**Importance**
Polypoidal choroidal vasculopathy (PCV) is a major cause of visual loss worldwide, particularly in Asia, and the appropriate understanding of the structures in PCV previously described as polypoidal lesions is important for understanding their pathogenesis, diagnosis, and prognosis.

**Objective**
To report the morphologic characteristics of polypoidal lesions and their association with branching vascular networks (BVNs) in eyes with PCV using swept-source optical coherence tomographic angiography (SS-OCTA).

**Design, Setting, and Participants**
This cross-sectional observational study included 20 participants recruited from Shanghai General Hospital with a diagnosis of PCV based on the presence of focal hyperfluorescent spots on indocyanine green angiography (ICGA). Data were collected from December 1, 2017, to September 1, 2018, and analyzed from June 1 through September 30, 2018.

**Main Outcomes and Measures**
Polypoidal lesions in eyes with PCV were characterized using multimodal imaging that included fundus photography, fluorescein angiography, ICGA, SS-OCT, and SS-OCTA, and the images were anatomically aligned. Subfoveal choroidal thickness was manually measured as the distance between the Bruch membrane and the sclerochoroidal interface on the SS-OCT images.

**Results**
Of the 20 Asian patients, 5 (25%) were women and 15 (75%) were men. The mean (SD) age was 61.1 (7.6) years, and the mean (SD) logMAR visual acuity was 0.358 (0.294) (Snellen equivalent, 20/50 [20/40]). Twenty-three eyes underwent imaging and were diagnosed with PCV. Indocyanine green angiography identified 43 polypoidal lesions, and all corresponded to the structures that appeared as clusters of tangled vessels on SS-OCTA images. In addition, SS-OCTA detected 16 tangled vascular structures not seen on ICGA. Branching vascular networks were detected on SS-OCTA imaging in all eyes, but ICGA identified BVNs in only 17 of 23 eyes (74%). Of the 43 tangled vascular structures, 40 (93%) were located at the edge of a BVN and 3 (7%) were associated with type 2 neovascularization.

**Conclusions and Relevance**
In eyes with PCV undergoing SS-OCTA imaging, previously described polypoidal lesions may appear as tangled vascular structures associated with BVN or type 2 neovascularization. The identification of polypoidal lesions in patients with PCV as neovascular tangles rather than actual polypoidal lesions or aneurysmal dilatations may help facilitate understanding of their pathogenesis and response to treatment.

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Polypoidal lesions were first recognized as features of polypoidal choroidal vasculopathy (PCV) as described by Yannuzzi et al in 1990. At that time, PCV was thought to represent a distinct clinical entity from neovascular age-related macular degeneration. Branching vascular networks (BVNs), another feature of PCV, are now considered to be a variant of type 1 neovascularization, and the polypoidal lesions are described as terminal dilatations based on indocyanine green angiography (ICGA), which has been the criterion standard imaging method for diagnosis of PCV. On the basis of multimodal imaging, polypoidal lesions were thought to be structural variants associated with BVNs rather than the result of a distinct pathogenic pathway. Indocyanine green angiography and structural optical coherence tomography (OCT) have shown that polypoidal lesions appear to be focal dilatations of blood vessels at the margins of type 1 neovascularization. Inoue et al speculated that these polypoidal lesions represent aneurysmal lesions, and this pathological feature exists in a range of disorders. The investigators proposed a change in the name of PCV to aneurysmal type neovascularization.

Although OCT angiography (OCTA) has greatly facilitated the detection of BVNs and has provided detailed descriptions of their structure, polypoidal lesions have been poorly visualized on en face spectral-domain OCTA (SD-OCTA). Chan et al described polypoidal lesions as clusterlike structures, and Peiretti et al described polypoidal lesions as round structures with increased flow characteristics. None of these studies described polypoidal lesions as aneurysmal-like lesions. Even in clinicopathological studies, no definitive evidence has been provided about the anatomical structure of these polypoidal lesions. To date, the precise origin and composition of polypoidal lesions have yet to be clearly described, and an accurate description is the first step toward understanding the pathophysiological mechanisms involved in PCV. However, observations in this study using swept-source OCTA (SS-OCTA) have suggested that the use of the term aneurysm does not accurately describe the clinical appearance of these polypoidal lesions in PCV.

