikian, MD, PhD,† Hoon Jung, MD,† Zhongdi Chu, PhD,‡ Xiao Zhou, BEng,‡ Qingin Zhang, PhD,‡ Raghu C. Mudumbai, MD,† Ruikang K. Waang, PhD,‡‡ and Philip P. Chen, MD†

Précis: We found no significant differences in peripapillary and macular microcirculation blood flow metrics in eyes with open-angle glaucoma of African descent (AD) and European descent (ED) as detected by optical coherence tomography angiography (OCTA).

Purpose: The purpose of this study was to investigate the peripapillary retinal nerve fiber layer (RNFL) and macular vascular microcirculation in subjects of AD and ED with open-angle glaucoma using OCTA.

Patients and Methods: One eye from each subject was scanned using AngioPlex OCTA system covering both a 6×6 mm scanning area centered at the optic nerve head and at the fovea. Peripapillary RNFL and macular microcirculation were measured by calculating the overall flux and vessel area density excluding the large retinal vessels. Two-sample, independent t-tests were used to compare the OCTA metrics between AD and ED eyes. Linear regression models were used to investigate the correlation between OCTA metrics and structural and functional parameters.

Results: Twenty-eight eyes of AD and 56 eyes of ED were included in the study. There was no significant difference in age, sex, hypertension, antihypertensive medications, diabetes, systolic and diastolic blood pressure, mean ocular perfusion pressure, RNFL thickness and visual field (VF) mean deviation and VF pattern standard deviation (P ≤ 0.054) between AD and ED eyes included. Both groups had similar OCTA blood flow metrics (P ≥ 0.161). OCTA blood flow metrics were significantly correlated with VF mean deviation (r ≥ 0.466), VF pattern standard deviation (r ≤ −0.366) and RNFL thickness (r ≥ 0.333).

Conclusions: No significant differences were found in peripapillary and macular microcirculation detected by OCTA between AD and ED eyes. The overall structural and functional parameters were used to investigate the correlation between OCTA metrics and structural and functional parameters.

Key Words: blood flow, OCTA, optic nerve, macula, glaucoma (J Glaucoma 2020;29:885–889)

The global prevalence of glaucoma continues to rise and is expected to affect nearly 80 million individuals worldwide in 2020.1 In addition, the prevalence of glaucoma is higher among some populations compared with others. Quigley and Bronman1 reported approximately 4.39% of Africans older than 40 years are to be affected by glaucoma by 2020, which is the highest prevalence among populations worldwide. Individuals of African descent (AD) are also more likely to progress more rapidly and have worse clinical outcomes compared with individuals of European descent (ED).2

Despite recognition that some populations are disproportionately impacted by glaucoma compared with others, the reason for this remains elusive. It has been proposed that vascular dysfunction and reduced blood supply to the nerves and other components of the eye is the primary factor for glaucoma development.3 Systemic vascular disease such as arteriolosclerosis has also been associated with a variety of ocular pathologies.4 Individuals of AD have a higher prevalence of risk factors for developing a systemic vascular disease such as hypertension and diabetes along with higher rates of other cardiovascular sequelae.4,5

Previous studies using color Doppler imaging (CDI) of the retrobulbar vessels have evaluated the differences in blood flow in healthy and open-angle glaucoma (OAG) patients of AD and ED. Siesky et al6 in 2015 used CDI to measure peak systolic velocity and end-diastolic velocity of the ophthalmic artery, central retinal artery (CRA), nasal posterior artery and the temporal posterior ciliary artery in 66 AD and 123 ED (based on self-reported race). They reported a uniform reduction in retrobulbar circulation in persons of AD compared with individuals of ED. Later Siesky et al7 prospectively studied retrobulbar blood flow using CDI in 59 ED and 20 AD with no baseline difference in intraocular pressure (IOP), visual field (VF) mean deviation (MD), or optical coherence tomography (OCT) structural changes. They reported that reductions in retrobulbar blood flow strongly correlated with changes in the optic nerve head (ONH) and macular thickness over 4 years in patients of AD only. Finally, Kaskan et al8 also used CDI to study the ophthalmic artery, CRA, and nasal posterior ciliary artery and the temporal posterior ciliary artery of 24 AD and 34 ED healthy subjects and reported a significant higher resistive index in the CRA and TPCA of AD when compared with ED.

