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Ophthalmic Artery Flow Pattern-related Stump Pressure and Ischemic Tolerance during Balloon Test Occlusion of the Internal Carotid Artery

Nobuyuki Izutsu,[1] Takeo Nishida,[1] Masatoshi Takagaki,[1] Tomohiko Ozaki,[1] Tomofumi Takenaka,[1] Shuhei Kawabata,[1] Yuichi Matsui,[1] Shuhei Yamada,[1] Eisaku Terada,[1] Hajime Nakamura,[1] and Haruhiko Kishima[1]

[1]*Department of Neurosurgery, Osaka University Graduate School of Medicine, Suita, Osaka, Japan*

Abstract

Very few studies have described the blood flow pattern in the ipsilateral ophthalmic artery (OphA) during internal carotid artery (ICA) balloon test occlusion performed to estimate the risk of cerebral ischemia associated with therapeutic ICA sacrifice. This study aimed to investigate the relationship between ipsilateral OphA flow patterns just after ICA temporary occlusion and balloon test occlusion findings. We retrospectively reviewed 32 balloon test occlusion procedures performed at our institution between 2010 and 2019, and analyzed the OphA flow patterns and the conventional balloon test occlusion assessment items: neurological symptoms, stump pressure, stump-pressure ratio, collateral circulations, and venous phase delay. The flow patterns were categorized as type I (retrograde flow reaching the middle cerebral artery [MCA]), type II (retrograde flow to the ICA not reaching the MCA), or type III (no retrograde flow). Tolerance to balloon test occlusion was observed in 4/21 patients (19.0%), 4/6 patients (66.7%), and all five patients with types I, II, and III flows, respectively. The mean pressure ratios during balloon test occlusion in flow types I, II, and III were 35.6% ± 3.5%, 56.4% ± 6.5%, and 69.4% ± 7.1%, respectively (*P* <0.001). The mean stump pressures in flow types I, II, and III were 36.2 ± 3.6 mmHg, 46.6 ± 6.7 mmHg, and 66.6 ± 7.3 mmHg, respectively (*P* = 0.003). The mean venous phase delay in flow types I, II, and III were 0.99 ± 0.14 s, 0.25 ± 0.25 s, and 0.0 ± 0.28 s, respectively (*P* = 0.004). All the above variables showed significant flow-related differences. These results suggest that the OphA flow patterns may provide an additional diagnostic criterion for balloon test occlusion.

Keywords: balloon test occlusion, ophthalmic artery flow pattern

Introduction

Balloon test occlusion (BTO) is a presurgical test to estimate the risk of cerebral ischemia associated with therapeutic internal carotid artery (ICA) sacrifice in patients with ICA aneurysms or tumors in the neck or skull base. Temporary ICA occlusion for 10–30 min with only neurological monitoring is insufficient to estimate the risk of delayed cerebral ischemia after ICA sacrifice.[1] Consequently, additional examinations have been proposed to improve sensitivity, including stump-pressure measurement,[2,3] venous phase delay measurement,[4] perfusion tests,[5–7] electrophysiological tests including electroencephalography[8] and measurement of somatosensory evoked potentials,[9] transcranial Doppler ultrasonography,[10] and near-infrared spectroscopy.[11] However, the BTO procedure and the evaluation criteria for its results remain controversial and vary among facilities.

BTO is an invasive test associated with thromboembolic complications of 0.8–6.0%,[12–16] partly due to the prolonged ICA occlusion. To reduce the complication rate, we focused on determination of the ophthalmic artery (OphA) flow direction just after ICA temporary occlusion because OphA flow

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direction might be associated with intracranial collateral perfusion.[17)]

The objective of this study was to investigate the relationship between ipsilateral OphA flow patterns just after ICA temporary occlusion and BTO findings.

Materials and Methods

This study was approved by the institutional review board of Osaka University Hospital (approval No. 19220). Considering the retrospective nature of the study and the use of anonymized patient data, the requirement for informed consent was waived.

