

FOREFRONT REVIEW

Organizer: Hiroyuki Iijima, MD, PhD



## Arteriovenous crossing associated with branch retinal vein occlusion

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Received: 20 November 2018 / Accepted: 16 May 2019 / Published online: 8 August 2019  
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### Abstract

Branch retinal vein occlusion (BRVO) is defined as the focal occlusion of a first or second-order branch of retinal vein, which occurs most frequently at an arteriovenous (AV) crossing. Direct ophthalmoscopy, color fundus photography, and fluorescein angiography facilitate observation of AV crossings parallel to the retinal plane. Optical coherence tomography (OCT), with its high-depth resolution, enables observation of retinal lesions perpendicular to the retinal plane. OCT angiography (OCTA) provides depth-resolved images of the retinal vasculature by segmenting three-dimensional data. In this review, we discuss novel findings related to affected AV crossings associated with BRVO obtained via OCT and OCTA. The high-depth resolution of OCT or OCTA is useful for observation of the narrowed vein and determination of the vessel position of the affected AV crossing. Studies using OCT and OCTA have shown that BRVO caused by a venous overcrossing is more prevalent than previously reported, and that venous narrowing was significantly greater in instances caused by a venous overcrossing than in those caused by an arterial overcrossing. Moreover, OCTA also revealed that the retinal nonperfusion area size was larger in eyes with BRVO caused by a venous overcrossing than in those with BRVO caused by an arterial overcrossing. This contrasts with earlier findings obtained by conventional imaging modalities predating OCT, which showed that an arterial overcrossing was more common than a venous overcrossing at the causative venous occlusion site in eyes with BRVO. This review discusses these findings and their significance in the study of AV crossing associated with BRVO.

**Keywords** Branch retinal vein occlusion · Arteriovenous crossing · Venous overcrossing · Optical coherence tomography · Optical coherence tomography angiography

### Introduction

Branch retinal vein occlusion (BRVO) is defined as the focal occlusion of a first or second order retinal vein [1–5], which occurs most frequently at an arteriovenous (AV) crossing [6–10]. The affected AV crossing can generally be categorized into one of two patterns: an arterial overcrossing, in which the adjacent retinal artery runs over the affected vein, or a venous overcrossing, in which the affected retinal vein runs over the adjacent artery [9, 11, 12]. Direct

ophthalmoscopy, color or infra-red photography, and fluorescein angiography (FA) were frequently used to image the morphologic alterations in affected retinal vessels prior to the introduction of optical coherence tomography (OCT) and OCT angiography (OCTA) [8–13]. These methods, combined with their contemporaries, revealed that, in BRVO arterial overcrossings were dominant and venous overcrossings were very rare [8, 9, 11, 12].

In the past decade, OCT has become available for use in clinical practice as well as for research. Compared to older imaging modalities, OCT enables more detailed evaluation of the retinal vasculature perpendicular to the retinal plane [14–19]. OCTA, building on the OCT platform, also provides the depth-resolved images of the retinal capillary plexuses by segmenting three-dimensional data [20–25]. In addition to the use of OCT and OCTA for evaluation of macular lesions, we recently applied these imaging modalities to evaluations of the morphological and functional alterations in both affected and unaffected AV crossings [26–28]. We

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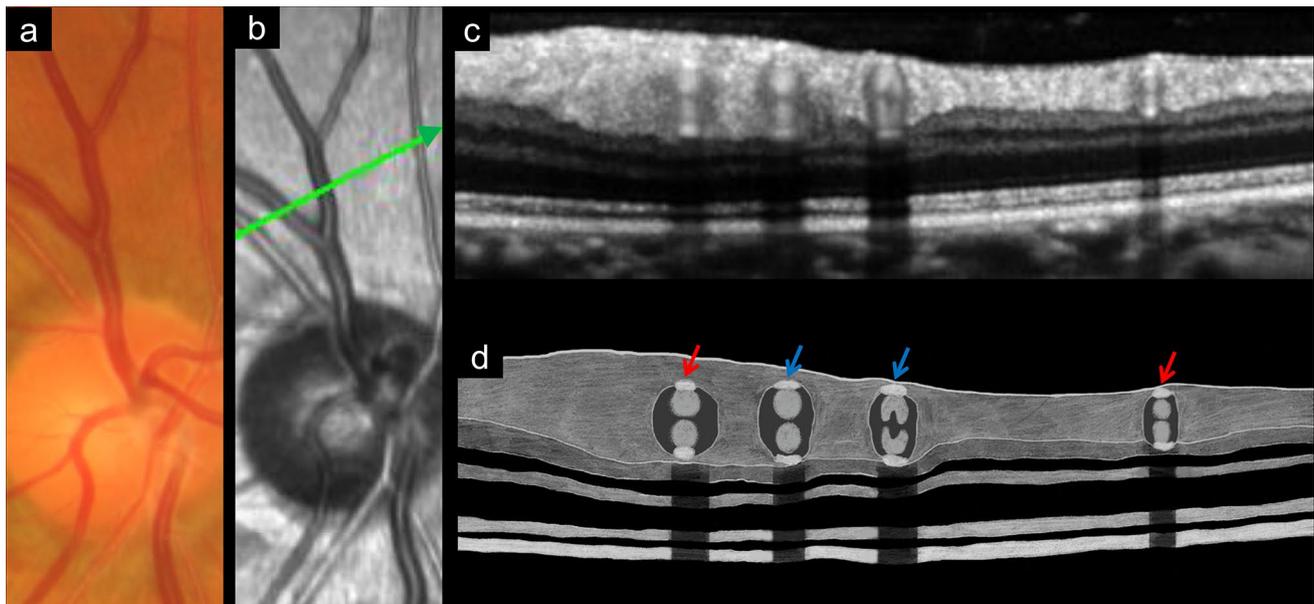
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**Fig. 1** Cross optical coherence tomography (OCT) section of normal retinal vessels. Fundus photograph (a) and infrared image (b) of an unaffected contralateral eye. (c) An OCT image shows cross-sections of the retinal vessels along the green arrow. Major retinal vessels are seen as oval-shaped configurations with 4 distinctive hyperreflectivities. The top and bottom portions of the vessel walls show the inner-

most and outermost hyperreflectivities. The reflectivity from the arterial walls is higher, compared with that from venous walls. All retinal vessels with a physiological blood flow show inside hourglass-shaped hyperreflectivities. (d) An illustration of Figure 1c. Red arrows indicate arteries and blue arrows indicate veins. This figure was previously published in *Ophthalmology* (Ref. 26)

then examined their association with retinal pathologies and the clinical relevance of BRVO [26, 27].