The radial peripapillary capillary (RPC) network is a unique plexus of capillary beds lying in the inner part of the retinal nerve fiber layer (RNFL) and oriented parallel to the RNFL axons. It has fewer anastomoses compared with other...
retina layers, which makes it particularly vulnerable to glaucoma damage. Optical coherence tomography angiography (OCTA), is a noninvasive technique which can be used to analyze the vasculature of the eye. In addition, semiautomatic segmentation of the 3-dimensional (D) volume allows for the extraction of specific layers within the retina, including the RPC. Previous studies have shown that blood flow metrics of the retina correlate with glaucoma disease severity.

In this study, we used OCTA to quantify and compare the vascular microcirculation in peripapillary and macular with AD and ED OAG eyes.

PATIENTS AND METHODS

Subjects
This study was approved by the Institutional Review Board of the University of Washington (UW), the Institutional Review Board of the Veterans Affairs (VA) Puget Sound Health Care System, and informed consent was obtained from all subjects before imaging. This study followed the tenets of the Declaration of Helsinki and was conducted in compliance with the Health Insurance Portability and Accountability Act.

Subjects with the diagnosis of OAG were enrolled at the UW Medicine Eye Institute and the VA Puget Sound Health Care System. Inclusion criteria were best-corrected visual acuity of 20/40 or better, and refractive error between −6.0 and +3.0 D spherical equivalent. The racial background of the patient (AD vs. ED) was obtained by self-identification, as listed in the hospital chart. Exclusion criteria was significant media opacity preventing high-quality imaging, any ocular disease other than glaucoma or cataract, and previous intraocular surgeries other than uncomplicated glaucoma or cataract surgery.

All patients were scanned using AngioPlex OCTA system (Zeiss Meditec Inc., Dublin, CA) covering a 6×6 mm scanning area centered at the ONH and covering a 6×6 mm scanning area centered at the foveola. Blood pressure (BP) was also evaluated on each patient during the same visit with the patient in a seated position using an automated BP monitor. BP was used to calculate the mean ocular perfusion pressure (MOPP). MOPP was defined as 2/3 (mean arterial pressure−IOP), where mean arterial pressure=diastolic BP+1/3 (systolic BP−diastolic BP).

Additional information including sex, systemic hypertension diagnosis, systemic hypertension medications, diabetes mellitus diagnosis, IOP, glaucoma medications, cup-to-disc ratio (CDR), VF MD, VF pattern standard deviation (PSD), and RNFL thickness was obtained from electronic medical records.

Segmentation and Quantification
After the generation of the 3D volumes, semiautomatic segmentation was used to extract the peripapillary RNFL from the ONH scans as well as the ganglion cell-inner plexiform layer (GCIPL) from the macula scans. The software was then used to create 2D en face images of the desired layer. The en face image was then analyzed using a custom MATLAB (The MathWorks Inc., Natick, MA) program to extract various quantitative vessel metrics including flux, vessel area density (VAD), and vessel diameter index (VDI).

The blood flux is the blood volume per unit area per unit time and represents the amount of blood flowing through vessels over time. VAD is calculated as a unitless ratio of the total image area occupied by the vasculature to the total image area in the binary vessel maps and incorporates both vessel length and diameter in the calculation. VDI is a calculation of the average vessel caliber within an image with units of microns. The metrics were calculated for the entire 6×6 mm area for the images containing the macula and within an annulus centered at the ONH (2.5 and 3.7 mm as inner and outer diameters) for images containing the ONH. Large retinal vessels were removed in both cases as has been described previously. Scans with an OCT signal strength <7 (as recommended by the manufacturer) were excluded from the analysis.