Study design and patients

Between January 2010 and June 2019, 41 patients underwent ICA BTO at Osaka University Hospital. Of these 41 patients, nine were excluded because of a lack of ipsilateral common carotid artery (CCA) angiography data during BTO in six patients, undetected antegrade OphA flow on ICA angiography in two patients, and incomplete medical records in one patient. Thus, we retrospectively evaluated the relationship between BTO results and OphA flow findings in 32 patients.

BTO procedure

BTO was performed using a biplane neuro X-ray system (Allura Xper FD 20/20; Philips Healthcare, Best, The Netherlands) under local anesthesia. Intravenous heparin was administered for systemic heparinization with a target-activated clotting time of 300 s during the procedure, after placement of a 5-Fr sheath introducer in both common femoral arteries. A 5-Fr double-lumen balloon catheter (Selecon; Terumo Clinical Supply, Gifu, Japan) was placed in the cervical portion of the ICA after diagnostic angiography. While the ICA was occluded for up to 20 minutes, the patient underwent neurological evaluation (consciousness, speech, grip, and ankle movement), stump-pressure measurement, systemic blood pressure measurement, and angiographic collateral flow evaluation. When the patient showed a change in neurological status, the procedure was immediately terminated. The stump pressure at the distal end of the inflated balloon catheter and the systemic blood pressure were recorded at 5-min intervals. Immediately after ICA occlusion with balloon inflation, approximately 3 mL of contrast medium (iopamidol, 300 mgI/mL [OYPALOMIN; Fuji Pharma, Toyama, Japan]) was manually injected slowly through a 4-Fr diagnostic catheter (Performa; Merit Medical, South Jordan, UT, USA) placed in the ipsilateral CCA to confirm complete occlusion of the ICA and to assess OphA flow during ICA occlusion. Angiography of the contralateral CCA and the unilateral vertebral artery (VA) was performed provided that the patient was neurologically intact during the BTO.

Diagnostic criteria for BTO

Ischemic tolerance during BTO was evaluated on the basis of neurological symptoms and the stump-pressure ratio, which is defined as mean stump pressure/mean systemic blood pressure. The patients were considered "tolerant" to ischemia during BTO only if they showed no neurological change during the 20-min temporary ICA occlusion and their stump-pressure ratio was more than 50%. For all other cases, we assessed the patients as "intolerant."

Classification of OphA flow types

We classified the OphA flow findings into three different types on the basis of the ipsilateral CCA angiogram during BTO. The OphA flow types were defined as follows: (Fig. 1) type I, retrograde OphA flow reaching the middle cerebral artery (MCA) territory; type II, retrograde OphA flow that did not reach the MCA territory but showed contrast medium pooling in the proximal ICA; and type III, no retrograde OphA flow on the ipsilateral CCA angiogram during BTO.

Collateral circulation and venous phase delay

Collateral circulation and venous phase delay were also evaluated. Collateral blood flow via the anterior communicating artery (AcomA) and the posterior communicating artery (PcomA) were graded on a 5-point scale, which was based on the visualization of the anterior cerebral artery (ACA) and the MCA on the tested side by the collateral blood flow.[18)] According to established anatomical segment of each artery,[19)] it was graded as A1-4 for the ACA and M1-4 for the MCA; it was graded as A0/M0 when each artery was not visualized. Venous phase delay was defined as a delayed opacification of cortical veins on the tested side compared with that on the contralateral side.[4)]

Statistical methods

Statistical analyses were performed using JMP 14 (SAS Institute inc., Cary, NC, USA). Numerical data were expressed as mean ± SE. Continuous data were analyzed using one-way ANOVA with a multiple-comparison post-hoc test using the Tukey–Kramer method. Group comparisons of categorical data were analyzed using a Fisher's exact test. For all statistical analyses, a P value of less than 0.05 was considered statistically significant.

