Multimodal Assessment for Balloon Test Occlusion of the Internal Carotid Artery

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Objective: Permanent therapeutic occlusion of the carotid artery is one of the treatment options for patients with a large/giant internal carotid artery aneurysm or tumor involving the neck or skull base. Balloon test occlusion (BTO) is performed to predict the tolerance of parent artery occlusion (PAO). The authors combined various modalities to improve the sensitivity of BTO. The purpose of this study is to present the efficacy of the multimodal BTO.

Methods: Between January 2008 and September 2014, a total of 50 patients (internal carotid aneurysms: 39, neck or skull base tumor: 8, others: 3; mean 58.4 years, range 7–81 years; 10 men and 40 women) underwent multimodal BTO. Tolerance of PAO was evaluated by the algorithm with various assessment modalities including neurological symptoms with/without induced hypotension, findings of angiogram (collateral flow, venous phase laterality), perfusion CT, and stump pressure. Clinical data of patients with BTO were analyzed retrospectively. Procedures were performed in the angio/CT combination suite. BTO was performed in the usual fashion and when the patient passed the immediate test occlusion, perfusion CT was performed. Subsequently, the angiogram under balloon inflation followed. If the patient did not show neurological symptoms for 20 min, hypotension was induced by intravenous injection of the vasodilator. Neurological symptoms were then checked for more than 30 min.

Results: By multimodal assessment of BTO, 33 patients were considered tolerable, six were partially tolerable, and 11 were intolerable. Thirteen of 33 patients with predictive tolerance underwent PAO without bypass, and all but one showed no hemodynamic ischemia postoperatively. Three of six patients with predictive partial tolerance were treated by PAO with extracranial-intracranial bypass, and they experienced no hemodynamic ischemia. In contrast, one with predictive partial tolerance treated by PAO without bypass developed ischemic events as feared.

Conclusion: The multimodal BTO is helpful to evaluate the tolerance of PAO and is a reliable predictor of postoperative ischemic events. It reduces risks and increases treatment safety for permanent therapeutic occlusion of the carotid artery.

Keywords ► balloon test occlusion, internal carotid artery, multimodal

Introduction

Parent artery occlusion (PAO) of the internal carotid artery (ICA) is one of the treatment options for large/

giant or thrombosed internal carotid aneurysms. Balloon test occlusion (BTO) is performed to evaluate the ischemic tolerance associated with therapeutic internal carotid artery occlusion and the necessity of bypass surgery.¹⁾ BTO is also performed when there is the possibility of vascular resection or occlusion in the process of surgery for malignant tumors involving the neck or skull base and surgery for carotid body tumors.²⁾ However, the procedure of BTO and the method for the evaluation of its results are not standardized and vary among facilities. At our facility, the tolerance to BTO is evaluated by combining multiple evaluation methods. BTO based on multimodal assessment at our facility and its results are reported.

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Fig. 1 Multimodal assessment algorithm for balloon test occlusion of internal carotid artery.

Material and Methods

Subjects

The results of BTO of the internal carotid artery performed in 50 patients during the 7 years between 2008 and 2014 were analyzed retrospectively. The subjects were 10 males and 40 females aged 7–81 (mean $\pm$ SD: 58.4 ± 16.7) years. The target diseases were internal carotid aneurysm in 39, cervical aneurysm/cervical tumor in eight, skull base tumor in one, and carotid-cavernous sinus fistula in one. The severity of neurological complications was evaluated according to the modified Rankin Scale (mRS) 2 months after the treatment.

Procedure of BTO

BTO was performed under local anesthesia without using sedatives, in principle, for accurate neurological evaluation. A balloon catheter for ICA occlusion was inserted via the femoral artery, and a diagnostic catheter for angiography during occlusion was inserted via the brachial artery. A 5Fr double-lumen catheter (Selecon MP Catheter, Terumo Clinical Supply Co., Ltd., Gifu, Japan) was used as the balloon catheter for occlusion. Basically, the balloon catheter was guided to the cervical ICA, and BTO was performed in the cervical region. Depending on the access route, presence of plaque in the carotid artery, and degree of tortuosity of the ICA, the cervical ICA was temporarily occluded using PercuSurge GuardWire (Medtronic, Santa Rosa, CA, USA) as a substitute.³⁾ Except in early cases, if the persistent primitive artery was present, the furcation of the persistent primitive artery or more distal part of the ICA was occluded using a micro-balloon catheter (HyperForm/HyperGlide, Covidien, Irvine, CA, USA) in addition to