Statistical Analysis
Data from prior studies was used to guide sample size calculation. Given a mean peripapillary RNFL flux in POAG patients of 0.66 and SD of 0.04, the sample size needed to detect a 15% difference in flux between glaucoma groups was calculated as 28 per group, with 80% power and α error set to 0.05. Two-sample, independent t tests were used to compare the peripapillary and macular flux, and VAD between eyes of AD and eyes of ED. Linear regression models were further used to investigate the correlation between peripapillary and macular flux, VAD, VDI, RNFL thickness, CDR, and VF indices. One-way analyses of variance were performed to analyze the macular and peripapillary vascular microcirculation differences among groups. The Pearson correlation was used to determine the correlation coefficient between blood flow metrics and VF severity. The Fisher r to z transformation methods were used to compare the correlation coefficients. Holm-Bonferroni adjustment was used for multiple comparisons. A P-value <0.05 was considered statistically significant.

RESULTS
Twenty-eight eyes from subjects of AD and 56 eyes from subjects of ED with OAG were enrolled (Table 1). There was no significant difference in age, sex, systemic hypertension, number of antihypertensive medications, systolic BP, diastolic BP, MOPP, diabetes mellitus, IOP, prior cataract or glaucoma surgery, RNFL thickness and VF MD and VF PSD between AD and ED eyes included (adjusted P≥0.054).

Table 2 presents the quantitative blood flow metrics obtained for the RNFL and the GCIPL among both groups. There was no significant difference in RNFL and GCIPL blood flow metrics between AD and ED groups (P≥0.161).

Table 3 presents the correlation and univariate regression between flux and VAD in both the AD and ED groups and structural and functional parameters. We found significant correlations between blood vessel metrics and structural and functional measurements (P≤0.012) in all comparisons except for the GCIPL flux AD and CDR (r=−0.213, P=0.276) and GCIPL VAD AD and CDR (r=−0.229, P≥0.141).

Table 4 presents the comparison of the correlation coefficients between blood flow metrics and structural and functional parameters. Although both AD and ED showed significant correlations between RNFL thickness and RNFL VAD and RNFL thickness and macula VAD (P≤0.012), eyes of AD had a significantly higher correlation (P=0.001 for RNFL VAD and P=0.031 for macula VAD) when compared with ED eyes.

886 | www.glaucomajournal.com Copyright © 2020 Wolters Kluwer Health, Inc. All rights reserved.
**TABLE 1.** Baseline Information Among African and European Descent Subjects \((N=84)\)

|                       | African Descent \((N=28)\) | European Descent \((N=56)\) | Adjusted \(P^\text{‡}\) |
|-----------------------|-----------------------------|-----------------------------|-------------------------|
| Age (y)               | 69.2 ± 7.7                  | 70.9 ± 8.6                  | 1.000*                  |
| Male/female           | 25/3                        | 41/15                       | 1.000†                  |
| Systolic blood pressure (mm Hg) | 135.6 ± 24.9               | 133.0 ± 25.0                | 1.000*                  |
| Diastolic blood pressure (mm Hg) | 81.9 ± 12.5               | 77.8 ± 9.9                  | 1.000*                  |
| MOPP (mm Hg)          | 49.4 ± 9.0                  | 51.8 ± 10.2                 | 1.000*                  |
| Systemic hypertension | 21 (75.0)                   | 24 (42.8)                   | 0.102‡                  |
| Diabetes mellitus     | 10 (35.7)                   | 7 (12.5)                    | 0.336†                  |
| Systemic hypertension medications (n) | 1.64 ± 1.36               | 0.84 ± 1.02                 | 0.054*                  |
| Glaucoma type         |                             |                             |                         |
| POAG                  | 21 (80.7)                   | 40 (71.4)                   | 1.000§                  |
| NTG                   | 7 (19.3)                    | 16 (26.8)                   |                         |
| Intraocular pressure (mm Hg) | 14.5 ± 2.3                | 13.2 ± 4.2                  | 1.000*                  |
| No. glaucoma medications | 2.7 ± 1.3                 | 2.4 ± 1.4                   | 1.000*                  |
| Central corneal thickness (µm) | 532.67 ± 34.63         | 550.54 ± 36.85              | 0.600*                  |
| Prior cataract surgery | 8 (28.6)                   | 29 (51.8)                   | 0.868†                  |
| Prior glaucoma surgery | 4 (14.3)                   | 12 (21.4)                   | 1.000†                  |
| Cup-to-disc ratio     | 0.76 ± 0.16                 | 0.77 ± 0.15                 | 1.000*                  |
| VF MD (dB)            | −7.18 ± 8.81                | −6.13 ± 5.44                | 1.000*                  |
| VF PSD (dB)           | 5.64 ± 4.03                 | 6.89 ± 3.91                 | 1.000*                  |
| RNFL thickness (µm)   | 66.8 ± 21.7                 | 64.1 ± 11.9                 | 1.000*                  |