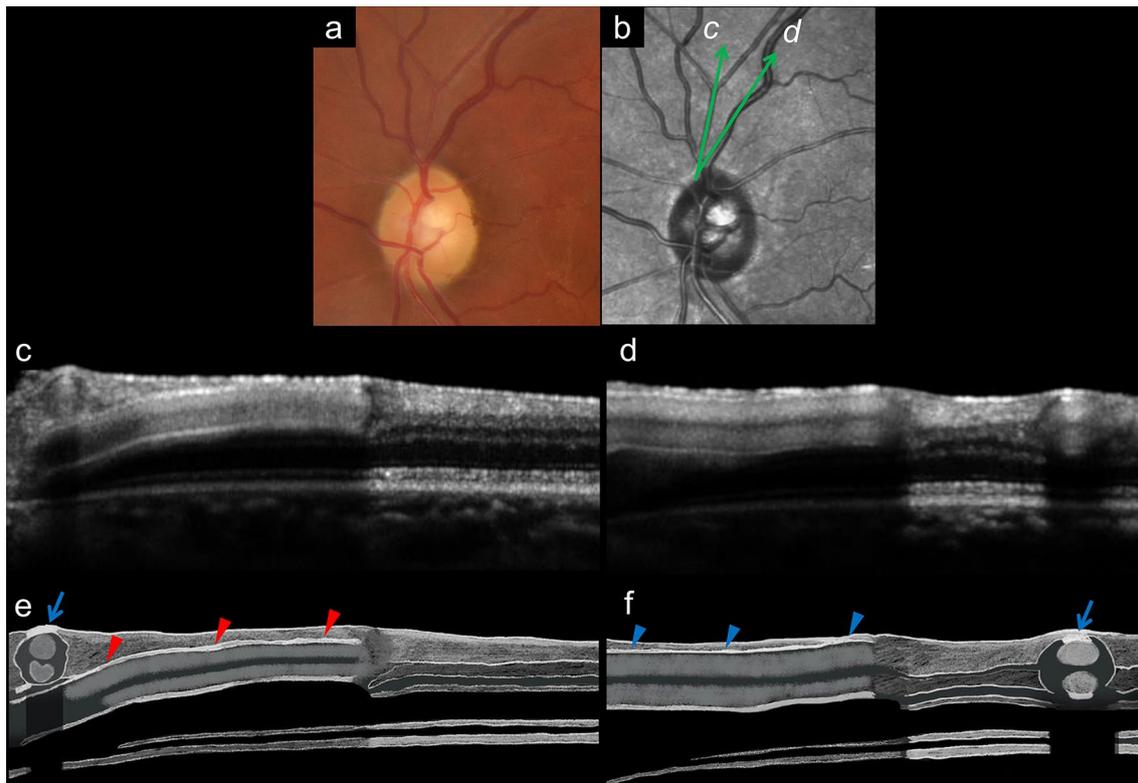
In this review, we describe the novel findings obtained via OCT and OCTA imaging that allow for further speculation about the pathogenesis of BRVO. We further compare the OCT and OCTA results with previous histological findings and those obtained via conventional imaging modalities that predate OCT and OCTA.

### Previous findings for AV crossing in BRVO

BRVO occurs mainly at AV crossings and occasionally at the optic disc margin or other sites where the adjacent retinal artery and affected vein run in parallel [3–5, 29, 30]. Jensen used direct ophthalmoscopy to examine AV crossing sites in 50 healthy subjects and found venous overcrossings in 30% of all AV crossings [31]. Using color fundus photography and FA, Duker and Brown report that a case series of 25 patients with BRVO could not reveal any venous overcrossings at the site of occlusion [8]. The authors additionally examined corresponding crossings in the opposite side of the same eyes and found crossings associated with first- and second-order branches in 26 subjects without BRVO [8]. The frequencies of venous overcrossings were 35% and 32%, respectively. Using color stereoscopic photographs, red-free photographs, and FA, Weinberg et al. examined 1,939 AV crossings in 103 eyes with BRVO, 90

fellow eyes, and 99 control eyes without BRVO [9]. Interestingly, venous overcrossings were seen at only 2 of 82 (2.4%) occlusions of branch retinal veins. In contrast, venous overcrossings were seen in 162 of 728 (22.3%) crossings in involved-eyes and in 239 of 724 (33.0%) crossings in control eyes. The authors speculate that this distribution bias in affected AV crossings might have been due to a difference in the distensibility of the vein lying beneath the artery in an arterial overcrossing, as opposed to between the internal limiting membrane (ILM) and the artery in a venous overcrossing [9].

Old age, hypertension, and arteriosclerosis are known to be risk factors for BRVO [4, 10, 32, 33]. Previous histological studies suggest that the major arteries and veins share a common adventitial sheath at the arteriovenous crossing and that the mechanical compression of rigid arterial walls causes narrowing of the venous lumen, resulting in flow disturbance at crossing sites [6, 34]. Based on this mechanism, AV sheathotomy has been performed for about 10 years for the treatment of complicated macular edema [1, 7, 35–38]. However, the sheathotomy often led only to transient improvements in retinal blood flow. A subsequent study using FA reports that most eyes with BRVO exhibited venous lesions not upstream but downstream of the affected AV crossing [39, 40]. If BRVO occurs as a result of mechanical compression of the rigid arterial walls, the venous lesions should be formed not downstream but



**Fig. 2** Longitudinal optical coherence tomography (OCT) section of normal retinal vessels. Fundus photograph (a) and infrared image (b) of an unaffected contralateral eye. OCT images along green arrows c and d capture longitudinal sections of the major retinal artery (c) and vein (d). Consistent with the cross-sections of the major retinal vessels, retinal vessels show 4 hyperreflective bands. The innermost and

outermost bands are derived from the vessel walls, and the 2 intermediate bands are derived from the bloodstream. (e, f) Illustrations of Figure 2c and 2d. Red arrows indicate arteries and blue arrows indicate veins. This figure was previously published in *Ophthalmology* (Ref. 26)