Swept-source OCTA uses a laser light source with a longer wavelength (1060 nm) than SD-OCTA (840 nm); as a result, less sensitivity roll-off occurs under the retinal pigment epithelium (RPE), and structural and angiographic images appear superior to SD-OCT-based images. As a result, the SS-OCT platform allows for better visualization of type 1 neovascularization and the polypoidal lesions. Using SS-OCTA, we investigated the morphologic characteristics of polypoidal lesions, BVNs, and their spatial associations in a Chinese population with PCV.

**Methods**

This cross-sectional study included patients from the Department of Ophthalmology at Shanghai General Hospital, Shanghai, China. The patients were evaluated from December 1, 2017, to September 30, 2018. The study design was approved by the medical ethics committee of Shanghai General Hospital, and all investigations followed the tenets of the Declaration of Helsinki. All patients provided verbal informed consent.

Inclusion criteria for the study were confirmed by at least 2 experienced ophthalmologists (F.W. and X.S.). The diagnosis of PCV was based on a modified inclusion criteria of the EVEREST study, which includes the presence of focal hyperfluorescent spots on ICGA plus at least I of the following: BVN, pulsatile polypl, nodular appearance on indirect ophthalmoscopic or noncontact slitlamp fundus biomicroscopic examinations, presence of a hypofluorescent halo, and/or an orange subretinal nodule on color fundus imaging. Exclusion criteria were high myopia (≥6.00 diopters), severe media opacity, previous vitrectomy, presence of hemorrhage that prevented adequate ICGA or OCTA examinations, diabetic retinopathy, and the presence of other concomitant retinal diseases.

All patients underwent a complete ophthalmologic examination, including review of medical records, best-corrected visual acuity, fundus photography (Visucam 200 digital fundus camera; Carl Zeiss Meditec AG), simultaneous fluorescein angiography and ICGA (Spectralis; Heidelberg Engineering, Inc), SS-OCT, and SS-OCTA (PLEX Elite 9000; Carl Zeiss Meditec, Inc). The SS-OCTA was performed at the same visit as the ICGA in all patients before any treatment or observation decisions were made. The choroidal thickness was manually measured as the subfoveal distance between the Bruch membrane and the sclerochoroidal interface using structural sectional OCT images. Swept-source OCTA was performed using 3 × 3-mm and 6 × 6-mm macular raster scans centered on the lesion in all cases. For en face imaging, a custom segmentation strategy was used first to visualize the BVNs and polypoidal lesions. The inner boundary followed the RPE, and the outer boundary followed the Bruch membrane, also known as the RPE-fit boundary layer on the instrument. The segmentation boundaries were then manually adjusted to optimally visualize the polypoidal lesions and BVNs. The data collected from each patient included their history of eye diseases, treatments, choroidal thickness measurements, and interpretations of their fundus photographic, fluorescein angiographic, ICGA, and SS-OCT images. The SS-OCTA images were overlaid on the magnified ICGA images to determine the position of polypoidal lesions.
Statistical Analysis

Data were analyzed from June 1 through August 30, 2018. Two ophthalmologists (Q.B. and Q.Y.) and 1 retina specialist (F.W.) evaluated the lesions. The ophthalmologists marked and counted the number of polypoidal lesions independently, first on ICGA and then on SS-OCTA images, and the retina specialist adjudicated any discrepancies. In this study, the SS-OCTA images were evaluated on the point-by-point manually aligned ICGA images. All the retinal vascular projections in SS-OCTA images were removed to eliminate the artifact of retinal blood flow within the slab that would complicate the interpretation of choroidal new vessels and structures within the polypoidal lesions. This process used the automated projection-artifact removal software that was integrated with the PLEX Elite 9000 instrument.18 The quantitative data were presented as means (SDs).