*Two-tailed independent sample \(t\) test.
†Fisher exact test.
‡Pearson chi-square.
MD indicates mean deviation; MOPP, mean ocular perfusion pressure; NTG, normal-tension glaucoma; POAG, primary open-angle glaucoma; PSD, pattern standard deviation; RNFL, retinal nerve fiber layer; VF, visual field.

**TABLE 2.** Summary of Optical Coherence Tomography Angiography Blood Flow Parameters Among African and European Descent Subjects \((N=84)\)

|                       | African Descent \((N=28)\) | European Descent \((N=56)\) | \(P\) |
|-----------------------|-----------------------------|-----------------------------|-------|
| RNFL flux             | 8.908 ± 2.922               | 8.953 ± 2.922               | 0.943*|
| RNFL vessel area density | 0.140 ± 0.038              | 0.140 ± 0.033               | 0.981*|
| RNFL vessel diameter index | 2.723 ± 0.073             | 2.729 ± 0.081               | 0.773*|
| GCIPL flux            | 4.697 ± 1.067               | 5.148 ± 1.358               | 0.161*|
| GCIPL vessel area density | 0.071 ± 0.013              | 0.072 ± 0.015               | 0.915*|
| GCIPL vessel diameter index | 2.803 ± 0.123            | 2.786 ± 0.112               | 0.559*|

*Two-tailed independent sample \(t\) test.
GCIPL indicates ganglion cell-inner plexiform layer; RNFL, retinal nerve fiber layer.

**DISCUSSION**

In this study, we investigated peripapillary and macular microcirculation in glaucoma patients of AD and ED using OCTA. A commercially available OCTA device was used to collect images. We found no significant differences in OCTA blood flow metrics between the 2 populations of this study \((P ≥ 0.161)\).

OCTA is a recently developed imaging technique based on OCT, which allows noninvasive visualization and assessment of the microcirculation in the ONH, the peripapillary retina, and the macula and is a promising tool that may improve diagnosis and management of glaucoma. OCTA has proven to be a repeatable and accurate method of retinal microvasculature analysis. While there may be an association between systemic vascular dysfunction and glaucoma, it as well as decreased retrolubar blood flow,6-8 the pathogenesis of glaucoma has remained elusive. In addition, we still do not understand whether vascular changes within the peripapillary capillary layer leads to subsequent optic nerve damage or arises through reduced consumption in damaged tissue.

Nelson et al20 studied 6×6 mm ONH scans of 1029 eyes of 1029 healthy African American subjects and found lower mean RNFL thickness \((P<0.001)\) and longer axial length \((AL) (P<0.001)\) were associated with lower peripapillary VD after controlling for age and signal strength. Chun et al23 studied 3×3 mm macular scans of 93 eyes of 23 healthy subjects self-identified as black and 24 healthy subjects self-identified as white and showed black subjects had lower foveal VD in the superficial capillary plexus \((P<0.05)\), lower VD in the parafovea and in the 3×3 mm image in the deep capillary plexus \((P<0.05)\), and hypothesized these findings could be significant in the context of the high prevalence of diabetic retinopathy in black populations and the current lack of consistent explanations which can account for this health disparity. In our study, we used 6×6 mm optic disc and macular scans and chose to study the RNFL and GCIPL because, in glaucoma, reduction in perfusion is more pronounced in superficial layers than in the deeper retina layers. We found no difference between AD and ED. It is possible that the differences in our results are related to our study population as Nelson et al20 only included healthy AD in their study and did not provide a comparison with ED. It may also be related to imaging processing as Chun et al21 used automatic segmentation to delineate the superficial capillary plexus and we choose to use semiautomatic segmentation.