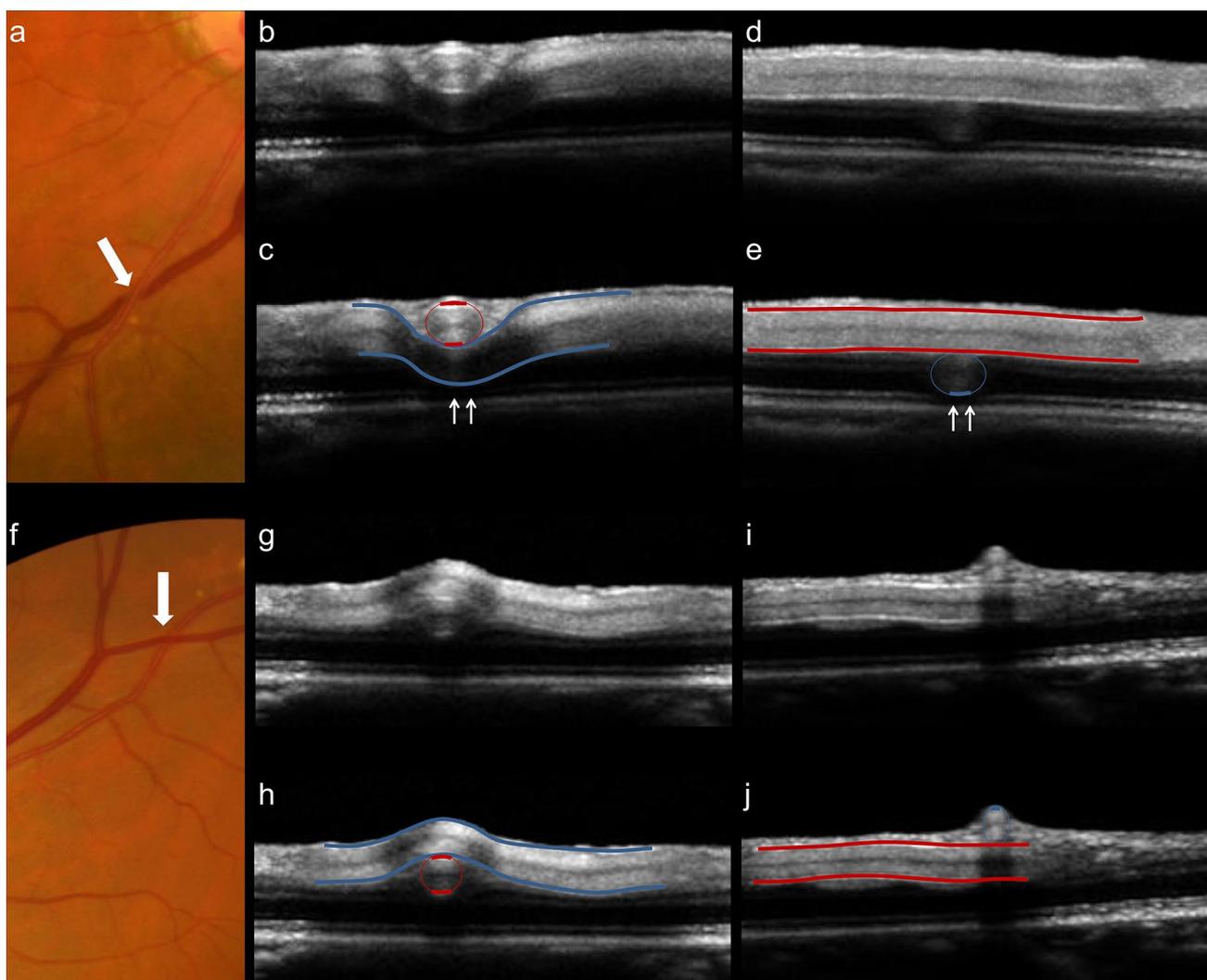
upstream of the affected AV crossings. Therefore, factors beyond mechanical compression may be associated with the pathogenesis or progression of BRVO.

### Retinal vessels of normal and aged subjects examined by OCT

The excellent depth resolution of OCT has enabled detailed observations of the retinal architecture and contributes to our understanding of retinal pathology [15–19, 26, 41, 42]. To study how OCT allows for delineation of retinal vasculature, we first examined the major retinal vessels in healthy eyes [18, 26, 28] (Figs. 1, 2, 3) and those in aged subjects without BRVO [28] (Fig. 4). OCT revealed cross-sections of retinal vessels to be oval-shaped mainly in the retinal nerve fiber and ganglion cell layers [18, 26] (Fig. 1). Cross-sections of physiological vessels revealed four distinctive hyperreflectivities in a line. The top and bottom portions of the vessel walls, vertical to the OCT light source, showed the innermost and outermost hyperreflectivities. All retinal vessels with physiological blood flow exhibited internal, paired

hyperreflectivities, which were frequently hourglass-shaped [18, 26] (Fig. 1). In the longitudinal sections of the major retinal vessels, retinal vessels had four hyperreflective bands, of which the innermost and outermost were derived from the vessel walls [26, 28]. Furthermore, the two intermediate bands were derived from the bloodstream and appeared to be integral to the cross-sections of major retinal vessels [26, 28] (Fig. 2).

In sites with arterial overcrossing in younger subjects, the retinal arteries ran straight within the inner retina, with the retinal veins abruptly changing direction and passing under the arteries [26, 28] (Fig. 3). In sites with venous overcrossing in younger subjects, retinal arteries ran straight within the inner retina and the retinal veins protruded into the vitreous cavity to pass over the arteries [18, 28] (Fig. 3). In contrast, in sites with arterial overcrossing in aged subjects, the retinal veins exhibited focal narrowing of the lumen around the crossing [26, 28] (Fig. 4). The retinal veins with venous overcrossing in aged subjects exhibited more severe narrowing between the ILM and the arterial wall at the site of crossing [26, 28], as compared to venous configurations of



**Fig. 3** Arteriovenous crossings in younger subjects. (a-e) An arterial overcrossing. A retinal artery runs straight within the inner retina. At the crossing, the retinal vein abruptly changes direction and passes under the retinal artery. (f-j) Venous overcrossing. A retinal artery runs straight within the inner retina. At the crossing, the retinal vein

protrudes into the vitreous cavity to pass over the arteries. The white arrows indicate arteriovenous crossings examined. The red lines outline arteries while the blue lines outline veins. This figure was previously published in *Investigative Ophthalmology and Visual Science* (Ref. 28)

younger subjects [26, 28] (Fig. 3) and those of aged subjects with arterial overcrossing [26, 28] (Fig. 4).

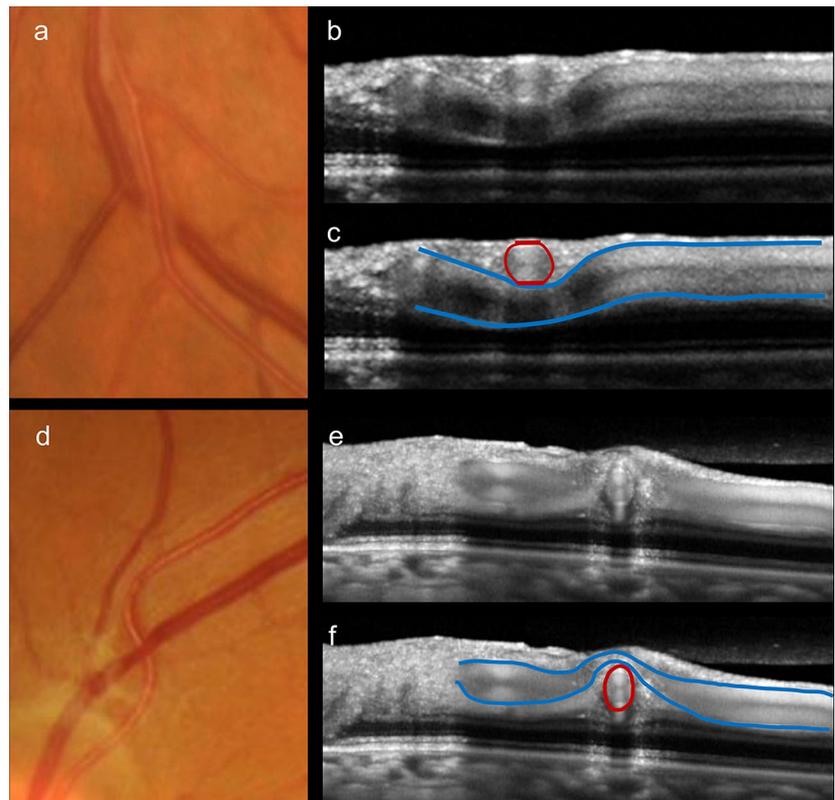
### BRVO associated-retinal vasculature examined by OCT