occlusion of the cervical ICA using a balloon catheter. If no neurological symptoms were observed immediately after balloon occlusion of the ICA, angiography and perfusion CT were carried out as imaging evaluation. During ICA occlusion, angiography of the contralateral common carotid artery (CCA), ipsilateral CCA (practically external carotid artery, because the ICA was occluded), and vertebral artery was performed to examine the presence or absence of collateral blood flows, and the hemodynamics was evaluated.

The procedure of perfusion CT at our facility is outlined. CT was performed using TOSHIBA AREX-VT800A/Asterion 4 Multi-slice (Toshiba Medical Systems, Tochigi, Japan). It is a so-called angio-CT system, in which a CT system is installed in the cerebral angiography suite.^{4,5)} The analytical software was Perfusion Mismatch Analyzer (PMA) (ASIST-Japan). The cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and time to peak (TTP) were qualitatively imaged.

The stump pressure during ICA occlusion was measured using an arterial line.^{6–8)} Whether or not the ICA was sufficiently occluded was confirmed according to the change in the stump pressure between before and after ICA occlusion.

If no neurological symptoms were confirmed to occur during ICA occlusion with a duration of about 20 min, a hypotensive challenge was applied.^{2,9)} The systolic blood pressure was reduced by about 30% (or to 80–90 mmHg) by intravenously injecting nicardipine, and the presence or absence of neurological symptoms was examined during ICA occlusion with a duration of about 30 min including the hypotensive challenge.

Fig. 2 BTO results of 50 cases depending on multimodal assessment. BTO: balloon test occlusion

Evaluation of tolerance by multimodal assessment

Tolerance to BTO was judged by comprehensive evaluation of 4 items, which are arranged as follows in the order of priority: (1) Neurological symptoms without hypotensive challenge, (2) neurological symptoms with hypotensive challenge, (3) cerebral angiographic findings, and (4) perfusion CT findings and stump pressure. Importance is attached to neurological symptoms with and without hypotensive challenge and cerebral angiographic findings. By cerebral angiography, the degree of supply by the collateral blood flows, such as the anterior and posterior communicating arteries, was evaluated,¹⁰⁾ and asymmetry in the capillary to venous phases during balloon occlusion was examined as an index of tolerance.^{8,11,12)} The judgment was not tolerant when the delay was 2 s or longer, borderline when it was 1–2 s, and tolerant when it was less than 1 s.

On perfusion CT, the CBF, CBV, MTT, and TTP were evaluated comprehensively on a qualitative basis, but the judgment was made primarily according to the CBF: Tolerant when there was no asymmetry, borderline when there was mild asymmetry, and intolerant when there was clear asymmetry. Perfusion CT images were interpreted by experienced interventionists.

A stump pressure of 50 mmHg or higher was regarded as tolerant, 30–50 mmHg as borderline, and less than 30 mmHg

as intolerant. The algorithm of tolerance assessment is shown in Fig. 1.

Results

Complications associated with BTO

Ischemic complications associated with BTO were observed in three patients (6.0%). Shower embolism occurred in two patients, and mild paralysis (mRS 2) persisted in one of them. While occlusion of peripheral middle cerebral artery (MCA) due to thromboembolism was angiographically observed in one patient after the release of balloon occlusion, it was asymptomatic. The three patients with ischemic complications all showed neurological symptoms during ICA occlusion or hypotensive challenge and were intolerant. Arterial dissection due to wire manipulation during guiding of the balloon catheter was observed in one patient, but the condition was asymptomatic.

Assessment of tolerance by BTO

During 30-min ICA occlusion including hypotensive challenge, 35 patients exhibited no neurological symptoms. Two of them were judged to be “partially tolerant by BTO,” because asymmetry was observed on cerebral angiography. Thus, 33 patients were judged to be “tolerant by BTO.”