Result

The 20 Asian patients included 5 women (25%) and 15 men (75%). The mean age was 61.1 (7.6) years, and mean logMAR visual acuity was 0.358 (0.294) (Snellen equivalent, 20/50 [20/40]). Twenty-three eyes underwent imaging and were diagnosed with PCV. The mean choroidal thickness was 332.5 (101.2) mm. Demographic and clinical characteristics of patients are summarized in the Table. A total of 8 eyes were treatment-naive, 11 had received multiple injections of vascular endothelial growth factor (VEGF) inhibitors, and 4 underwent multiple anti-VEGF treatments and photodynamic therapy.

Branching vascular networks were detected on SS-OCTA in all 23 eyes (100%), and ICGA detected BVNs in 17 of 23 eyes (74%). In 6 eyes, the BVNs that could not be clearly identified on ICGA were detected on SS-OCTA. By adjusting the segmentation boundaries to interpret the SS-OCTA images, we were able to identify all the polypoidal lesions. The internal blood flow of the 43 polypoidal lesions found on ICGA appeared as tangled vascular structures on SS-OCTA. In addition, 16 structures similar to polypoidal lesions were detected on SS-OCTA that were correlated with the peaked or notched pigment epithelial detachments (PEDs) connected to flat irregular PEDs on OCT B-scans (eFigure 4 in the Supplement) but not clearly detected on ICGA (Figure 1). Of the 43 tangled vascular structures, 40 (93%) were located at the edge of BVNs, and 3 (7%) were connected with type 2 neovascularization. The en face images of these polypoidal lesions appeared as round, branched, or other irregular shapes. Tangled vascular structures were at the border of BVNs in all 23 eyes but also within the BVN in 2 eyes.

<table>
<thead>
<tr>
<th>Patient No./Sex/Age, y</th>
<th>Eye</th>
<th>Treatment</th>
<th>CNV Type</th>
<th>SFCT, μm</th>
<th>No. of Polypoidal Lesions in ICGA</th>
<th>No. of Tangled Vessels in OCTA</th>
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<td>6</td>
<td>6</td>
</tr>
<tr>
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<td>8</td>
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<td>BVN</td>
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Abbreviations: BVN, branching vascular networks; CNV, choroidal neovascularization; ICGA, indocyanine green angiography; OCTA, optical coherence tomographic angiography; PDT, photodynamic therapy; SFCT, subfoveal choroidal thickness; VEGF, vascular endothelial growth factor.
Patient 6
A 53-year-old woman diagnosed with PCV received 12 anti-VEGF treatments (ranibizumab [Lucentis; Novartis], 0.5 mg) for 5 years. Best-corrected visual acuity was 16/20 OD. Fundus examination revealed 4 orange-red lesions in the macula (Figure 2A). Indocyanine green angiography revealed focal hyperfluorescence and a BVN in the early frame (Figure 2B). The BVN and polypoidal lesions were seen on the SS-OCTA cross-sectional images (Figure 2C). The SS-OCTA boundary segmentation showed that the BVN terminal vessels appeared intertwined with tangled vascular structures that corresponded to a PED on B-scans (eFigure 1A-D in the Supplement). The polypoidal lesions appeared to be composed of numerous vascular tangles when the lesions were magnified (eFigure 1E-H in the Supplement), as outlined in our schematic drawing (Figure 2D). In addition, SS-OCTA showed several globular lesions at baseline, consistent with the polypoidal lesions on ICGA. After photodynamic therapy, the SS-OCTA en face image showed a reduction in the size of the vascular tangles and BVN (eFigure 1I-J in the Supplement). Some polypoidal lesions appeared less vascular, and some disappeared on SS-OCTA. The vascular tangles were observed to recur 2 months after photodynamic therapy, and the tangled vascular structure seemed more distinct in some polypoidal lesions (eg, the polypoidal lesions numbered 1 and 2 in eFigure 1K in the Supplement). Four months after photodynamic therapy, denser vascular tangles were observed at the end of BVN and were associated with some newly formed lesions (eFigure 1L in the Supplement). This case demonstrated that polypoidal lesions resembled a lesion consisting of vascular tangles rather than a dilated pouch that arose from a vessel.

