Differences of Retinal Blood Flow Between Arteries and Veins Determined by Laser Speckle Flowgraphy in Healthy Subjects

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Abstract: To characterize the total retinal blood flow determined by laser speckle flowgraphy (LSFG) of healthy subjects.

This prospective cross-sectional study was conducted at the Nagoya University Hospital. One hundred fifteen right eyes of 115 healthy subjects (mean age: 39.4 ± 16.1 years) were studied. The total blood flow in the retinal arteries and veins around the optic nerve head was measured separately using the total retinal flow index (TRFI), which represents blood flow volume. The lumen diameters of the retinal vessels determined by LSFG and by adaptive optics (AO) camera were compared. The images obtained by LSFG and AO camera were merged, and the distribution of the mean blur rates (MBRs), which represent the velocities of the erythrocytes, was evaluated on the images.

The mean TRFI in veins (1812 ± 445, arbitral units) was significantly higher than that in arteries (1455 ± 348, arbitral units; $P < 0.001$). Linear regression analysis showed a significant correlation between the TRFI in the arteries and veins ($P < 0.001$). Linear regression analysis also showed a highly significant correlation between the diameters of arteries and veins determined by LSFG and by the AO camera (arteries, $r = 0.94$, $P < 0.001$; veins, $r = 0.92$, $P < 0.001$). The ratios of the lumen diameters determined by LSFG to that by AO camera was significant lower in arteries (0.068 ± 0.005, arbitral units) than in veins (0.074 ± 0.007, arbitral units) ($P < 0.001$). The MBRs of veins were homogeneous throughout the width of the lumen; however, the MBRs in the arteries were higher at the center and lower close to the walls of the lumen.

The higher TRFIs in the veins than in the arteries indicate that there is a smaller volume of retinal blood flow in arteries than veins. However, the possibility remains that LSFG has inherent problem that the arterial lumen diameter determined by LSFG is smaller than actual one because of the characteristics of arteries. This would result in a smaller volume of retinal blood flow in the arteries than veins in LSFG.

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Abbreviations: AO = adaptive optics, DBP = diastolic blood pressure, IOP = intraocular pressure, LSFG = laser speckle flowgraphy, MAP = mean arterial blood pressure, MBR = mean blur rate, MOPP = mean ocular perfusion pressure, ONH = optic nerve head, RFV = relative flow volume, SBP = systolic blood pressure, TRFI = total retinal flow index.

INTRODUCTION

Many diseases which cause blindness are associated with alterations of retinal blood flow.[1–5] Thus, knowledge about retinal blood flow is important for understanding the pathophysiology of various diseases including diabetes retinopathy[3] and glaucoma.[4,5] A variety of techniques have been developed to measure retinal blood flow including fluorescein angiography,[6] radioactive microsphere technique,[7] hydrogen clearance method,[8] and laser Doppler velocimetry.[9,10] However, each of these has limitations.

Laser speckle flowgraphy (LSFG) is another method that has been used to measure the relative blood flow velocity in the retina and choroid. LSFG can detect the pattern of the speckle contrast produced by the interference of the illuminating laser light that is scattered by the movement of the erythrocytes in the blood vessels and can measure the relative blood flow velocity as the mean blur rate (MBR) in the vessels in the retina and choroid noninvasively.[11,12] Although the pattern of speckle contrast detected by LSFG is thought to be closely associated with the blood velocity,[13] earlier studies have shown a possibility that the speckle signal obtained from the retinal vessels is affected by the blood flow in the underlying choroid and the velocity of the erythrocytes they contain.[14]

A recent update of the software embedded in the most recent LSFG (LSFG Analyzer, v. 3.1.6, Softcare Co., Ltd., Fukutsu, Japan) provides a new measurement parameter of the retinal vessels called the relative flow volume (RFV). In addition, a new method of measuring the total retinal blood flow using the RFV named the total retinal artery and vein analysis has been incorporated into the software.

The RFV is produced by subtracting the background choroidal blood flow from the overall blood flow rate in a region of interest centered on a retinal vessel. The RFV depends on both the retinal flow velocity and the vascular diameter. Shiga et al have shown that the RFV index of blood flow was an accurate and reliable parameter that can be used to evaluate alterations in retinal blood flow.[5] However, they also stated that there were technical limitations of the RFV index because the

most current version of the technology cannot determine the blood vessel diameter accurately.[15] Thus, it is essential to know how accurate the measurement of vessel diameter is when the RFV index is used.

An adaptive optics (AO) camera is able to record the fine structure of the retinal vasculature and measure the vascular diameter accurately.[16,17] We have measured the diameter of the retinal blood vessels using an AO camera and compared the diameter to that obtained when determining the RVF. In addition, we merged the images obtained by LSFG and by AO to investigate the distribution of erythrocytes which should be related to the vessel diameters and the accuracy of the RVF index.