To investigate changes in retinal vasculature associated with BRVO, 25 eyes of 25 patients with acute BRVO were examined with OCT (Figs. 5, 6, 7) [26]. It is sometimes difficult to determine the relative anatomical positions of the artery and vein at the affected AV crossing using a fundus examination alone. In 3 of 25 eyes, FA did not elucidate the anatomical position of the adjacent arteries and veins at the affected AV crossings. However, sequential thin sections of

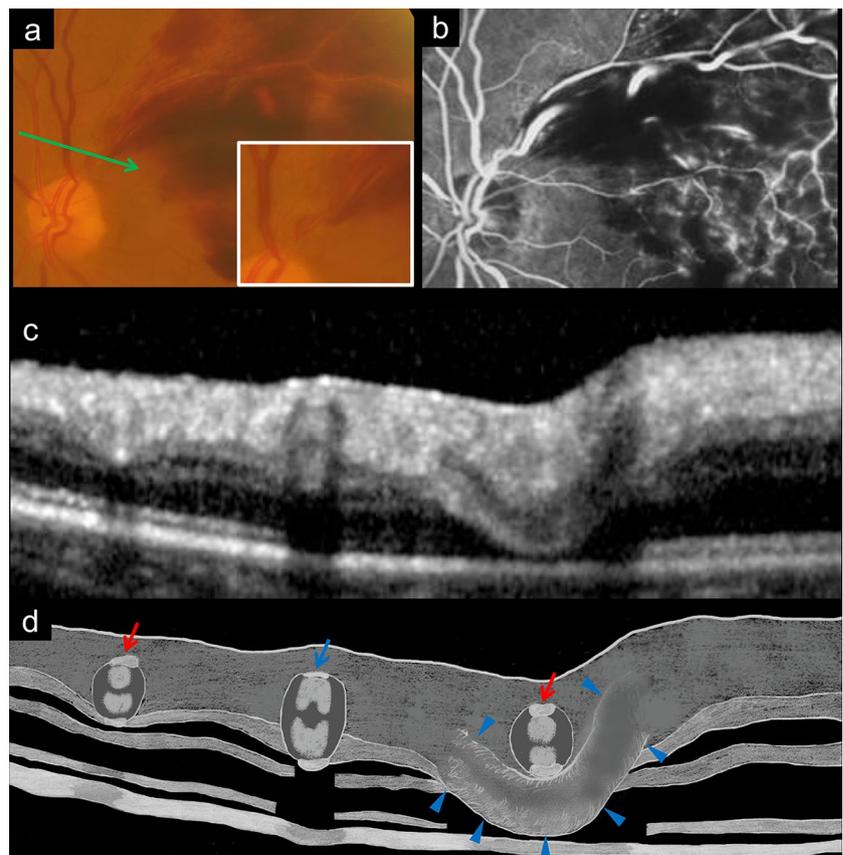
OCT revealed the anatomical position in all assessed eyes. At the affected AV crossings, arterial overcrossing was seen in 17 eyes (68%), while venous overcrossing was seen in only 8 (32%).

OCT imaging of the occlusions caused by an arterial overcrossing revealed that the retinal vein ran deep below the artery and the venous lumen appeared to be preserved at the AV crossing (Fig. 5) [26]. The affected retinal vein may thus preferentially exhibit its tortuosity in the anteroposterior direction because most of the retinal neuroglial cells, including Müller cells, spread their bodies in the anteroposterior direction rather than the horizontal direction [19]. In contrast to tortuous veins with arterial overcrossing, affected veins with venous overcrossings were often compressed between

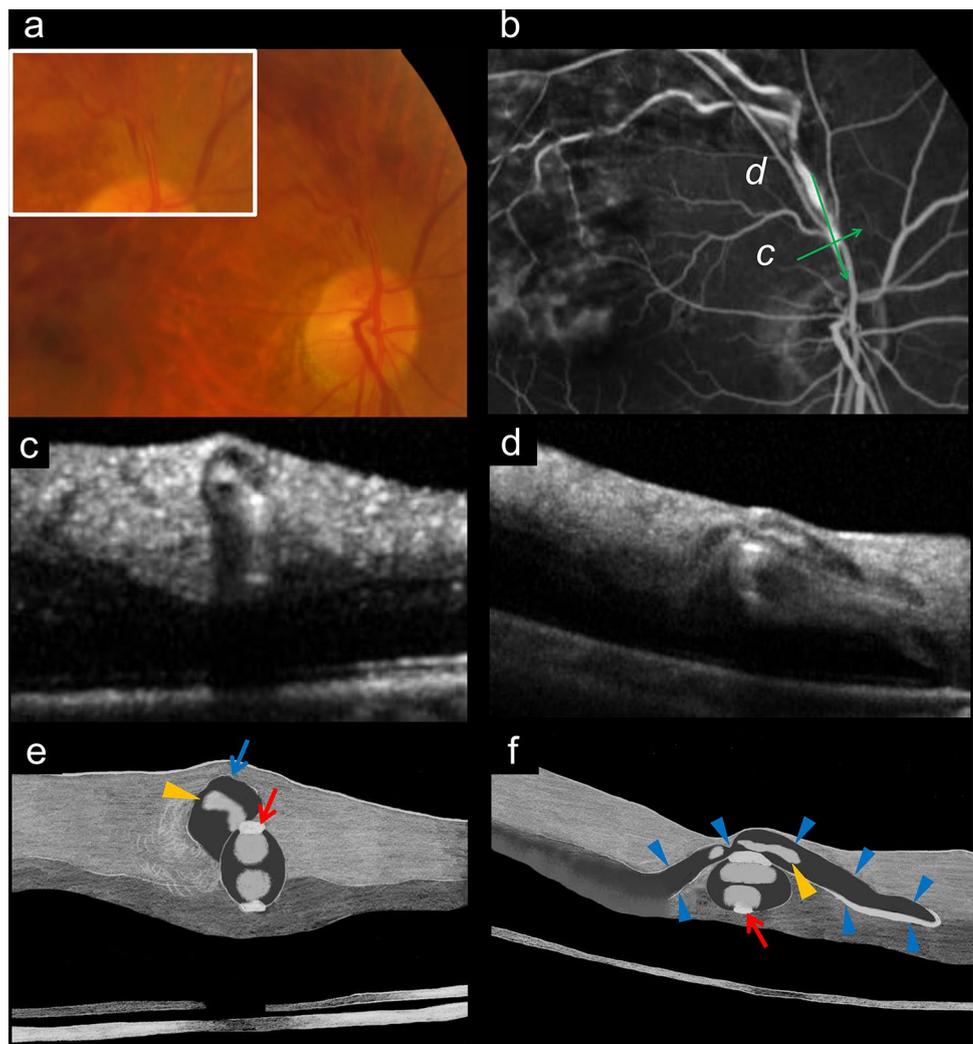
**Fig. 4** Arteriovenous crossings of aged subjects. (a-c) An arterial overcrossing that depicts crossing phenomena. The retinal vein shows focal narrowing of the lumen around the crossing different from the venous configurations of younger subjects. (d-f), A venous overcrossing in aged subjects. When compared to the venous configurations of younger subjects, venous overcrossing in aged subjects exhibits more severe narrowing between the ILM and the arterial wall at the crossing. The red lines outline arteries while the blue lines outline veins. A part of this figure was previously published in *Investigative Ophthalmology and Visual Science* (Ref. 28)