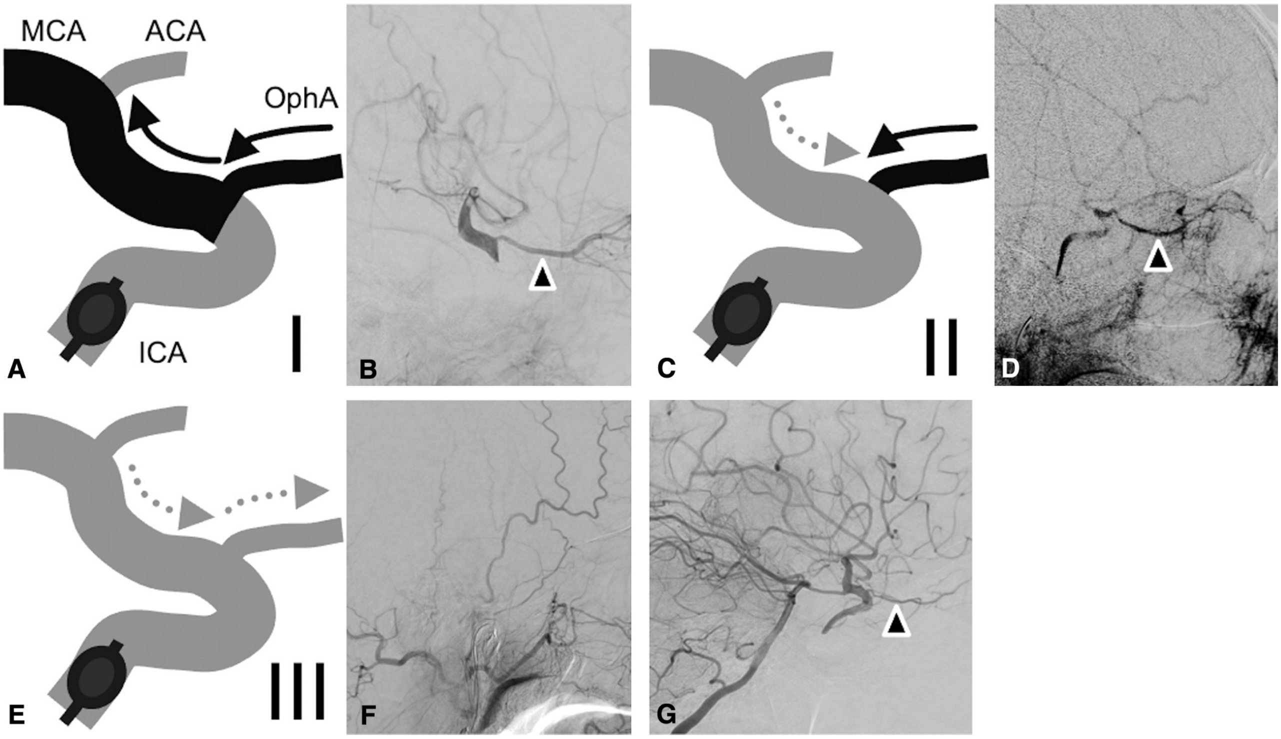

Fig. 1 Classification of OphA flow patterns during balloon test occlusion. Drawings and angiographic images showing the different types of OphA flow patterns (arrowheads). Black represents contrast agent filling. Type I: retrograde flow of the OphA reaching the MCA (A and B). Type II: retrograde flow of the OphA not reaching the MCA and pooling within the proximal ICA (C and D). Type III: OphA not showing opacification on an external artery angiogram (E and F). In a case with type III flow, the antegrade OphA is opacified via the PcomA on VA angiogram (G). ACA: anterior cerebral artery, ICA: internal carotid artery, MCA: middle cerebral artery, OphA: ophthalmic artery, PcomA: posterior communicating artery, VA: vertebral artery.