Total retinal artery and vein analysis can determine the total RFV index of the major retinal vessels around the optic nerve head (ONH) semiautomatically as the total retinal flow index (TRFI). It can also analyze the total retinal artery and vein blood flow separately. It has been reported that the blood flow of retinal arteries and veins is comparable to that determined by laser Doppler velocimetry.[10,18,19]

The purpose of this study was to determine the differences of the total retinal blood flow between retinal arteries and veins using the TRFI, and to measure the diameter of retinal vessels accurately with the AO camera and compare it to that obtained by LSFG. In addition, we evaluated the differences in the distribution of the MBRs which represented the velocities of the erythrocytes within the lumen of retinal arteries and veins using the merged images obtained from LSFG and AO.

METHODS

Subjects and Testing Protocol

This was a prospective study, and the procedures used were approved by the Ethics Committee of Nagoya University Hospital. The procedures conformed to the tenets of the Declare of Helsinki, and an informed consent was obtained from the subjects after an explanation of the nature and possible complications of the study.

One hundred fifteen eyes of 115 healthy volunteers with no ophthalmic or systemic diseases were studied. Only the right eye was used for the measurements. All of the subjects had a best-corrected visual acuity of $\geq 20/20$ and had a standard ophthalmic examination to confirm that no ocular disease was present. Slit-lamp examinations and indirect ophthalmoscopy were used to examine the anterior and posterior segments of the eye. Subjects were also screened for any medical condition that could influence the hemodynamic of the eye such as diabetes, hypertension, arrhythmia, and vascular diseases. The exclusion criteria included history of ophthalmic or general disorders, ocular laser or incision surgery in either eye, systemic or topical medications, and refractive error greater than −6.0 diopters.

All participants were asked to abstain from alcoholic and caffeinated beverages from the morning of the day of the examination because the intake of alcohol and caffeine can influence the intraocular pressure (IOP)[20,21] and blood pressure.[22,23] Thirty minutes before the examinations, 0.4% tropicamide (Mydrin P; Santen Pharmaceutical Co., Ltd., Osaka, Japan) was used to dilate the pupil. Each subject rested for 10 to 15 minutes in a quiet dark room before the examination. All of the examinations were performed in the sitting position. The refractive error (spherical equivalent) was measured with an autorefractometer (KR8900; Topcon, Tokyo, Japan), and the axial lengths were measured. The axial lengths were used to

adjust the size of the AO image so that it could be merged to the images obtained by partial optical coherence interferometry (IOLMaster; Carl Zeiss Meditec, La Jolla, CA). The IOP was measured with a handheld tonometer (Icare; Tiolat Oy, Helsinki, Finland). The systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured at the left brachial artery at the height of the heart in a sitting position with an automatic sphygmomanometer (CH-483C; Citizen, Tokyo, Japan). The mean arterial blood pressure (MAP) and the mean ocular perfusion pressure (MOPP) were calculated as follows: MAP = DBP + 1/3(SBP-DBP) and MOPP = 2/3MAP-IOP.[24] Finally, the 4 independent experiments were performed according to the individual protocols.

Determination of Retinal Flow Velocity (RFV) in Blood Vessels by Laser Specular Flowgraphy (LSFG)

The LSFG-NAVI™ was used to determine the RFV index. The principles of LSFG have been described in detail.[25–29] Briefly, this instrument consists of a fundus camera equipped with a 830 nm diode laser as the light source and a standard charge-coupled device sensor (750 width × 360 height pixels) as the detector. After switching on the laser, a speckle pattern appears due to the interference of the light scattered by the movements of the erythrocytes. The MBR is a measure of the relative blood flow velocity, and it is determined by examining the pattern of the speckle contrast produced by the interference of the laser light that is scattered by the movement of the blood cells in the ocular blood vessels.[30] The MBR images are acquired at a rate of 30 frames/seconds over a 4-secconds period. The MBRs for the retinal vessels always include the background of choroidal blood flow. However, the influence of choroidal blood flow can be reduced by manually selecting a region of interest centered in a region where the retinal vessels predominate and subtracting the background choroidal blood flow from the overall MBR value. The resulting LSFG values are the RFVs (Figure 1).

The threshold MBR (MBR$_{threshold}$) values between the retinal vessels and the background choroidal blood flow were determined by the following calculation:

$$MBR_{threshold} = (Max(f(x)) - offset) \times 1/e + offset$$

In this formula, f(x) represents the distribution function of the MBR in a cross-sectional area of the blood vessel, the offset is the measured MBR outside the area of the vessel, and e indicates a mathematical constant of the natural logarithm. Next, RFV is calculated as follows (Figure 1). The width of the function at MBR$_{threshold}$ is represented by a and b:

$$RFV = \int_a^b (f(x) - offset) \, dx$$

Measurements of Total Retinal Flow Index

The total retinal artery and vein values can be used to calculate the total RFV index for all of the major retinal vessels around the ONH semiautomatically as the TRFI (Figure 2A). Rectangular areas were set around each of the major vessels around the ONH, and the TRFIs of the arteries and veins were calculated after the arteries and veins were identified semiautomatically (Figure 2B, C). When there was an error in the placement, the location of the rectangle was corrected manually.