Chang et al22 studied 1029 eyes from 1029 healthy African Americans using 6×6 mm optic disc OCTA scans of the peripapillary region and found older age, male sex, and longer diabetes duration were independent predictors of reduced RPC vessel density. Interestingly, all variables related to hypertension, including diagnosis of hypertension, BP, and use of antihypertensive medication, were not significant in the final multivariate model. Liu et al17 reported no significant association of BP parameters with peripapillary VD in both healthy and glaucoma groups. Rao et al23 studied 171 optic disc scans (104 healthy subjects) and 157 macular scans (100 healthy subjects) and reported the vessel density of the whole en face disc scan was significantly lesser in eyes of subjects with hypertension \((P=0.02)\), whereas the parafoveal densities were higher in subjects with hypertension \((P=0.01)\). In our study, although subjects had similar BP measurements, more subjects of AD compared with subjects of ED had been diagnosed with hypertension.
and were being treated (75% vs. 43%, adjusted P = 0.102). We found that all OCTA blood vessel metrics analyzed showed similarity between groups (P ≥ 0.161). Longitudinal studies examining the association of duration of hypertension and peripapillary VD will help clarify whether there is a relationship between increased BP and reduced VD in glaucoma.

Prior studies using CDI\(^6,7\) reported a lower retrobulbar flow in healthy and glaucoma AD patients. We believe the differences with our results are related to the different vascular beds that were studied with OCTA compared with CDI. It is possible that the reductions in different vascular flow velocities found with CDI in persons of AD are part of an overall systemic vascular disease process apparent in the AD population as they have a higher prevalence of risk factors for developing systemic vascular disease.\(^4,5\)

As previously established, OCTA blood flow metrics consistently correlate with glaucoma severity.\(^13-17\) In our study, we found that standard measures of glaucoma severity, such as the CDR, VF MD, VF PSD, and RNFL thickness, were similar between AD and ED groups (adjusted P = 1.000).

Several limitations were inherent in this paper. Our study populations consisted of self-identified AD and ED, and the exact genetic background of our participants is unknown. Data was collected from 2 locations; this may have introduced sampling bias. We did not obtain data on AL for our patients, and AL > 26 mm has been shown to affect signal strength and repeatability of OCTA measurements\(^24,25\); however, even if there was an effect of AL in our scans, both AD and ED should have been equally affected. Our study population was predominately male, making the results less generalizable to outside populations. In addition, some studies have shown that the prevalence of glaucoma was higher in women after adjusting the age\(^26\) and a recent OCTA study showed that peripapillary and macular vessel density were lower in men than in women with glaucoma.\(^27\) Further research with a more equal gender distribution is warranted. There was also an uneven sample of AD compared with ED participants. This reduces the power of the study and may skew the statistical analysis given the relatively small n of the study. Furthermore, participants with both normal-tension glaucoma and high-pressure OAG were included, and this is another limitation of our study. Finally, although there was no significant difference in the diagnosis of hypertension and diabetes between AD and ED, the disease themselves can have effects on retinal vasculature\(^22\) and are potential confounding factors. In addition, long-term effects of hypertension cannot be determined by the clinical diagnosis of hypertension itself, BP measurement readings from a single day, or the use of antihypertensive medication at the time of the OCTA scans.

In conclusion, we found no significant differences in OCTA blood flow metrics of the peripapillary area and macula in eyes with OAG of AD compared with ED. Further research is needed to clarify the impact and association of vessel architecture on glaucoma development. Future studies with larger sample sizes, subdivided by the severity of glaucoma, may also help uncover differences.