Results

Patient characteristics and BTO results are summarized in Table 1. We found no significant intergroup differences in patient characteristics between OphA flow types. The most common type of OphA flow was type I (n = 21; 65.6%), followed by type II (n = 6; 18.8%), and type III (n = 5; 15.6%).

The pressure ratios during BTO in type I, type II, and type III flows were 35.6% ± 3.5%, 56.4% ± 6.5%, and 69.4% ± 7.1%, respectively, with significant differences between the groups (P <0.001, Fig. 2A). In addition, the mean stump pressures in types I, II, and III were 36.2 ± 3.6 mmHg, 46.6 ± 6.7 mmHg, and 66.6 ± 7.3 mmHg, respectively, with significant differences between the three types (P = 0.003, Fig. 2B).

Three patients (14.3%) with type I flow developed a transient neurological change during BTO: two of them showed impaired consciousness and the third showed hemispatial neglect (Fig. 3). However, all patients with type II and III flows were neurologically intact during the 20-min ICA occlusion. The number of patients with a stump–pressure ratio less than 50% in the type I, type II, and type III groups was 17, 2, and 0, respectively. On the basis of our criteria, the number of patients who were assessed as intolerant in the type I, type II, and type III groups was 17 (81.0%), 2 (33.3%), and 0 (0%), respectively, with significant differences between the groups (P <0.001).

Angiography of the contralateral CCA and the unilateral VA was completed in 30 patients (93.8%). All of them had a good collateral blood flow via AcomA to the tested side A4 segment of the ACA. The grade of the collateral blood flow to the tested side MCA territory via the AcomA or PcomA was varied, but there was no significant difference between the groups (P = 0.73 and 0.56 for via AcomA and PcomA, respectively).

Of the five patients with type III flow, four had antegrade OphA flow via the PcomA on VA angiography during BTO, and one showed no contrast filling in the OphA on the CCA or VA angiogram during BTO. None of the patients showed any complications associated with BTO.

Table 1 Patient characteristics and balloon test occlusion results

Case number	Age (year) /sex	Diagnosis	Tested side	OphA flow pattern	Neurological symptom	Mean systemic blood pressure	
						Before occlusion (mmHg)	At 20min occlusion (mmHg)
1	74/F	ICA aneurysm	Right	I	Impaired consciousness at 5min	91.0	84.0*
2	77/F	ICA aneurysm	Right	I	Hemispatial neglect at 20 min	87.0	88.7*
3	73/F	ICA aneurysm	Right	I	No	92.0	93.3
4	57/F	ICA aneurysm	Left	I	No	95.3	93.3
5	61/F	Neck tumor	Right	I	Impaired consciousness at 3min	98.7	103.7*
6	64/M	ICA aneurysm	Left	I	No	76.3	81.7
7	66/F	ICA aneurysm	Right	I	No	135.3	121.0
8	58/M	ICA aneurysm	Left	I	No	137.3	147.0
9	53/F	ICA aneurysm	Right	I	No	85.7	87.0
10	58/F	Neck tumor	Left	I	No	126.0	130.0
11	50/F	ICA aneurysm	Right	I	No	85.7	89.0
12	45/M	Neck tumor	Left	I	No	89.0	97.7
13	54/F	Neck tumor	Left	I	No	123.0	120.7
14	34/F	Neck tumor	Right	I	No	82.3	86.0
15	61/M	Neck tumor	Left	I	No	89.7	102.3
16	66/F	ICA aneurysm	Left	I	No	83.0	96.7
17	79/F	Neck tumor	Left	I	No	103.3	115.0
18	42/F	Neck tumor	Left	I	No	119.3	114.7
19	60/F	ICA aneurysm	Right	I	No	81.7	80.0
20	60/M	Neck tumor	Left	I	No	84.3	85.3
21	71/F	ICA aneurysm	Right	I	No	96.3	105.7
22	48/F	Neck tumor	Left	II	No	94.0	85.0
23	62/F	Neck tumor	Right	II	No	88.0	94.0
24	79/F	ICA aneurysm	Right	II	No	89.7	87.3
25	22/M	Neck tumor	Right	II	No	83.3	92.7
26	52/F	Neck tumor	Right	II	No	67.3	60.7
27	68/F	Neck tumor	Right	II	No	72.3	81.3
28	51/F	Neck tumor	Left	III	No	88.7	98.3
29	48/M	ICA dissection	Left	III	No	91.7	91.7
30	37/M	Neck tumor	Left	III	No	107.0	100.0
31	74/M	Neck tumor	Right	III	No	85.3	102.3
32	64/F	ICA aneurysm	Left	III	No	93.0	89.3