Fig. 3 65-year-old female with symptomatic large left ICA aneurysm. (A) Left internal carotid angiogram (A-P view). (B) 3D-DSA of left internal carotid angiogram (lateral view). (C) Perfusion CT image during BTO shows no asymmetry of CBF. (D and E) Right carotid angiogram of capillary and venous phase during BTO demonstrates synchronous filling between the two hemispheres. The patient had tolerance during BTO with hypotension. Stump pressure was 67/49 (mean 60). She was considered to be tolerant for permanent ICA occlusion. (F) Right carotid angiogram after internal trapping of left ICA. No neurological symptoms appeared postoperatively. BTO: balloon test occlusion; CBF: cerebral blood flow; ICA: internal carotid artery

Neurological symptoms were induced by hypotensive challenge in five patients. One was judged to be “intolerant by BTO,” because asymmetry was observed on cerebral angiography and perfusion CT, and because the stump pressure was low. The remaining four were judged to be “partially tolerant by BTO.”

Neurological symptoms appeared by ICA occlusion alone in 10 patients. They appeared immediately after ICA occlusion in six. These 10 patients were judged to be “intolerant by BTO.”

To summarize the above results, 33 were judged to be “tolerant by BTO,” six to be “partially tolerant by BTO,” and 11 to be “intolerant by BTO.” **Figure 2** shows the results of BTO based on the algorithm shown in **Fig. 1**. **Figure 3** shows a BTO-tolerant patient, and **Fig. 4** shows a partially- BTO-tolerant patient.

Therapeutic methods and complications

Table 1 shows the level of BTO tolerance, selected treatments, and complications associated with the treatments.

Treatments and complications in the 33 patients judged to be “tolerant by BTO”

Occlusion of the parent artery alone was performed in 11, PAO + high-flow bypass in three, and PAO + superficial temporal artery (STA)-MCA bypass in three, of the 33 patients. Thirteen patients were treated without internal carotid artery occlusion (e.g., stent-assisted coiling, balloon-assisted coiling, tumor resection preserving ICA), and three were observed without treatment. Parent artery occlusion was performed by internal trapping in nine and direct surgery in one.

Of the 11 patients who underwent PAO alone, a symptomatic ischemic complication due to a hemodynamic mechanism appeared in one (9.1%). In this patient, the primitive trigeminal artery was present between the ICA and basilar artery, and the assessment was insufficient due to the presence of the primitive trigeminal artery. Also, an ischemic complication due to a thromboembolic mechanism during internal trapping was observed in one. In both patients, the symptoms disappeared (mRS 0) without sequelae. In five patients other than these two, small high-signal areas were noted by

Fig. 4 The patient is a 77-year-old female with symptomatic large left ICA aneurysm. **Panel A** and **B** show the left internal carotid angiogram (A-P view) and 3D-DSA, respectively. Perfusion CT image during BTO shows asymmetry and CBF decreases in the left hemisphere (**C**). Right carotid angiogram of capillary (**D**) and venous phase (**E**) during BTO demonstrates asynchronous activities between the two hemispheres. The patient had no apparent neurological symptoms during BTO, and stump pressure was 55/42 (mean 48). She was considered to be partially tolerant for permanent ICA occlusion. The authors recommended ICA occlusion and STA-MCA bypass. However, the patient refused the bypass procedure; therefore, only internal trapping was performed. Postoperatively, the patient repeatedly presented transient ischemic symptoms, and MRI diffusion weighted image demonstrated high intensity spots in the left watershed (**F**). Rescue STA-MCA bypass was performed and her symptoms completely disappeared. ICA: internal carotid artery; BTO: balloon test occlusion; CBF: cerebral blood flow; STA-MCA: superficial temporal artery-middle cerebral artery

diffusion-weighted imaging of MRI. From the distribution of the ischemic foci, the findings were judged to have been caused by an intraoperative thromboembolic mechanism in two and due to a hemodynamic mechanism in five.

Of three patients judged to be “tolerant by BTO,” high-flow bypass was selected in one because of the young age and because of the presence of contralateral aneurysms in two. In one patient, a symptomatic complication occurred due to ischemia of the bypass region but was resolved (mRS 0).