**Fig. 5** Branch retinal vein occlusion (BRVO) caused by an arterial overcrossing. Fundus photograph (a) and fluorescein angiogram (b) of BRVO. Fluorescein angiogram confirms vein occlusion caused by an arterial overcrossing. (c) Sectional image was obtained along the green arrow using optical coherence tomography. The vein appears to run deep in the retinal layers below the overcrossing artery. The lumen of the vein at the crossing site is maintained. Red arrows indicate arteries while blue arrows and arrow heads indicate veins. (d) An illustration of Figure 5c. This figure was previously published in *Ophthalmology* (Ref. 26)



**Fig. 6** Branch retinal vein occlusion (BRVO) caused by a venous overcrossing. Fundus photograph (a) and fluorescein angiogram (b) of BRVO. (c, d) Sectional image (along green arrows *c* and *d*) obtained with optical coherence tomography. (c) Cross sectional image confirmed vein occlusion with a venous overcrossing. (d) The retinal vein appears to be compressed and choked between the ILM and the arterial wall at the crossing. A thrombus was seen within the lumen at the crossing site. Red arrows indicate arteries and blue arrows indicate veins. Yellow arrows indicate the thrombus. (e, f) Illustrations of Figure 6c and 6d. This figure was previously published in *Ophthalmology* (Ref. 26)



the ILM and the arterial wall (Fig. 5) [26]. In occlusions with venous overcrossings, mechanical factors made by ILM and the upper arterial wall were more strongly associated with the onset of BRVO.

In eyes with acute BRVO, OCT examination often revealed thrombus formation around the affected AV crossing (Figs. 6, 7) [26]. Thrombi were detected in 14 of 17 eyes (82.3%) with arterial overcrossing and in 7 of 8 eyes (87.5%) with venous overcrossing. Most of the thrombus was seen downstream of the AV crossing (Figs. 6 and 7) [26]. Thrombi occasionally extended to both sides of the affected AV crossing. None of the eyes contained thrombi only at the crossing site or upstream from the site [26].

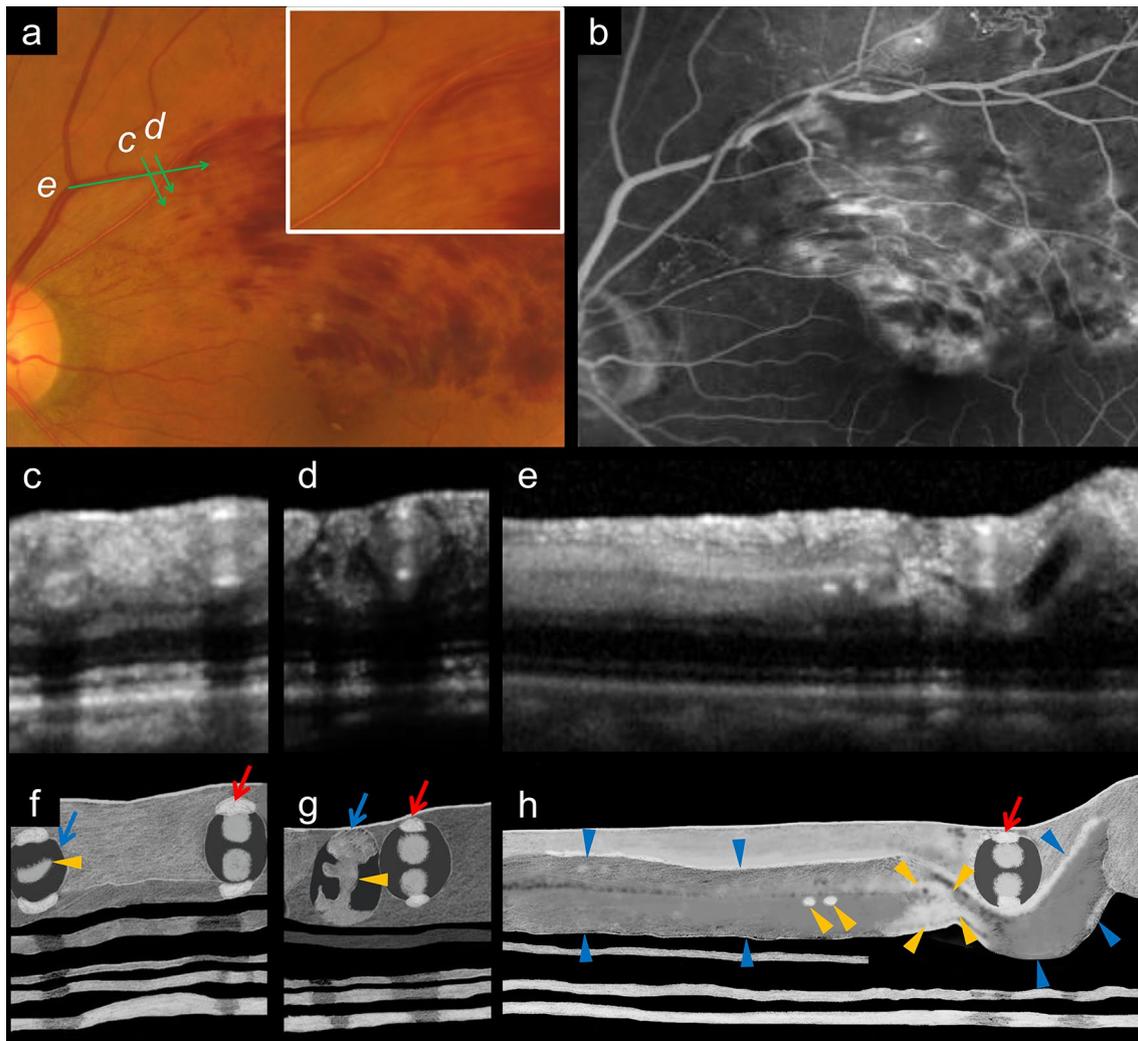
Considering these findings, mechanical compression of the affected vein, resultant hemodynamic changes downstream of the AV crossing site, and endothelial damage to the affected vein may also be important mechanisms underlying BRVO. We contend that the pathogenesis of BRVO is likely, at least in part, due to patterns of relative anatomical positions of crossing vessels. Additionally, configuration

of the affected veins, indicated by our OCT examinations, opposes the hypothesis of Weinberg et al. speculating that there might have been a difference in the distensibility of the vein lying beneath the artery in an arterial overcrossing, as opposed to between ILM and the artery in a venous overcrossing [9].