Patient 1
A 62-year-old man was diagnosed with PCV for 1 year and had received 1 ranibizumab (0.5-mg) injection 1 year previously. He experienced acute deterioration in the vision of
his right eye. Best-corrected visual acuity was 12/20 OD. Fundus examination revealed a reddish-orange lesion associated with a large macular PED (Figure 3A). Early-phase fluorescein angiography showed evidence of focal hyperfluorescence (eFigure 2A in the Supplement), and late-phase fluorescein angiography showed leakage with a smokestack configuration that suggested the diagnosis of active central serous chorioretinopathy (eFigure 2B in the Supplement). Indocyanine green angiography revealed focal hyperfluorescence with a BVN in the early frames (Figure 3B). The BVN and tangled vascular structures of polypoidal lesions were clearly seen on SS-OCTA before anti-VEGF treatment (Figure 3C). Two months after the second ranibizumab (0.5-mg) injection, SS-OCTA showed regression of the terminal vessels in the polypoidal lesions that appeared as a dilated vessel connected to the BVN (Figure 3D). This case showed that the polypoidal lesions consisted of tangled vessels, and anti-VEGF treatment was associated with regression of these tangled neovascular structures.

Patient 2
A 62-year-old man experienced acute visual loss from his left eye. Best-corrected visual acuity was 40/100 OS (treatment naïve). Fundus examination revealed multiple reddish-orange lesions in the temporal macula (eFigure 3A in the Supplement). Fluorescein angiography showed evidence of early focal hyperfluorescence with late leakage consistent with type 2 neovascularization (eFigure 3C-D in the Supplement). Indocyanine green angiography revealed focal hyperfluorescence in the early frame (eFigure 3E in the Supplement). Swept-source OCTA showed tangled vascular structures that corresponded to the polypoidal lesions seen on ICGA (eFigure 3G in the Supplement). Types 1 and 2 neovascularization and polypoidal lesions were seen when the boundary layers on the cross-sectional SS-OCTA B-scan transitioned from the top of the lesion to choroid (Figure 4). This case demonstrated that BVN and type 2 neovascularization coexisted in the same eye, and polypoidal lesions may have been derived from one or both of these neovascular lesions, as outlined in our schematic drawing (eFigure 3H in the Supplement).
Discussion

In the present study, SS-OCTA identified BVNs and polypoidal lesions in PCV better than ICGA, and SS-OCTA revealed the appearance of polypoidal lesions as tangled vascular structures that were associated with type 1 or type 2 neovascularization in patients with PCV. The observation that polypoidal lesions appear to be tangled vascular structures differs from the proposal that polypoidal lesions are aneurysmal dilatations of neovascular tissue and similar to aneurysms in the systemic circulation.5,19 Several independent clinicopathological investigations11,20-22 have shown that polypoidal lesions of PCV were vascular in nature and speculated that the polypoidal lesions arose directly from the inner choroidal circulation. However, the single aneurysmal structure has not been definitely detected in most of the histopathologic examinations.22,23 Our OCTA observations suggest that the polypoidal lesions on ICGA were part of the neovascular complex. Most of the polypoidal lesions were found to consist of tangled vessels, such as a glomerular-type lesion, rather than a single aneurysm. The findings are consistent with the cluster-like structure reported in the study of Chan et al.9(p1190) in which they observed that “the polypoidal lesion showed a cluster-like shape in the OCTAs.” Because of the relative lower image quality of SD-OCTA, they were unable to describe more detailed information about the polypoidal lesions. Yuzawa et al21 reported “internal IGA findings of polypoidal lesions” that included microaneurysmal dilatations, large aneurysmal dilatations, and large vessel deformations, which suggest that polypoidal lesions have different variants in nature. We also observed variants of polypoidal lesions on SS-OCTA; the flow signal from the polypoidal lesions appeared consistent with that of abnormally tangled vessels that could be focally dilated and form loose or dense globular structures, presenting different shapes and sizes.