Adaptive Optics Imaging

An AO camera (rtx1, Imagine Eyes, Orsay, France) was used to obtain in situ images of the retinal structures. We used the images to measure the diameter of the retinal vessels and also to observe the structure of the vessels. The images were also
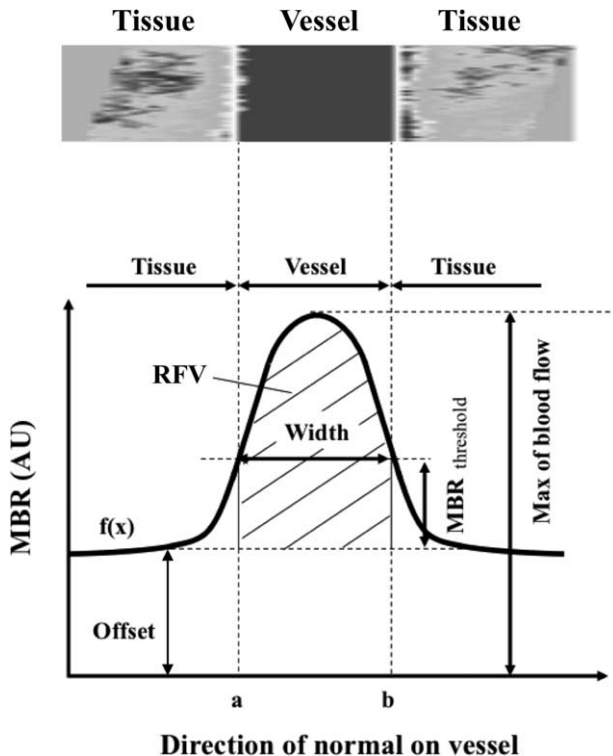
FIGURE 1. Determination of the RFV. The MBR$_{threshold}$ is the threshold difference between the MBR values in the retinal vessels and the background choroid. f(x) is the distribution function of MBR in a cross-sectional area of the blood vessels. The width of the function at MBR$_{threshold}$ is represented by a and b. The RFV in the retina was calculated by subtracting choroidal MBR from overall MBR. AU = arbitral units, MBR = mean blur rate, RFV = retinal flow volume.

used to construct the merged images to compare the distribution of the velocities of the erythrocytes of the arteries and veins.

Experiment 1: Assessment of Total of Blood Flow in Retinal Arteries or Veins by Total Retinal Artery and Vein Analysis

One hundred fifteen right eyes of 115 Japanese healthy subjects (mean age: 39.4 ± 16.1 years, male: female = 59:56) were studied. The total blood flow in the retinal vessels around the ONH was measured using the TRFI, and the TRFI of the arteries were compared to that of the veins. The measurements were made at the same location in 2 consecutive examinations on the same day.

Experiment 2: Comparison of Retinal Blood Flow Obtained With LSFG and Physiological Variables

A comparison of the TRFI and physiological variables including the BP, MAP, IOP, and MOPP was done with the data obtained in Experiment 1.

Experiment 3: Comparison of Vessel Diameter Determined by LSFG and Lumen Diameter of Vessels by Adaptive Optics

Twenty one right eyes of 21 healthy subjects (mean age: 26.3 ± 3.6 years, male/female = 10:11) were studied. After the

TRFI measurements were done by LSFG-NAVI (Figure 3A, B), the AO camera (rtx1, Imagine Eyes) images were recorded to measure the lumen diameter of the retinal arteries and veins where the rectangular areas were placed for the TRFI measurements (Figure 3C). We compared the lumen diameters obtained by LSFG to that obtained by the AO camera.

Experiment 4: Evaluation of Erythrocyte Movements in Retinal Arteries and Veins

We merged the images obtained by LSFG (Figure 4A) and by AO (Figure 4B) after altering the LSFG image to overlap the AO image (Figure 4C). The distribution of the MBRs represented by the differences of the color and contrast density within the lumen was evaluated in the merged images.

Statistical Analyses

All data are presented as the means ± standard deviations. Independent *t*-tests were used to compare normally distributed data. Spearman rank correlation tests were used to determine the correlations between the variables. All statistical analyses were performed with JMP software (Pro version 10.0.2, SAS Institute Japan Inc., Tokyo, Japan). The significance level was set at $P < 0.05$.

