

Validity of venous phase delay assessment in balloon occlusion test of internal carotid artery

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Abstract. The aim of the present study was to investigate the utility of venous phase delay assessment to evaluate the balloon occlusion test (BOT) of the internal carotid artery (ICA). A total of 38 patients who received BOT of the ICA were included in this retrospective study. Clinical examination and venous phase assessment were performed in all patients to evaluate their suitability for the evaluation of the BOT of the ICA. The venous phase delay assessment compared the venous phase of supratentorial and infratentorial structures between hemispheres. Venous phase delay was defined as the time lag for opacification of the first cortical vein between the occluded hemisphere and the hemisphere examined. The results of the clinical examination and the venous phase delay assessment were compared. In most patients negative on clinical examination, the venous phase delay was no more than 2 sec, while for most patients positive on clinical examination, the delay was >2 sec. All patients with a venous phase delay of >4 sec had a positive clinical result. The present results indicated that venous phase delay assessment is a reliable method for evaluating BOT of the ICA, and in those with a delay of <2 sec, parent vessel occlusion of the ICA, which may be used as a pre-operative procedure prior to tumor resection for patients suffering from neck or skull-base tumors, was considered safe.

Introduction

When treating certain types of vascular disease, it is appropriate to perform parent vessel occlusion (PVO) of the diseased area. PVO may be used as a pre-operative procedure prior to tumor resection for patients suffering from neck or skull-base tumors (1,2). In such cases, internal carotid artery (ICA) endovascular occlusion is a necessary pre-operative maneuver. However,

as there is a significant risk of ischemic events associated with ICA occlusion, patient selection is crucial. Thromboembolic and hemodynamic ischemia are the major complications associated with PVO (3). Therefore, it is crucial to identify patients that are likely to develop hemodynamic ischemia prior to PVO. A previous study demonstrated that temporary balloon occlusion of the ICA can be used to identify patients at risk for stroke during carotid artery sacrifice (4). The temporary balloon occlusion test (BOT) is useful in evaluating ischemic risk prior to permanent ICA occlusion (5). During the BOT, several methods may be used to assess the clinical tolerance of PVO, which include clinical examination assessment, venous phase delay assessment, stump pressure assessment, perfusion scanning assessment and neurophysiological monitoring (3). The clinical examination assessment is the most useful and broadly used method to determine whether a patient is able to tolerate PVO (6). There are several types of BOT assessment each with various advantages and disadvantages. For example, the CT perfusion method involves knowledge of image post-processing. This procedure also involves the transfer of the patient to the CT suite with a balloon catheter in the carotid artery, which may increase the risk of carotid artery injury (3). Venous phase delay assessment is a simple angiographic BOT criterion. To investigate the utility of venous phase delay assessment in evaluating the results from the BOT, the clinical examination assessment and the venous phase delay assessment during BOT of the ICA.

Materials and methods

Patients. A total of 38 patients without contraindications underwent a BOT of the ICA between January 2012 and July 2016 at The Second Xiangya Hospital of Central South University (Changsha, China). Clinical examinations and venous phase assessments were performed. Patients with a head and neck tumor or traumatic carotid cavernous fistulae were included in the study. The present study was approved by the Ethics Committee of the Second Xiangya Hospital of Central South University (Changsha, China). All patients provided informed consent.

BOT method. A 6-F femoral sheath was introduced into the femoral artery using the single-wall puncture technique. Cervical and cerebral angiograms were recorded with 4-F diagnostic catheters in the anteroposterior and lateral projection, respectively. Each patient was given 70-100 units per

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kg of heparin prior to the angiogram. Subsequently, a 6-F guiding catheter was positioned in the common carotid artery. A non-detachable 4x15 mm silicon balloon catheter (cat. no. BCo415C; MicroVention Medical Technology, Co., Ltd., Hang Zhou, China) was positioned in the petrous ICA. After the diseased vessel was completely filled, the balloon was inflated for a total of 30 min. During the 30 min procedure, a neurological examination was performed every 5 min (3). The patient was asked a series of questions to assess their motor, sensory, speech and memory capacity, as well as their analytical and/or calculation skills. If any neurological deficits were detected during balloon occlusion, the balloon catheter was immediately deflated. In this case, the clinical examination was considered positive. If no neurological deficit was detected by 30 min, the result was negative.