STA-MCA bypass was selected in three patients because of the surgeon’s will (two patients) and the patient’s wishes (one patient). No symptomatic complications appeared.

Treatments and complications in the six patients judged to be “partially tolerant by BTO”

Parent artery occlusion + STA-MCA bypass were performed in three of the six patients. One was treated without internal carotid artery occlusion, and one was observed without

treatment. In one, STA-MCA bypass was recommended, but PAO (internal trapping) alone was performed due to the strong wishes of the patient (**Fig. 4**). In this patient, emergency STA-MCA bypass was added, because neurological symptoms repeatedly appeared with falls in the blood pressure from immediately after PAO, and because MRI showed an ischemic focus in the watershed area. Eventually, mild neurological symptoms persisted (mRS 1). While mild ischemic symptoms appeared in one patient who underwent STA-MCA bypass, they disappeared after 1 week. And no ischemic foci were detected on diffusion-weighted imaging of MRI (mRS 0).

Treatments and complications in the 11 patients judged to be “intolerant by BTO”

Of the 11 patients, six were treated by high-flow bypass and PAO, four were treated without internal carotid artery occlusion, and one was observed without treatment.

Table 1 BTO results (tolerance status), selected procedures and complications

Tolerance status of BTO	Treatment	n	Neurological complication (n)	Cause of complication and mRS at 2 month follow-up
BTO Tolerance	Total	33		
	PAO	11	2	1; Ischemia, thromboembolic (mRS0)
	PAO + HFB	3	1	1; Ischemia, hemodynamic (mRS0)
	PAO + STA-MCA	3	0	1; Ischemia, surgical site (mRS1)
	Treatment w/o PAO	13	0	None
	Observation	3	0	None
BTO Partial Tolerance	Total	6		
	PAO	1	1	1; Ischemia, hemodynamic (mRS1)
	PAO + HFB	0	NA	NA
	PAO + STA-MCA	3	0	None
	Treatment w/o PAO	1	0	None
	Observation	1	0	None
BTO Intolerance	Total	11		
	PAO	0	NA	NA
	PAO + HFB	6	3	1; Hyperperfusion (mRS1), 1; Ischemia, thromboembolic (mRS2), 1; Subarachnoid hemorrhage (mRS6)
	PAO + STA-MCA	0	NA	NA
	Treatment w/o PAO	4	0	None
	Observation	1	0	None

BTO: balloon test occlusion; mRS: modified Rankin scale; PAO: parent artery occlusion; HFB: high-flow bypass; STA-MCA: superficial temporal artery-middle cerebral artery; NA: not available

Permanent complications were noted in two of the six patients who underwent high-flow bypass. In one, mild paralysis and aphasia due to hyperperfusion persisted (mRS 1). In one, an ischemic complication appeared due to insufficient ligation of the cervical ICA, and memory impairment persisted (mRS 2). Among the events other than the above, one patient died (mRS 6) due to rupture of a previously unruptured anterior communicating aneurysm that complicated the internal carotid aneurysm.

Discussion

Complications due to the BTO procedure

According to the previous reports on complications of the procedure of BTO itself, the incidence of all complications was 3.2%–4.2%, those with neurological symptoms accounted for 1.6%–1.7%, and those with permanent neurological symptoms accounted for 0.3%–0.8%.^{13–15} The causes of these complications were thromboembolic events during the procedure and dissection of the ICA similar to the present series. In this series, complications related to BTO were observed in four patients (8.0%), neurological symptoms due to ischemia were observed in two of them (4.0%), and the symptoms persisted in one (2.0%). All ischemic complications occurred in intolerant patients, who developed neurological symptoms during ICA occlusion or hypotensive challenge. Shower embolism, which is considered to have been related

to intolerance, was observed. No ischemic complications were noted in clearly intolerant patients, who exhibited neurological symptoms immediately after ICA occlusion, or tolerant patients, who tolerated 30-min or longer ICA occlusion. In clearly intolerant patients, the duration of ICA occlusion was short, and ischemic complications were less likely to occur, but attention to ischemic complications due to a hemodynamic mechanism is necessary in patients found to be intolerant during ICA occlusion. If a patient is expected to be intolerant from the development of the arterial circle of Willis based on MRA and/or 3D-CTA findings before the examination,¹⁰ the procedure should be performed with greater caution. At our facility, sufficient systemic heparinization (target activated clotting time: 250–300 s) is made, and elaborate perfusion with heparinized saline from the catheter tip is ensured, to prevent ischemic complications.