AcomA: anterior communicating artery, BTO: balloon test occlusion, ICA: internal carotid artery, n/a: not available, OphA: ophthalmic artery, PcomA: posterior communicating artery, STA-MCA: superficial temporal artery-middle cerebral artery.
*A value measured at reperfusion due to the neurological change.

Mean stump pressure at 20min occlusion (mmHg)	Pressure ratio (%)	Result of BTO	Collateral blood flow		OphA blood flow		Venous phase delay (sec)	Treatment
			via AcomA	via PcomA	via AcomA	via PcomA		
7.0*	8.3	Intorelant	A4M1	n/a	No	n/a	n/a	Observation
15.3*	17.0	Intorelant	A4M0	A0M4	No	No	0.0	ICA conserving surgery
17.3	18.6	Intorelant	A4M4	A0M1	No	No	1.3	ICA conserving surgery
17.3	18.6	Intorelant	A4M4	A0M1	No	No	2.3	Observation
22.3*	21.5	Intorelant	n/a	n/a	n/a	n/a	n/a	ICA conserving surgery
17.7	21.6	Intorelant	A4M4	A0M1	No	No	1.8	ICA occlusion with STA-MCA bypass
28.3	23.4	Intorelant	A4M4	A0M2	No	No	1.0	ICA conserving surgery
41.3	28.1	Intorelant	A4M4	A0M4	No	No	0.3	ICA conserving surgery
26.7	30.7	Intorelant	A4M2	A0M4	No	No	1.0	ICA occlusion with STA-MCA bypass
43.3	33.3	Intorelant	A4M3	A0M3	No	No	2.3	ICA conserving surgery
30.0	33.7	Intorelant	A4M4	A0M0	No	No	0.7	ICA conserving surgery
34.3	35.2	Intorelant	A4M4	A0M2	No	No	1.0	ICA occlusion with STA-MCA bypass
45.3	37.6	Intorelant	A4M4	A0M1	No	No	0.7	ICA conserving surgery
34.0	39.5	Intorelant	A4M4	A0M3	No	No	0.3	ICA conserving surgery
44.0	43.0	Intorelant	A4M4	A0M2	No	No	1.3	Observation
41.7	43.1	Intorelant	A4M4	A0M3	No	No	1.0	ICA conserving surgery
54.0	47.0	Intorelant	A4M3	A0M4	No	No	1.0	ICA conserving surgery
58.7	51.2	Tolerant	A4M4	A0M2	No	No	0.3	ICA conserving surgery
41.0	51.3	Tolerant	A4M3	A0M4	No	No	0.0	ICA conserving surgery
52.0	60.9	Tolerant	A4M4	A0M1	No	No	0.3	ICA conserving surgery
89.0	84.2	Tolerant	A4M1	A0M4	No	No	2.3	ICA occlusion alone
39.3	46.3	Intorelant	A4M3	A0M4	No	No	0.7	ICA conserving surgery
46.7	49.6	Intorelant	A4M4	A0M4	No	No	0.5	ICA conserving surgery
47.0	53.8	Tolerant	A4M4	A0M1	No	No	0.3	ICA conserving surgery
53.3	57.6	Tolerant	A4M3	A0M4	No	No	0.0	ICA conserving surgery
39.7	65.4	Tolerant	A4M4	A0M4	No	No	0.0	ICA conserving surgery
53.3	65.6	Tolerant	A4M0	A0M4	No	No	0.0	ICA conserving surgery
50.7	51.5	Tolerant	A4M4	A0M4	No	Yes	0.0	ICA conserving surgery
56.7	61.8	Tolerant	A4M4	A0M4	No	Yes	0.0	ICA conserving surgery
68.3	68.3	Tolerant	A4M4	A0M1	No	Yes	0.0	ICA conserving surgery
74.0	72.3	Tolerant	A4M1	A0M4	No	Yes	0.0	ICA conserving surgery
83.3	93.3	Tolerant	A4M4	A0M4	No	No	0.0	ICA conserving surgery