RESULTS

Determination of Total Blood Flow Indices (TRFIs) of Retinal Arteries and Veins

The clinical characteristics of the participants and their total blood flow values represented by the TRFI are shown in Table 1. The mean TRFI for veins was 1812 ± 445 arbitral units which was significantly higher than the mean TRFI for arteries of 1455 ± 348 arbitral units ($P < 0.001$) (Figure 5A). The ratio of the mean TRFI of veins to arteries was 1.25 ± 0.14. Linear regression analysis showed a highly significant correlation between the TRFI of veins and arteries ($r = 0.89$; $P < 0.001$; Figure 5B).

Comparison of Total of Blood Flow Obtained from Total Retinal Artery and Vein Measurements and Physiological Variables

The correlations between the TRFI of arteries and age ($r = -0.19$, $P = 0.06$), SBP ($r = -0.07$, $P = 0.48$), DBP ($r = 0.08$, $P = 0.80$), IOP ($r = 0.07$, $P = 0.49$), MAP ($r = 0.03$, $P = 0.74$), and MOPP ($r = 0.03$, $P = 0.74$) were not significant. In addition, the correlations between the TRFI of veins and age ($r = -0.09$, $P = 0.33$), SBP ($r = -0.01$, $P = 0.96$), DBP ($r = 0.16$, $P = 0.11$), IOP ($r = -0.01$, $P = 0.86$), MAP ($r = 0.10$, $P = 0.28$), and MOPP ($r = 0.05$, $P = 0.61$) were also not significant.

Comparison of Vessel Diameter Determined by LSFG and by AO Camera

Linear regression analysis showed a highly significant correlation between the blood vessel lumen diameters (width of the MBR$_{threshold}$ in the RVF index) determined by LSFG and that determined in the AO images for the arteries ($r = 0.94$, $P < 0.001$) and veins ($r = 0.92$, $P < 0.001$; Figure 6A and B).

The lumen diameters of the veins determined by LSFG and that measured in the AO images were significantly larger than the lumen diameters of the arteries ($p < 0.001$, and $p < 0.001$; Table 2, Figure 6C and 6D). The ratio of the lumen diameters
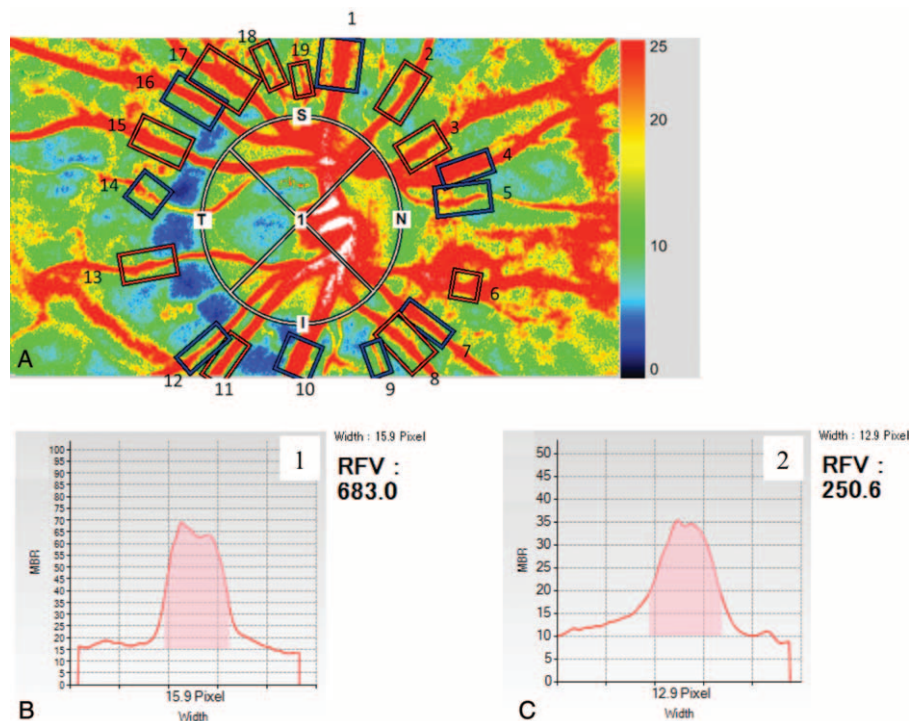
FIGURE 2. Total retinal artery and vein analysis measurements. The red color indicates a higher MBRs and the blue color indicates lower MBR in LSFG-NAVI. The rectangular areas (1–19) were set semiautomatically to the vessels around the optic nerve head concentrically (A) and the total of RFV in each area was calculated. B and C show the RVF index in rectangles 1 and 2, respectively. LSFG = laser speckle flowgraphy, MBR = mean blur rate, RFV = retinal flow volume.

determined by LSFG to that determined by AO camera for the arteries was significant lower than that for the vein ($p < 0.001$) (Figures 6E).