The polypoidal lesions also appeared to respond to anti-VEGF therapy and decrease in size and complexity (Figure 3), which also is consistent with the observations by others that some polypoidal lesions disappeared after anti-VEGF

Figure 3. Multimodal Imaging in Patient 1

A, The fundus photograph shows an orange-red polypoidal lesion (arrowhead). B, Early-phase indocyanine green angiography shows a focal polypoidal lesion (arrowhead) and branching vascular network (BVN). C, Swept-source optical coherence tomographic angiography (SS-OCTA) shows BVN (pink arrowheads) and a polypoidal lesion (yellow arrowhead) that appear as tangled vessels before anti–vascular endothelial growth factor treatment. D, Two months after the second ranibizumab injection, SS-OCTA shows regression of the terminal vessels in the polypoidal lesion (yellow arrowhead) and appears as tangled dilated vessels connected to the BVN (pink arrowheads).
This finding is consistent with the observations that in neovascular age-related macular degeneration, the complexity of the neovascularization diminishes after anti-VEGF therapy, whereas the larger, more mature vessels are unchanged. Moreover, aneurysms would not be expected to respond to anti-VEGF treatment, whereas a tangle of new vessels is likely to respond. Perhaps SS-OCTA of polypoidal lesions will provide important clues about classifying polypoidal lesions as active or quiescent in PCV, and the vascular complexity of these polypoidal lesions may provide prognostic indications of whether they will respond to anti-VEGF therapy or recur after treatment.

The belief that polypoidal lesions represented pouchlike or aneurysmlike lesions is based on the phenomenon of dye washout and pulsatile or turbulent blood flow that was observed on ICGA. However, these features could also be found within a tangled vascular structure. Moreover, the tangled vessels were seen in all polypoidal lesions, whereas the ICGA phenomenon described above was not observed in all polypoidal lesions, indicating that polypoidal lesions are not a uniform entity but have a variety of configurations. We propose that the variability is in the complexity of the neovascular tangles, not in the configuration of the aneurysms. In addition, Yuzawa et al. and Watanabe et al. showed that the BVNs and polypoidal lesions arise from the choroidal vasculature; thus, the thinner-walled dilated vessels within the polypoidal lesions may display pulsatile blood flow. We also found that the tangled vessels appeared to be derived from the existing BVNs and were arranged in a ring or whorl pattern or in a cluster or bunch-of-grapes pattern. The ring pattern would be consistent with the views of Yuzawa et al. that the tangled vessels would be visible as a ring of hyperfluorescence on ICGA as the dye intensity fades from the central lumens during the washout period. Finally, we also support the notion of turbulent flow within these tangled vessels because of the presence of dilated vessels of varying caliber. The presence of vascular dilation and changes in vascular caliber and direction within the tangled vascular networks may contribute to turbulent flow.

Previous SD-OCT and postmortem studies have located polypoidal lesions above the Bruch membrane and beneath the RPE. We identified all the polypoidal lesions consisting of tangled vessels as located between the Bruch membrane and RPE layer at the margins of the BVNs (type 1 neovascularization) in 40 cases (93%) and at the margins of type 2 neovascularization in 3 cases (7%). This supported the findings by Liang et al. that BVN and type 2 neovascularization can coexist in the same eye with PCV. We also observed that polypoidal lesions coexisted with types 1 and 2 neovascularization in the same eye, which further suggests that polypoidal lesions are neovascular structures, rather than unique aneurysmal variations of type 1 neovascularization.

To date, the criterion standard for the diagnosis of PCV has been ICGA, which we now question, given the findings of several studies in which the detectability of BVNs was better with OCT. In the present study, SS-OCTA was better than ICGA.
for the detection of polypoidal lesions. A total of 43 polypoidal lesions were counted on ICGA, and all the lesions could be overlapped with the vascular tangles corresponding to polypoidal lesions seen on SS-OCTA. Moreover, 16 additional tangled vascular structures, which corresponded to the peaked or notched PEDs connected to flat irregular PEDs on OCT B-scans, were detected by SS-OCTA. As a result, SS-OCTA may be more sensitive for the detection of polypoidal lesions in PCV than ICGA, and, if confirmed by others, SS-OCTA might be considered the new criterion standard for the diagnosis and monitoring of PCV.

Limitations
The present study has several limitations that include its cross-sectional nature and a relatively small sample of patients. In addition, not all the patients whom we recruited were treatment naive, and others had heterogeneous treatment histories. Moreover, studies are needed to confirm our findings and determine whether this phenotype correlates with certain PCV genotypes or certain underlying medical diagnoses.