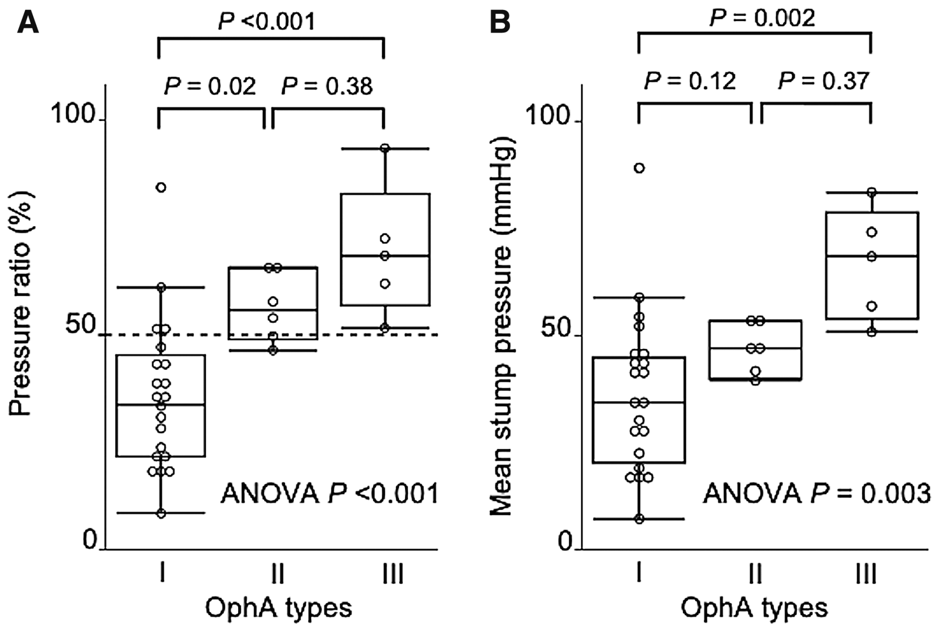

Fig. 2 Distribution of OphA flow patterns and pressure ratio, and mean stump pressure. The pressure ratio in patients with type I flow was significantly lower than that in patients with type II and III flows (A). Mean stump pressure was significantly lower in patients with type I flow than in those with type III flow (B). ANOVA: analysis of variance, OphA: ophthalmic artery.

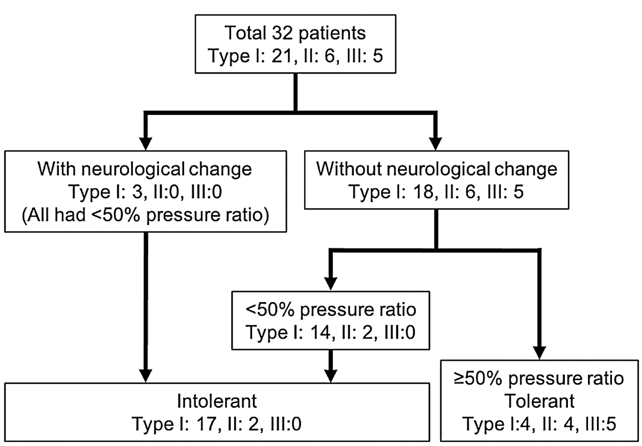

Fig. 3 Balloon test occlusion results of the patients

The mean delay time in the venous phase in type I, II, and III flows was 0.99 ± 0.14 s, 0.25 ± 0.25 s, and 0.0 ± 0.28 s, respectively, with significant differences between the groups (P = 0.004, Fig. 4). No venous phase delay was observed in patients with type III flow type.