Distribution of MBR Within Vessels

The MBRs of veins were homogeneous throughout the width of the lumen (Figure 7A, B); however, the MBRs in the arteries were higher at the center and lower close to the walls of the lumen (Figure 7C). At the center of the lumen of arteries, the MBR was comparable to that in veins. The region close to the

wall appeared to be a layer of low MBR (Figure 7C). This trend was observed in most of the vessels especially in the larger vessels.

DISCUSSION

Our results showed that the TRFI was significantly higher in veins than in the arteries ($P < 0.001$). In addition, the ratio of the TRFI of the veins to the arteries was approximately 1.25. Linear regression analysis showed a highly significant corre-
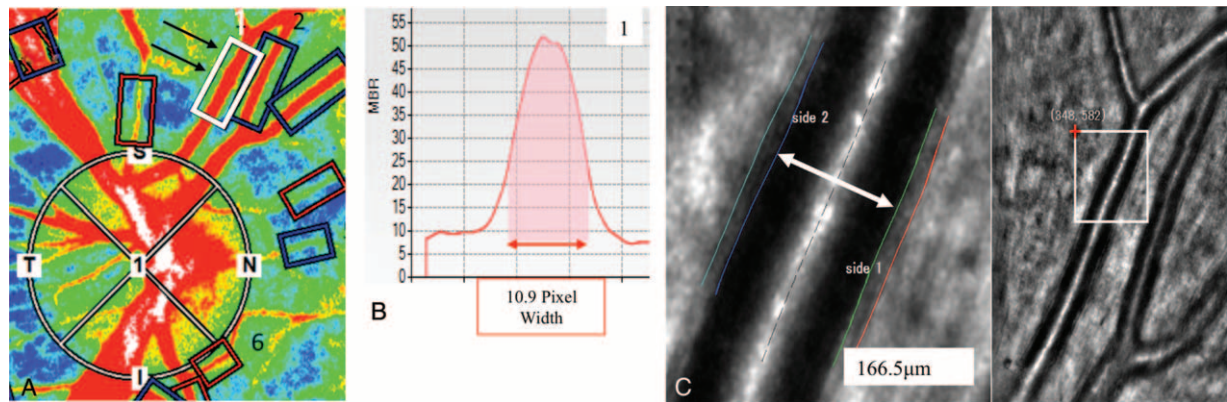
FIGURE 3. Comparison of lumen diameter determined by laser speckle flowgraphy and that measured by AO camera. After a rectangular area was set (A), the lumen diameter was determined for the calculation of the RVF index (B). The AO camera measured the lumen diameter of the vessel where the rectangles are placed. AO = adaptive optics, MBR = mean blur rate, RFV = retinal flow volume.
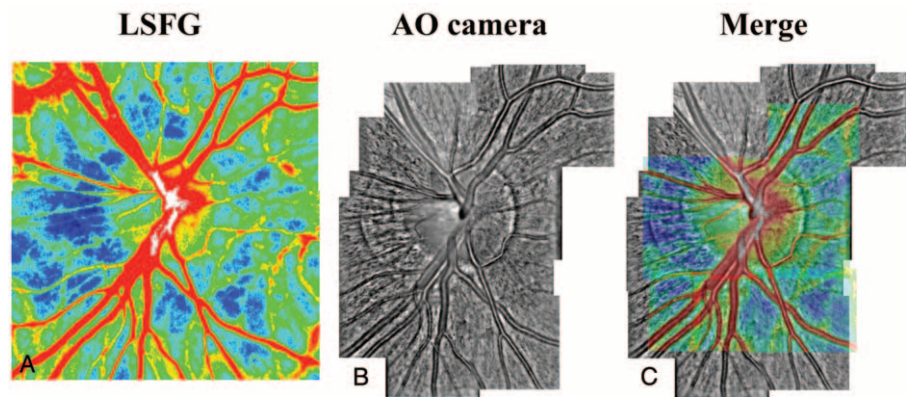
FIGURE 4. Representative merged figure. Laser speckle flowgraphy image (A) and adaptive optics image (B) were merged into C.

lation between the TRFI of arteries and veins. In addition, linear regression analysis showed that the lumen diameter (width of the $MBR_{threshold}$ in the RVF index) determined by LSFG was significantly correlated with the lumen diameter measured by AO images. However, the ratio of the lumen diameters determined by LSFG to that determined by AO images for the arteries was significant lower than that of veins. The uniformity of the MBR within the arteries was different from that in veins in the merged images obtained from LSFG and AO camera.

Shiga et al[15] demonstrated that the RFV index of the blood flow was an accurate and reliable value to evaluate the alterations in retinal blood flow. The TRFI was used to calculate the total RFV index for the major retinal vessels around the ONH, thus providing the total retinal blood flow in the arteries and veins.