Conclusions
Using a commercialized SS-OCTA platform, we examined the tangled vascular blood flow properties of polypoidal lesions in patients with PCV. We found that polypoidal lesions consisted of densely or loosely tangled vascular structures at the margins of BVNs or type 2 neovascularization, consistent with the proposal that polypoidal lesions are a form of neovascularization rather than an aneurysmal structure. Further studies are needed to confirm our findings and better characterize the evolution, natural history, and response to therapy of these different tangled vascular structures in PCV using SS-OCTA.

REFERENCES
Polypoidal choroidal vasculopathy (PCV) is a clinical syndrome with unique indocyanine green angiography (ICGA) features of typical nodular hyperfluorescence that was initially thought to be an intrachoroidal vascular abnormality. Confoveal scanning laser ophthalmoscopic ICGA has shown that the associated branching vascular network (BVN) is similar to occult choroidal neovascularization angiographically. The advent of spectral-domain optical coherence tomography findings in polypoidal choroidal vasculopathy suggest a type 1 neovascular growth pattern. Clini Ophthalmol. 2014;8:1689-1695. doi:10.2147/OPTH.2014.8.76471


EYEDART STUDY 17 has highlighted the phenotypic significance of this subtype of CNV. Prompt treatment of PCV among Asian patients with combination verteporfin photodynamic therapy and ranibizumab therapy achieved better visual outcomes at 12 months while requiring fewer ranibizumab injections. 1 The result is significantly different from those of the Mont Blanc 18 and Denali 19 studies, in which the addition of verteporfin photodynamic therapy to ranibizumab therapy did not improve the visual outcome of choroidal neovascularization treatment. Even then, a wide range of responses occurred among eyes with PCV in the ranibizumab monotherapy arm: 34.4% of patients achieved complete polyp regression, and 58.8% achieved visual acuity of 69 letters (approximately 20/40 Snellen). 1

Several authors have suggested that different subtypes may exist within the case definition of PCV. Studies 4-5 have described subtypes based on the BVN characteristics. Type A PCV had a much better visual prognosis than type C PCV (odds ratio, 53.7) in a retrospective study of 107 patients. 4 Among patients in the EVEREST study, patients with types A and B PCV achieved better visual outcomes than those with type C PCV. 5

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Polypoidal choroidal vasculopathy is a clinical syndrome with unique indocyanine green angiography (ICGA) features of typical nodular hyperfluorescence that was initially thought to be an intrachoroidal vascular abnormality. Confoveal scanning laser ophthalmoscopic ICGA has shown that the associated branching vascular network (BVN) is similar to occult choroidal neovascularization angiographically. The advent of spectral-domain optical coherence tomography findings in polypoidal choroidal vasculopathy suggest a type 1 neovascular growth pattern. Clini Ophthalmol. 2014;8:1689-1695. doi:10.2147/OPTH.2014.8.76471


EYEDART STUDY 17 has highlighted the phenotypic significance of this subtype of CNV. Prompt treatment of PCV among Asian patients with combination verteporfin photodynamic therapy and ranibizumab therapy achieved better visual outcomes at 12 months while requiring fewer ranibizumab injections. 1 The result is significantly different from those of the Mont Blanc 18 and Denali 19 studies, in which the addition of verteporfin photodynamic therapy to ranibizumab therapy did not improve the visual outcome of choroidal neovascularization treatment. Even then, a wide range of responses occurred among eyes with PCV in the ranibizumab monotherapy arm: 34.4% of patients achieved complete polyp regression, and 58.8% achieved visual acuity of 69 letters (approximately 20/40 Snellen). 1

Several authors have suggested that different subtypes may exist within the case definition of PCV. Studies 4-5 have described subtypes based on the BVN characteristics. Type A PCV had a much better visual prognosis than type C PCV (odds ratio, 53.7) in a retrospective study of 107 patients. 4 Among patients in the EVEREST study, patients with types A and B PCV achieved better visual outcomes than those with type C PCV. 5