Discussion

This study yielded two important clinical observations. First, all patients without retrograde OphA flow during ICA temporary occlusion were tolerant to ischemia during BTO. Second, the OphA flow patterns during BTO were correlated with the mean stump pressure, pressure ratio, and venous phase delay.

In the present study, we focused on identification of the OphA flow pattern immediately after ICA temporary occlusion because the OphA flow direction during BTO presumably depends on intracranial collateral perfusion. In other words, we presumed that, in patients with poor intracranial collateral perfusion via the AcomA and PcomA, retrograde OphA flow might occur intracranially to support the insufficient intracranial collateral perfusion because the collateral perfusion pressure via AcomA and PcomA is lower than the retrograde OphA pressure.[17] In cases with rich intracranial collateral perfusion, a retrograde OphA flow might not be visible because the collateral perfusion pressure via AcomA and PcomA is higher than the retrograde OphA pressure. Therefore, we investigated the relationships among OphA flow patterns, BTO tolerance, and stump pressures during BTO.

In the current study, the stump pressure and stump-pressure ratio in the type III OphA flow pattern were higher than those in type I and II patterns. Since none of the patients with the type III pattern developed neurological changes or showed stump-pressure ratios lower than 50%, a

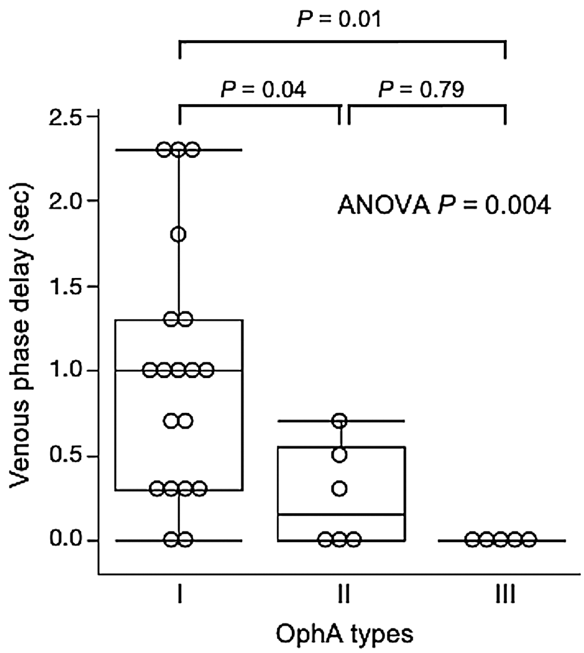

Fig. 4 Distribution of OphA flow patterns and venous phase delay time. The venous phase delay in patients with type I flow was significantly longer than that in patients with type II and III flows. ANOVA: analysis of variance, OphA: ophthalmic artery.

type III OphA flow pattern might be a predictor of BTO tolerance. On the other hand, the stump-pressure ratios in types I and II were widely distributed (below 50% in some patients), although none of the patients with the type II pattern developed neurological changes. Particularly, one patient with type I (case 21) had relatively high stump-pressure ratio and good collateral blood flow. Thus, type I or II OphA flow patterns could not predict BTO outcomes. Venous phase delay was also associated with OphA flow types. No venous phase delay was observed in patients with type III flow, which was consistent with the BTO result. It is assumed that the OphA flow pattern reflects the intracranial collateral blood flow condition; however, correlations between angiographical collateral blood flow and OphA flow patterns were not found. In this study, most patients had good angiographical collateral blood flow. However, strict evaluation of the comprehensive collateral circulation is difficult, which might have affected these results.