#### Anteroposterior relationship of the crossing artery and vein examined by OCTA

Advances in OCTA provide depth-resolved images of the retinal capillary plexuses by segmenting 3D angiographic data into en-face slabs of interest [20, 21, 43–45]. After OCT investigations, we added an additional 46 eyes with major BRVO and examined the vessel positions of affected AV crossings in these eyes using both FA and OCTA [27].

Though FA provided unique and substantial information on the affected vessels, such as venous laminar flow, vascular leakage and vascular wall staining, it could not elucidate the anteroposterior relationships of the retinal arteries



**Fig. 7** Thrombi within the affected retinal vein. Fundus photograph (a) and fluorescein angiogram (b) with branch retinal vein occlusion. (c–e) Sectional images along green arrows *c*, *d*, and *e* were obtained with OCT. Retinal vein proximal to the affected crossing exhibited thrombus formation without physiological appearance. (e) Longitudi-

dinal section of the retinal vein exhibits internal thrombus formation downstream of the affected crossing. (e–g) Illustrations of Figure 7c, 7d, and 7e. Red arrows indicate arteries and blue arrows indicate veins. Yellow arrows indicate thrombus. This figure was previously published in *Ophthalmology* (Ref. 26)

and veins at the causative crossing sites as clearly as OCTA (Fig. 8) [27]. The proportion of eyes with venous overcrossings seen with OCTA was higher than that with FA [27]. In addition, FA classified affected AV crossing patterns as arterial overcrossing in 23 eyes (50%), venous overcrossing in 11 eyes (24%), and screw type in 2 eyes (4%). In contrast, OCTA classified the pattern as arterial overcrossing in 21 eyes (46%), venous overcrossing in 20 eyes (44%), and screw type in 3 eyes (7%) [27].

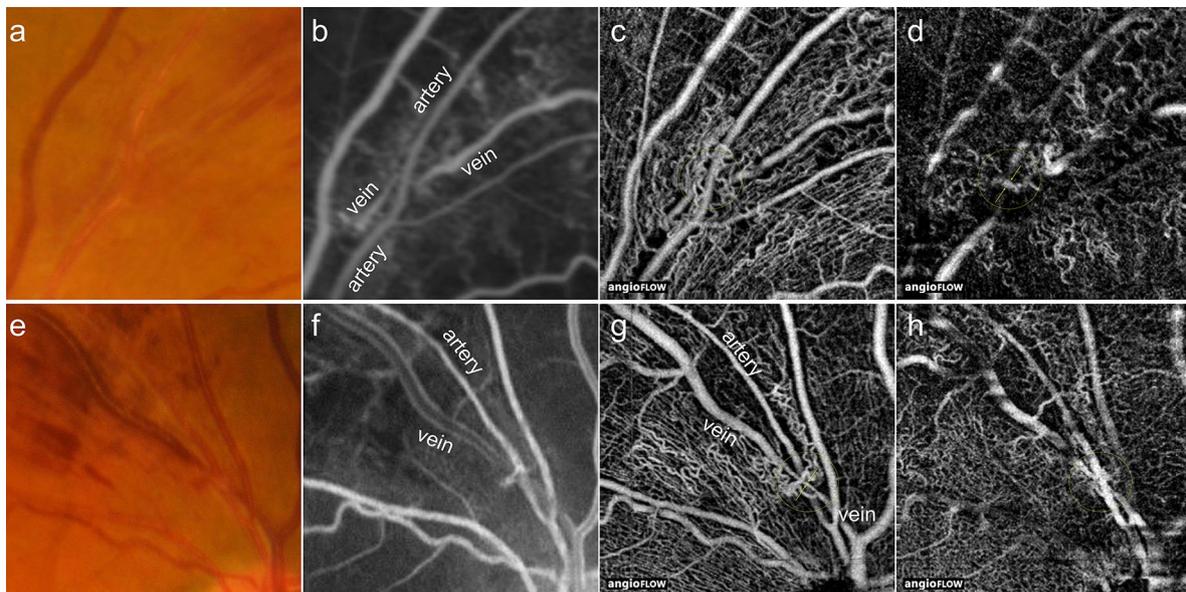
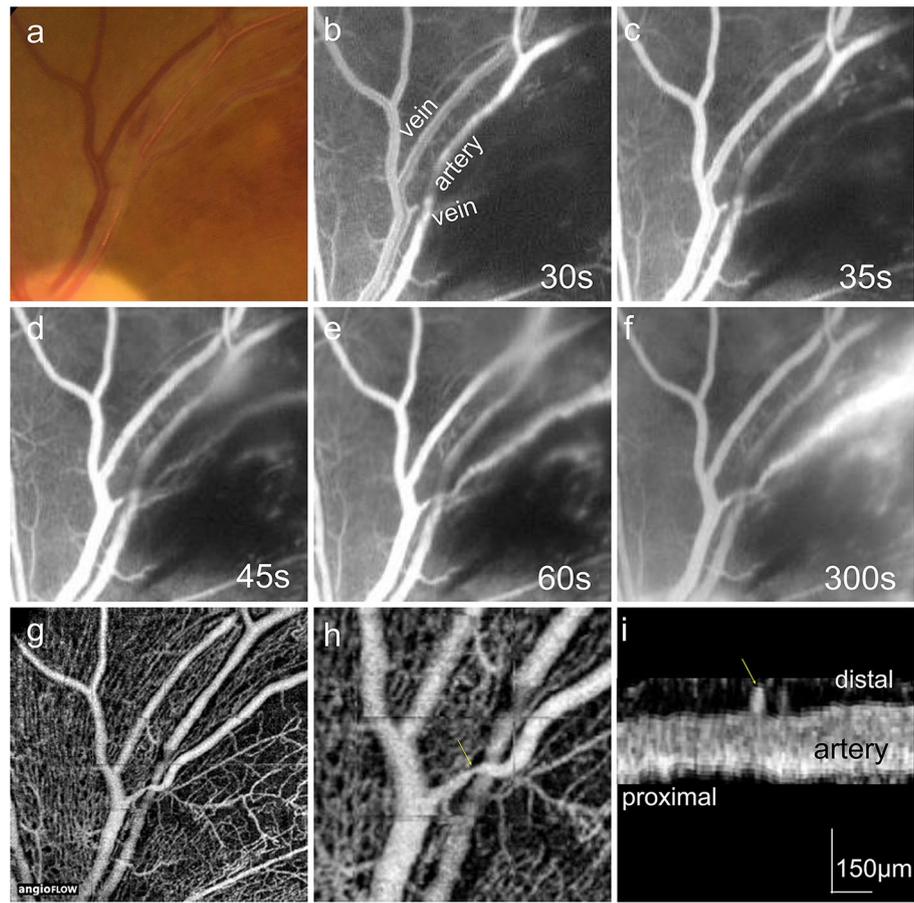
Results of OCTA imaging were different from those reported previously using direct ophthalmoscopy, color or infra-red fundus photography [8, 9, 11, 12, 46, 47], and the results identified by FA in our same study [27]. However, the proportion identified by OCTA [27] was relatively close to