**TABLE 3. Summary of Correlation and Univariate Regression Analyses Results Between Optical Coherence Tomography Angiography Blood Flow Parameters and Other Functional and Structural Clinical Measurements**

| Variables                              | RNFL Thickness (μm) | VF MD (dB) | VF PSD (dB) | Cup-to-Disc Ratio | RNFL Vessel Area Density | Macular Vessel Area Density |
|----------------------------------------|---------------------|------------|-------------|-------------------|--------------------------|-----------------------------|
| RNFL flux AD                           | 0.781               | < 0.001    | 0.687       | < 0.001           | -0.615                   | < 0.001                     |
| RNFL flux ED                           | 0.535               | < 0.001    | 0.547       | < 0.001           | -0.473                   | < 0.001                     |
| RNFL vessel area density AD            | 0.845               | < 0.001    | 0.704       | < 0.001           | -0.611                   | < 0.001                     |
| RNFL vessel area density ED            | 0.436               | < 0.001    | 0.466       | < 0.001           | -0.413                   | 0.001                       |
| GCIPFL flux AD                         | 0.587               | 0.001      | 0.643       | < 0.001           | -0.566                   | 0.001                       |
| GCIPFL flux ED                         | 0.420               | 0.001      | 0.481       | < 0.001           | -0.366                   | 0.005                       |
| GCIPFL vessel area density AD          | 0.700               | < 0.001    | 0.676       | < 0.001           | -0.689                   | < 0.001                     |
| GCIPFL vessel area density ED          | 0.333               | 0.012      | 0.508       | < 0.001           | -0.467                   | < 0.001                     |

Bold value indicates statistically significant (P < 0.05).

AD indicates African descent; ED, European descent; GCIPFL, ganglion cell-inner plexiform layer; MD, mean deviation; PSD, pattern standard deviation; RNFL, retinal nerve fiber layer; VF, visual field.

**TABLE 4. Comparison of Correlations Coefficients (Fisher r to z Transformation)**

| Variables                              | P |
|----------------------------------------|---|
| RNFL thickness (μm)                    | AD With ED RNFL Flux | AD With ED RNFL Vessel Area Density | AD With ED Macular Flux | AD With ED Macula Vessel Area Density |
| RNFL thickness (μm)                    | 0.08 | 0.001 | 0.352 | 0.031 |
| VF MD (dB)                             | 0.347 | 0.126 | 0.327 | 0.281 |
| VF PSD (dB)                            | 0.400 | 0.262 | 0.281 | 0.161 |
| Cup-to-disc ratio                      | 0.928 | 0.596 | 0.568 | 0.528 |

Bold value indicates statistically significant (P < 0.05).

AD indicates African descent; ED, European descent; MD, mean deviation; PSD, pattern standard deviation; RNFL, retinal nerve fiber layer; VF, visual field.
REFERENCES