Consistent with the current study, a retrograde OphA flow was considered as a marker of insufficient collateral cerebral blood flow in a previous investigation.[17] Extension of hemispheric circulation time during BTO in patients with collateral circulation via OphA has been reported.[20]

Apart from the increase in BTO sensitivity, a reduction in BTO-associated complication rate is important. The thromboembolic complication rate associated with BTO was reported to be 0.8%–6.0%.[12–16] In most facilities, a 20-min temporary ICA occlusion is performed to evaluate the neurological symptoms during BTO. Our findings suggest that patients with type III OphA flow can avoid this 20-min temporary ICA occlusion. Our classification was based on the OphA flow patterns during BTO, which were obtained by ipsilateral CCA angiography immediately after ICA occlusion. Therefore, if type III OphA flow is confirmed, the BTO may be terminated immediately, possibly reducing the risk of thromboembolic complications associated with prolonged ICA occlusion. A few other reports have mentioned methods to avoid the complications associated with BTO. These include studies providing prediction scores based on the MRA findings for the BTO results, which proposed that patients with obvious anterior collateral circulation on MRA could be omitted from the BTO.[21] On conventional angiographies with the Matas and Alcock maneuver, the presence of collateral blood flow via AcomA predicted no neurological change during 20-min BTO.[18] X-ray angiography perfusion analysis, which was obtained by aortography during BTO, may also reduce the occlusion duration.[22]

Lastly, the absence of an anastomosis between the ECA and OphA should be considered. In these patients, retrograde OphA flow via the ECA could not be recruited. Although the patients were classified in the type III OphA flow, which was not associated with their BTO results. The prevalence of an anastomosis between ECA and OphA was reported to be 85.7%–92.9%.[23–25] A previous brief report concluded that the presence or absence of retrograde OphA flow does not predict the patient's ischemic tolerance during BTO.[26] However, this conclusion was based on only one intolerant patient without retrograde OphA flow, whose ECA-OphA anastomosis or OphA origin was not depicted. In the present study, all patients showing type III flow were neurologically intact and had higher stump-pressure ratios during BTO. When the anastomosis between the ECA and OphA is absent, the stump-pressure ratio during BTO might be lower, even in patients with type III OphA flow. Therefore, in patients with type III OphA flow and a higher stump-pressure ratio, we might be able to assess the BTO result as "tolerant" immediately.

This study has some limitations. First, this study only included a small number of patients and was a retrospective study from a single institute. Second, we were not able to correlate the OphA flow pattern with cerebral perfusion images because we only measured the stump-pressure ratio and neurological status during BTO. Lastly, our BTO criteria and the obtained results are not well validated, because only one patient treated with ICA occlusion alone. However, the validity of our primary observations is that all patients without retrograde OphA flow during ICA temporary occlusion were tolerant to ischemia during BTO, and that the OphA flow patterns during BTO correlated to the mean stump pressure, pressure ratio, and venous phase delay.

Conclusion

In this study, all patients without retrograde OphA flow during ICA temporary occlusion showed tolerance to ischemia during BTO. OphA flow patterns during BTO were correlated with the mean stump pressure, stump-pressure ratio, and venous phase delay. The OphA flow patterns may provide an additional diagnostic criterion for balloon test occlusion. Further studies are warranted to confirm the results of this study and to improve the BTO method.

Conflicts of Interest Disclosure

The authors have no conflict of interest to disclose.

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Corresponding author: Takeo Nishida, MD, PhD
Department of Neurosurgery, Osaka University Graduate School of Medicine, 2-2 Yamadaoka, Suita, Osaka 565-0871, Japan.
e-mail: takeo.nishida@nsurg.med.osaka-u.ac.jp