that reported previously via OCT examination [26]. Using OCT, Satoh et al. most recently examined vessel position of affected AV crossings in a case series of 111 patients with BRVO and found that OCT-based images revealed venous overcrossing in 56 eyes (50.5%) [48]. Information from OCT or OCTA-based investigations suggests that venous overcrossings may serve as a risk factor for BRVO.

### Association between AV crossing pattern and retinal nonperfusion area

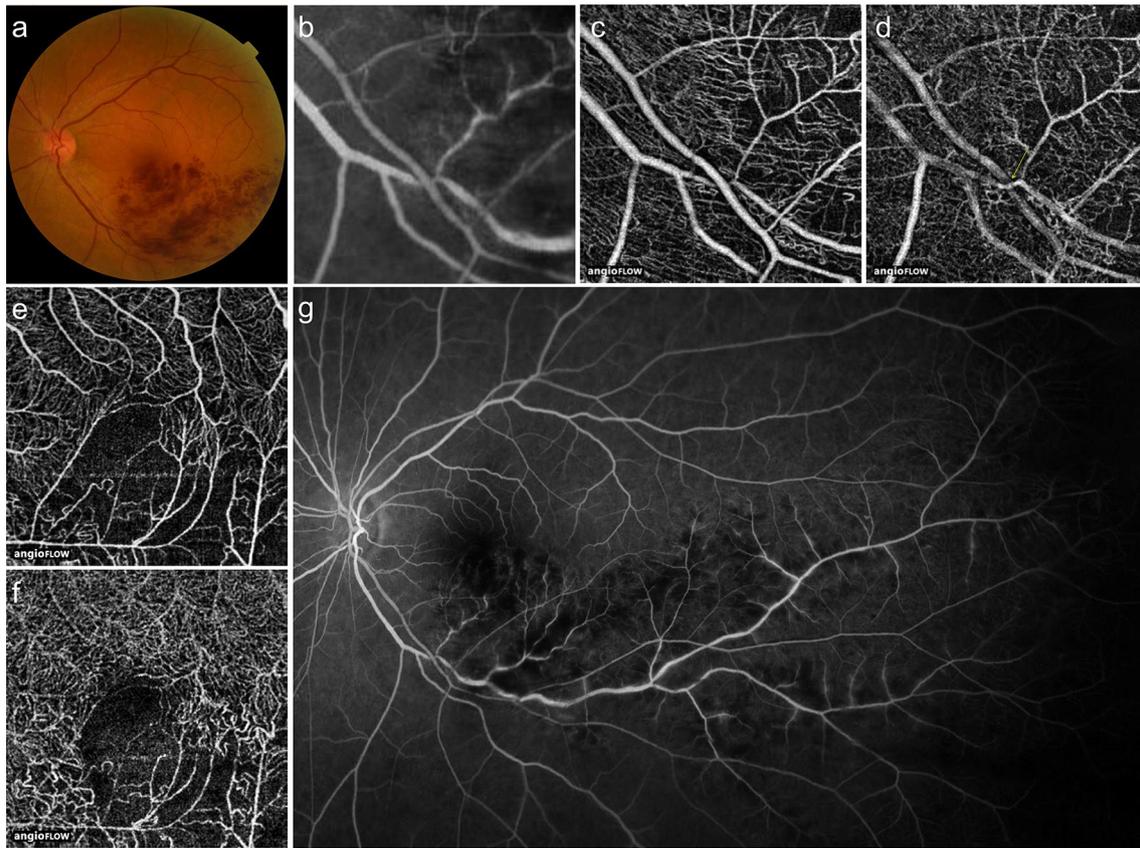
OCTA imaging of affected AV crossings exhibited markedly narrowed veins in eyes with venous overcrossing,

**Fig. 8** Discrepancy in the determination of the arteriovenous (AV) crossing pattern associated with branch retinal vein occlusion. The relative anatomical position of the retinal vessels cannot be accurately determined using color fundus photography (a) and a time-lapse analysis with fluorescein angiography (b-f) due to difficulty with differentiation of the narrowed vein. In contrast, optical coherence tomography (OCT) angiography (OCTA) enables determination of the crossing configuration type (f, g). The resliced OCT B-scan along the occluded vein confirms the en-face OCTA finding (i). A yellow arrow indicates the narrowed vein at the AV crossing. This figure was previously published in the *American Journal of Ophthalmology* (Ref. 27)



**Fig. 9** Differences in the degree of branch vein occlusions by arteriovenous crossing pattern. Branch retinal vein occlusion (BRVO) caused by an arterial overcrossing (a-d) and by a venous overcrossing (e-h). In a BRVO-eye caused by a venous overcrossing, the occluded

vein is markedly narrower at the point of crossing (g). In contrast, narrowing of the occluded vein is relatively mild in a BRVO-eye caused by an arterial overcrossing (d). This figure was previously published in the *American Journal of Ophthalmology* (Ref. 27)



**Fig. 10** Small retinal nonperfusion area (NPA) in branch retinal vein occlusion (BRVO) caused by an arterial overcrossing. (a–g) A representative case of acute BRVO caused by an arterial overcrossing. (a) Color fundus photograph. Magnified images of the crossing site are shown with fluorescein angiography (FA) (b), optical coherence tomography angiography (OCTA) in the superficial layer (c), and OCTA in the deep layer (d). (e, f) OCTA of the macular area