1. Quigley HA, Broman AT. The number of people with glaucoma worldwide in 2010 and 2020. Br J Ophthalmol. 2006;90:262–267.
2. Racette L, Wilson MR, Zangwill LM, et al. Primary open-angle glaucoma in blacks: a review. Surv Ophthalmol. 2003;48:295–313.
3. Flammer J, Orgül S, Costa VP, et al. The impact of ocular blood flow in glaucoma. Prog Retin Eye Res. 2002;21:359–393.
4. Chen CL, Wang RK. Optical coherence tomography based angiography. Biomed Opt Express. 2015:2:3127–3137.
5. Mozaffarian D, Benjamin E, Go A, et al. Heart disease and stroke statistics—2015 update: a report from the American Heart Association. Circulation. 2015;131:e29-322.
6. Siesky B, Harris A, Racette L, et al. Differences in ocular blood flow in glaucoma between patients of African and European descent. J Glaucoma. 2015;24:117–121.
7. Siesky B, Harris A, Carr J, et al. Reductions in retrobulbar and retinal capillary blood flow strongly correlate with changes in optic nerve head and retinal morphology over 4 years in open-angle glaucoma patients of African descent compared with patients of European descent. J Glaucoma. 2016;25:750–757.
8. Kaskan B, Ramezani K, Harris A, et al. Differences in ocular blood flow between people of African and European descent with healthy eyes. J Glaucoma. 2016;25:709–715.
9. Mansoori T, Sivaswamy J, Gamalapati JS, et al. Measurement of radial peripapillary capillary density in the normal human retina using optical coherence tomography angiography. J Glaucoma. 2017;26:241–246.
10. Chen CL, Wang RK. Optical coherence tomography based angiography. Biomed Opt Express. 2017;8:1056–1082.
11. Yin X, Chao JR, Wang RK. User-guided segmentation for volumetric retinal optical coherence tomography images. J Biomed Opt. 2014;19:086020.
12. Chu Z, Lin J, Gao C, et al. Quantitative assessment of the retinal microvasculature using optical coherence tomography angiography. J Biomed Opt. 2016;21:66008.
13. Chen CL, Bojikian KD, Gupta D, et al. Optic nerve head perfusion in normal eyes and eyes with glaucoma using optical coherence tomography-based microangiography. Quant Imaging Med Surg. 2016;6:125–133.
14. Chen CL, Zhang A, Bojikian KD, et al. Peripapillary retinal nerve fiber layer vascular microcirculation in glaucoma using optical coherence tomography-based microangiography. Invest Ophthalmol Vis Sci. 2016;57:OC1475–OC1485.
15. Chen CL, Bojikian KD, Wen JC, et al. Peripapillary retinal nerve fiber layer vascular microcirculation in eyes with glaucoma and single-hemifield visual field loss. JAMA Ophthalmol. 2017;135:461–468.
16. Jia Y, Morrison JC, Tokayer J, et al. Quantitative OCT angiography of optic nerve head blood flow. Biomed Opt Express. 2012;3:3127–3137.
17. Liu L, Jia Y, Takusagawa HL, et al. Optical coherence tomography angiography of the peripapillary retina in glaucoma. JAMA Ophthalmol. 2015;133:1045–1052.
18. Bojikian KD, Chen CL, Wen JC, et al. Optic disc perfusion in primary open angle and normal tension glaucoma eyes using optical coherence tomography-based microangiography. PLoS One. 2016;11:e0154691.
19. Lenhard W, Lenhard A. Hypothesis tests for comparing correlations. Psychometrica; 2014. Available at: www. psychometrica.de/correlation.html. Accessed January 20, 2020.
20. Nelson AJ, Chang R, LeTran V, et al. Ocular determinants of peripapillary vessel density in healthy African Americans: the African American Eye Disease Study. Invest Ophthalmol Vis Sci. 2019;60:3368–3373.
21. Chun LY, Silas MR, Dimitroyannis RC, et al. Differences in macular capillary parameters between healthy black and white subjects with optical coherence tomography angiography (OCTA). PLoS One. 2019;14:e0223142.
22. Chang R, Nelson A, LeTran V, et al. Systemic determinants of peripapillary vessel density in healthy African Americans: the African American Eye Disease Study. Am J Ophthalmol. 2019;207:240–247.
23. Rao H, Pradhan Z, Weinreb R, et al. Determinants of peripapillary and macular vessel densities measured by optical coherence tomography angiography in normal eyes. J Glaucoma. 2017;26:491–497.
24. Sampson DM, Gong P, An D, et al. Axial length variation impacts on superficial retinal vessel density and foveal avascular zone area measurements using optical coherence tomography angiography. Invest Ophthalmol Vis Sci. 2017;58:3065–3072.
25. Li M, Jin E, Dong C, et al. The repeatability of superficial retinal vessel density measurements in eyes with long axial length using optical coherence tomography angiography. BMC Ophthalmol. 2018;18:326.
26. Mitchell P, Smith W, Attebo K, et al. Prevalence of open-angle glaucoma in Australia. The Blue Mountains Eye Study. Ophthalmology. 1996;103:1661–1669.
27. Wang S, Mendez-Hernandez C, Arribas-Pardo P, et al. Gender-related influences on superficial papillary microcirculation measured with optical coherence tomography angiography in patients with glaucoma. Curr Eye Res. 2020. [Epub ahead of print].