Evaluation of tolerance by BTO

BTO is a technique to predict neurological symptoms and hemodynamics after permanent occlusion of the ICA by temporarily occluding it. The therapeutic approach is determined on the basis of the results of BTO, but the condition after occlusion cannot be completely simulated. Various methods with neurological evaluations are employed to enhance the reliability of the results, but accurate prediction is still difficult.

Various monitoring methods have been reported for BTO. First, it is most important to evaluate the presence or absence of neurological symptoms during ICA occlusion.¹⁾ In addition, neurological symptoms during hypotensive challenge is evaluated.^{2,9)} Concerning angiographic findings, asymmetry in the venous phase and circulation time during ICA occlusion,^{8,11,12)} and the degree of development of the arterial circle of Willis (collateral blood flows from the anterior and posterior communicating arteries)¹⁰⁾ are examined. Also, the stump pressure at the occluded stump of the ICA is measured.^{6–8)} For the measurement of the cerebral blood flow, various devices including SPECT,^{6,16)} perfusion CT,^{17–19)} transcranial Doppler,²⁰⁾ and PET-CT²¹⁾ are used. This conversely means that a universal device to measure the cerebral blood flow for the evaluation of ischemic tolerance has not been established. Presently, these monitoring devices are used according to the circumstances of each facility, and the evaluation is made by diversely combining the above evaluation items. At our facility, as mentioned above, the tolerance is judged by comprehensively evaluating neurological symptoms with and without hypotensive challenge, cerebral angiographic findings, and the results of perfusion CT and stump pressure measurement (multimodal BTO). While perfusion CT is given a supplementary role at our facility, angio-CT system is advantageous in that the patient need not be transferred to a special room for cerebral blood flow examination as in SPECT or PET-CT.

According to the literature, the false negative rate has been reported to be 13%–15% by neurological evaluation alone and 3%–10% with the addition of cerebral blood flow examination.^{2,22)} In this series, ischemic complications due to hemodynamic mechanisms occurred in only one (9.1%) of the 11 patients who were judged to be “BTO-tolerant” and underwent PAO alone. However, this patient also had persistent primitive trigeminal artery, and, in retrospect, the procedure of BTO itself was insufficient. After this case, if persistent primitive artery was present, we occluded the ICA after furcation of the persistent primitive artery as well as the cervical ICA. When BTO is performed in the cervical ICA, the possibility of false negative results due to the persistence of the collateral blood flow via the branches that spring from the ICA between the cervical region and the actual site of occlusion must be kept in mind.²³⁾

Ischemic symptoms due to a hemodynamic mechanism occurred in one patient who was judged to be “partially tolerant by BTO” and underwent PAO alone as expected from the results of BTO. In this series, methods without PAO were selected in many patients (23/50), and there may have been bias in the treatment selection, but the tolerance to ischemia due to PAO is considered to have been sufficiently evaluated.

Multimodal BTO in which neurological evaluation, cerebral angiographic findings, and stump pressure are combined, at present, with cerebral blood flow examinations depending on the circumstances of each facility (Fig. 1) is considered to be useful for the assessment of ischemic tolerance.

Many internal carotid aneurysms that are indications for BTO are accompanied by aneurysms in the contralateral ICA. If the parent artery is occluded, there is the possibility that existing aneurysms are stressed by changes in the blood flow, and this is a problem other than ischemic tolerance.²⁴⁾ A flow diverter, such as Pipeline, is an ideal treatment that can occlude the aneurysm while preserving the parent artery, but some unresolved problems such as thromboembolism and hemorrhagic complications remain.²⁵⁾ Under existing circumstances, if the patient is judged to have ischemic tolerance by BTO, PAO should be considered first because of its rapid effects on compression symptoms and high radicality as a treatment for aneurysms.²⁶⁾

Conclusion

Internal carotid artery BTO based on multimodal assessment is useful for accurate evaluation of ischemic tolerance.

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Disclosure Statement

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