Interestingly, the total retinal blood flow in the veins was significantly higher than that in the arteries. This is in contrast to the report that the blood flow of the retinal arteries and veins is similar as determined by laser Doppler velocimetry.[10,18,19] Riva et al[18] reported that the average total arterial and venous volumetric flow rates were 33 ± 9.6 and $34 \pm 6.3 \, \mu L/minutes$, respectively,[18] confirming the report of Feke et al[10] who found that the total retinal blood flow was similar in the arteries and veins. Garhofer et al[19] reported that the retinal blood flow of the retinal venules was $42.1 \pm 13.0 \, \mu L/minutes$ which was not significantly different from that in the arterioles at

$43.3 \pm 12.1 \, \mu L/minutes$. As best we know, there have been no studies demonstrating significant differences of the total retinal blood flow between arteries and veins as determined by laser Doppler velocimetry.

We analyzed the total retinal blood flow for all visible vessels around the ONH by LSFG. Thus, the measuring technique and the number and region of the measurements were different from that of earlier reports.[10,18,19]

Shiga et al[15] reported a possible technical limitation of the RFV index which was the inability of most current technology to measure the vessel diameter accurately. However, the lumen diameter, which is the width function at the $MBR_{threshold}$ for the measurement of the RFV index (Figure 1), was significantly correlated with the diameter of retinal arterial and venous lumen measured by AO camera which can measure the vascular diameter accurately.[16,17] The significant correlation implies that the LSFG-NAVI is theoretically capable of obtaining a precise measure of the diameter of the arteries and veins. However, the proportion of the lumen diameter determined by LSFG in arteries to the lumen diameter measured by AO was significant lower than that in the veins.

The retinal arteries had a nonuniform MBR in the lumen with the MBR higher at the center and lower close to the wall of the lumen. The veins had a higher uniform MBR in the lumen (Figure 6). Several reasons can cause this difference. First, LSFG-NAVI method did not accurately detect the erythrocytes which moved faster than the detectable level at the center of the retinal arterial vessels resulting in MBR lower than the actual value. Second, the MBR was detected to be lower than the real value in the arteries because of their thicker walls. And third, the movement of each erythrocyte within the vessels would be different between arteries and veins making different speckle patterns.

A cell-free plasma layer close to the wall of the lumen is dependent on the diameter of the vessel, flow rate, and rheological properties of the blood including the erythrocyte aggregation and deformability.[31] The migration of erythrocytes from the lumen wall to the flow axis results in an axial accumulation of erythrocytes.[32] This is induced by the tank-treated motion of the cell membranes under shear stress which creates a parietal cell-free plasma layer and a cell-rich central core.[33] Fast flow promotes an axial migration of erythrocytes by accelerating the tank-treated movement of cell membranes thus enlarging the cell-free layer.[34] In general, the blood flow velocity in arteries is faster than in veins resulting in a wider cell-free plasma layer in arteries. In addition, its formation can also be affected by the

TABLE 1. Subject Demographic, Ocular Biometric Parameter, Systemic Factors, and Total Retinal Flow Index

Subjects (number)	115
Age, year	39.4 ± 16.1
Gender (male/female)	59: 56
Systolic blood pressure, mmHg	118.8 ± 12.7
Diastolic blood pressure, mmHg	73.3 ± 10.8
Mean arterial blood pressure, mmHg	88.5 ± 10.8
Intraocular pressure, mmHg	13.9 ± 2.5
Ocular perfusion pressure, mmHg	45.1 ± 7.6
TRFI (AU)	3267.1 ± 768.1
TRFI (A) (AU)	1455.3 ± 347.6
TRFI (V) (AU)	1811.7 ± 444.6
TRFI (V)/TRFI (A)	1.25 ± 0.14

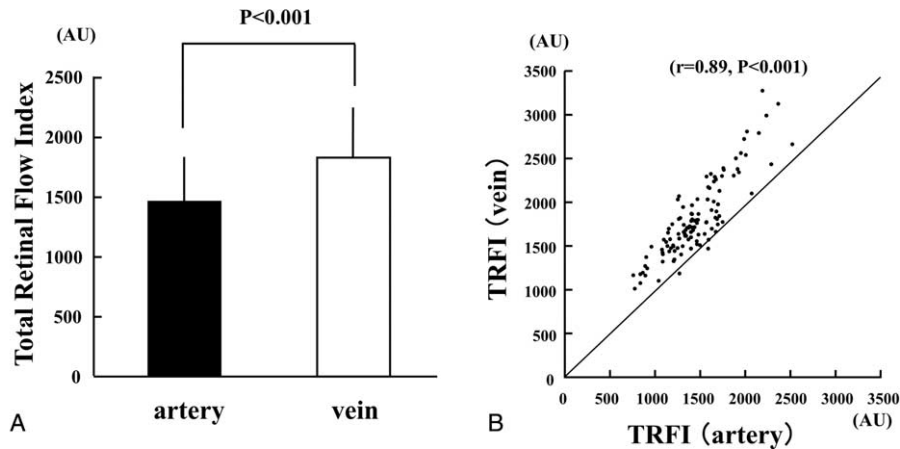A = artery, AU = arbitrary units, TRFI = total retinal flow index, V = vein.