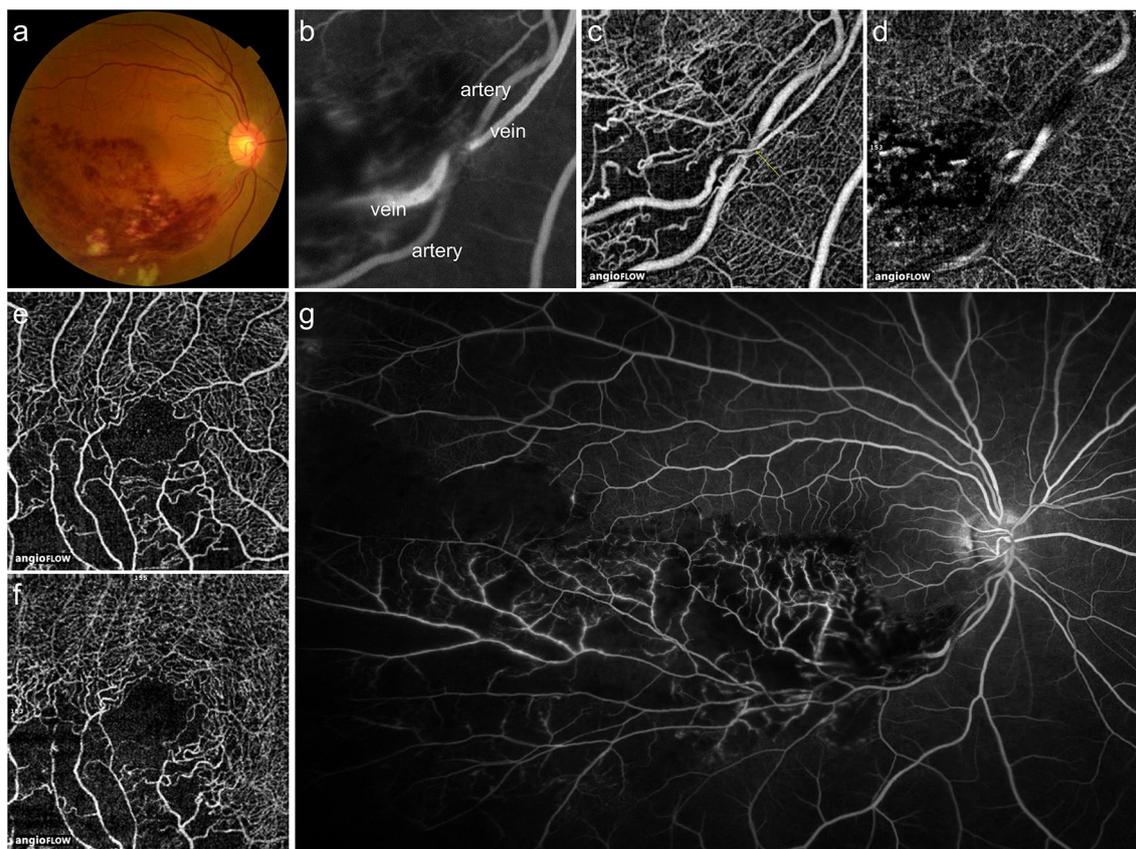
in the superficial (e) and deep (f) layers. (g) An ultra-widefield FA image. The macular NPA was  $1.86 \text{ mm}^2$  in the superficial layer and  $1.70 \text{ mm}^2$  in the deep layer when the macular edema was completely absorbed. The peripheral NPA is also not remarkable (g). This figure was previously published in the *American Journal of Ophthalmology* (Ref. 27)

significantly narrower than in eyes with arterial overcrossing (Fig. 9) [27]. Occluded veins with a venous overcrossing pattern might have been too narrow to be clearly detected by older imaging modalities [8, 9, 11–13, 46, 47] which predate OCT or OCTA. This may have contributed to disparities in the crossing pattern frequencies reported previously and those reported here, using OCT [26] or OCTA [27]. The superior depth resolution of OCT or OCTA was useful in the correct determination of the anatomic position of the retinal vessels at affected AV crossings.

Interestingly, OCTA-determined AV crossing patterns are associated with retinal nonperfusion area (NPA) size [27]. Additionally, macular NPA was significantly larger with venous overcrossing than with arterial overcrossing (Figs. 10, 11) [27]. Peripheral NPA was also significantly larger in eyes with venous overcrossing (Figs. 10, 11) [27]. The duration of symptoms, distance between the affected crossing site and the optic disc, presence or absence of hypertension, age, or the number of intravitreal ranibizumab

injections did not significantly differ between eyes with arterial overcrossing and those with venous overcrossing. We speculate that the constriction of the vein at the affected AV crossing site, which tends to be more marked in BRVO caused by a venous overcrossing, might be a cardinal factor for developing an NPA. More broadly, this may serve as a substrate for larger NPA in a venous overcrossing and smaller NPA in an arterial overcrossing.

BRVO is a classic and common retinal vascular disease, the clinical characteristics of which are well understood [1, 2, 10, 49]. However, findings obtained using high depth resolution imaging with OCT [18, 26] and OCTA [20, 22–24, 27, 50] may be new to most clinicians. The association between NPA size and the pattern of the affected AV crossing may aid in the development of an optimized treatment protocol for each patient with BRVO. In particular, the ILM peeling around the affected AV crossing, especially in eyes exhibiting venous overcrossing, might prevent the development of an NPA through an increased venous diameter



**Fig. 11** Large retinal nonperfusion area (NPA) in branch retinal vein occlusion (BRVO) caused by a venous overcrossing. (a–g) A representative case of acute BRVO caused by a venous overcrossing. (a) Color fundus photograph. Magnified images of the crossing site are shown with fluorescein angiography (FA) (b), optical coherence tomography angiography (OCTA) in the superficial layer (c), and OCTA in the deep layer (d). (e, f) OCTA of the macular area in the

superficial layer (e) and the deep layer (f). (g) An ultra-wide field FA image. The macular NPA was 2.08 mm<sup>2</sup> in the superficial layer and 2.15 mm<sup>2</sup> in the deep layer when the macular edema was completely absorbed. A large NPA is noted in the peripheral retina (g). This figure was previously published in the *American Journal of Ophthalmology* (Ref. 27)

caused by reduction of the compression between the ILM and underlying artery.

A critical limitation of the studies with OCT [18, 26, 28] and OCTA [27] is that most of the findings described here were obtained using a series of BRVO cases, the number of which was limited. However, we contend that OCT or OCTA-based findings might capture the essence of the pathological features of BRVO. To confirm the results reported here, as well as their relevance to clinical BRVO, further prospective studies on larger cohorts are necessary.

**Conflicts of interest** Y. Muraoka, Lecture fees (Santen, Senju, Nidek, Canon, Bayer); A. Tsujikawa, Grants (Novartis, Bayer, Santen, Canon), Lecture fees (Novartis, Bayer, Alcon, Santen, Senju, Nidek, AMO, Sanwa Kagaku, Kowa, Chugai, Johnson, Kyoto Drug, Hoya, Otsuka, Daiichi-Sankyo, Wakamoto, Janssen, Canon).

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