FIGURE 5. TRFI in the veins was significantly higher than that in the arteries ($P < 0.001$). Linear regression analysis showed a highly significant correlation between the TRFI in the arteries and the veins ($P < 0.001$). AU = arbitral units, TRFI = total retinal flow index.

presence of a glycocalyx layer that lines the luminal surface of the vessel walls especially in microvessels such as retinal vessel and is related to the cell-free layer.[35] Thus, the place where high MBR was not observed close to the wall of the artery would indicate a cell-free layer as shown in Figure 7. A wider cell-free layer would be detected as a smaller vessel diameter than the actual RFV index resulting in the smaller LSFG/AO ratio in arteries than in veins.

Thus, although the TRFI findings demonstrated that the retinal blood flow in the vein was significantly higher than that in the artery, a possibility remains that the arterial lumen

diameter determined by LSFG is smaller than the actual one that was used to measure the RVF index. This is because arteries would have more cell-free plasma layer close to the wall of lumen than veins, resulting in smaller volume of retinal blood flow in arteries than in veins. In addition, a highly significant correlation between the TRFI of arteries and the TRFI of veins in the linear regression analysis would support this possibility. Accordingly, attention should be paid to comparisons of the TRFI of arteries and veins by LSFG.

It is well established that changes in the walls of retinal vessels occur early in diabetic retinopathy.[36,37] The ability to
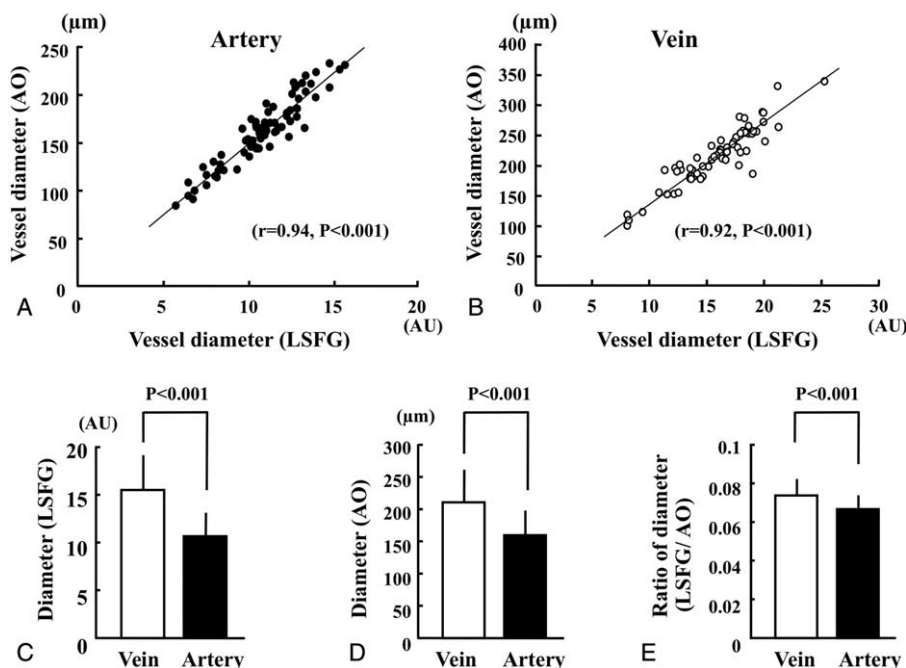
FIGURE 6. Linear regression analysis showed a highly significant correlation between the lumen diameter determined by LSFG and that measured by AO camera for arteries (A) and veins (B). Lumen diameters determined by LSFG and that measured by AO camera in veins were significantly larger than that in arteries (C, D) (Table 2). The ratio of the lumen diameter determined by LSFG to lumen diameter measured by AO camera in the arteries was significantly lower than that for veins ($P < 0.001$). AO = adaptive optics, AU = arbitral units, LSFG = laser speckle flowgraphy.

**TABLE 2.** Comparison of Vessel Lumen Diameter Determined by LSFG and by AO Camera

Measurement places (artery/vein) (number)	71:64
Diameter determined by LSFG (artery) (AU)	10.9 ± 2.3
Diameter determined by LSFG (vein) (AU)	15.7 ± 3.4
Diameter determined by AO (artery), μm	162.3 ± 35.7
Diameter determined by AO (vein), μm	213.5 ± 47.5
Ratio of diameter (LSFG/AO) (artery)	0.068 ± 0.005
Ratio of diameter (LSFG/AO) (vein)	0.074 ± 0.007

AO = adaptive optics, AU = arbitrary units, LSFG = laser speckle flowgraphy.

make these measurements raises the possibility of examining changes in early diabetes. In addition, other systemic diseases such as hypertension could produce quantifiable changes of the retinal vascular walls[38] and many other ocular conditions, for example, vein occlusions, could have some effect on the retinal vasculature.[1,2] The TRFI should be useful for future investigations as it has the advantage of being able to analyze all the retinal vessels around the ONH semiautomatically. Accordingly, future studies using the TRFI to investigate diabetic retinopathy and retinal vein occlusion, common vascular disorders that can cause vision-threatening complications, should lead to valuable findings. The merged images obtained by LSFG and AO provided important information, for example, the distribution of erythrocyte velocities in the lumen of the vessel, and they can detect changes in the lumen diameter and the wall thickness simultaneously.

This study has several limitations. Although we used the TRFI which represents the total RFV index for major retinal vessels around the ONH, it is not known what proportion of the retinal blood flow volume around ONH was measured. This difficulty can affect the results of the differences in the blood flow velocity between arteries and veins. However, most of retinal blood flow around the ONH was probably measured because the RFV index could be measured for the vessel with diameter of even less than 60 μm despite the average of the diameter was 186.3 μm. Another limitation is the possibility that the TRFI was affected by scattering in the underlying choroidal circulation due to the long wavelength of the laser. However, our findings that TRFI was not significantly correlated with the SBP, IOP, MAP, or MOPP suggest that the values reflect mainly the retinal blood flow autoregulation and are independent of the choroidal blood flow. Another limitation was that we did not measure the total retinal blood flow with laser Doppler velocimetry and could not compare the same population by LSFG and laser Doppler velocimetry. In addition, the size of the sample was not large enough to confirm the findings. Therefore, further studies to compare the present findings on a large number of healthy subjects by these 2 different measurement methods will be necessary for clarification.

In conclusion, the TRFI was measured in normal subjects, and the retinal blood flow in the vein was significantly higher than that in the artery. However, the possibility remains that LSFG has an inherent problem that the arterial lumen diameter determined by LSFG is smaller than the actual ones because of the characteristics of arteries. This would result in a smaller volume of retinal blood flow in the arteries than veins. Further studies are necessary to investigate the actual blood flow based
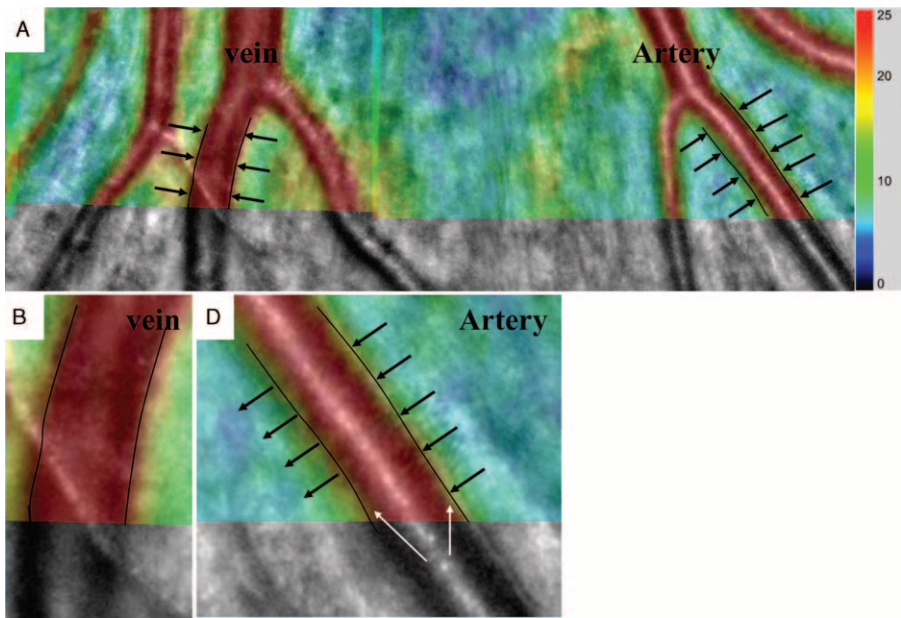
FIGURE 7. Distribution of mean blur rate (MBR) within the vessels in a merged image. Black arrows and lines indicate the lumen of the vessel (A). Vein had high and uniform MBR in the lumen homogeneously (B). On the other hand, the artery has a high MBR at the center and low MBR close to the wall of the lumen (white arrows showing low MBR layer) (C).

on the findings which arteries would have more cell-free plasma layer formation close to the wall of vessel than veins.

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