Anteroposterior angiography was performed on the entire skull after the neurologic assessment. The venous phase delay assessment was performed by comparing the time difference for opacification of the first cortical vein between the territories of the examined hemisphere and the occluded hemisphere.

Results

Patient characteristics. The clinical characteristics of the 38 patients are listed in Table I. Of the 38 patients enrolled, 18 (47%) were males and 20 (53%) were females, average age 50 (16-72) years. There were 22 patients with carotid aneurysms, 12 with extensive cervical tumors and 4 with traumatic carotid cavernous fistulae. Fig. 1 displays a representative angiogram of a BOT of the right ICA in a 52-year-old male patient with a cervical tumor. A representative angiogram of a BOT of the right ICA in a 47-year-old male patient with a large cervical tumor is provided in Fig. 2.

Clinical and venous phase delay examination during BOT. A comparison of the results of the clinical examination and the venous phase assessment is provided in Table II. According to the neurological examination during BOT, 30 patients (78.9%) were negative and 8 (21.1%) were positive. Of the 30 negative patients, venous phase delay occurred within 2 sec in 28 patients (93.3%), and between 2 and 4 sec in two patients (6.7%). None of the patients with a negative result had a delay of >4 sec. Of the eight patients with positive results, the venous phase delay was within 2 sec for one patient (12.5%), between 2 and 4 sec for two patients (25%) and >4 sec for five patients (62.5%).

Venous phase delay during BOT may be utilized to determine suitability for PVO. Although the data were not sufficient from a statistical perspective, the results allow for the prediction that for most patients with a negative clinical examination the venous phase delay was <2 sec. For the majority of patients with a positive clinical examination, the delay was >2 sec. All patients with a venous phase delay of >4 sec had a positive clinical examination result.

Discussion

The treatment of complex vascular pathologies depends on the evolution of endovascular technology (3). For the treatment of

certain vascular diseases, it is appropriate to perform PVO of the diseased area (1,2). Certain conditions, including wide-neck giant aneurysms, pseudoaneurysms, traumatic vascular injuries, carotid blowout and arteriovenous fistulas, require PVO (1,2). PVO may be used as a pre-operative treatment prior to tumor resection in patients suffering from neck or skull-base tumors (7). In the early 1970s, Serbinenko first reported on endovascular PVO with detachable balloons (8,9). It is necessary to perform ICA endovascular occlusion as a pre-operative maneuver for the treatment of certain head and neck diseases (4).

Hemodynamic ischemia and thromboembolism are the major complications associated with PVO. Thromboembolic complications may be managed by anti-coagulation treatment (5). However, it is difficult to avoid immediate or delayed hemodynamic cerebral ischemia during carotid artery occlusion, even during uncomplicated procedures. Identification of patients that are likely to develop hemodynamic ischemia prior to PVO is crucial for preventing this type of complication (3).

A temporary BOT is useful for evaluating ischemic risk prior to permanent ICA occlusion. Several techniques may be used for the BOT. The primary purpose of the BOT is to assess the ability of the intracranial collateral circulation to maintain perfusion of the affected vascular territory during temporary occlusion of the major arterial supply. An interventionist assesses whether a patient is able to tolerate PVO by applying the BOT. A clinical BOT of the ICA contributes to lower post-occlusion morbidity (10,11). A study by Linskey *et al* (5), which included 516 patients, demonstrated that the use of an ICA BOT reduced the morbidity of permanent ICA occlusion from 26 to 13%.

Several methods may be used to assess the clinical tolerance to PVO. These may include neurological examination assessment, venous phase delay assessment (6), stump pressure assessment (12), perfusion scanning assessment [including single-photon emission computed tomography (SPECT) (13), xenon CT perfusion (14), CT perfusion with an acetazolamide challenge (15)], as well as magnetic resonance (MR) perfusion (16) and neurophysiological monitoring (NPM) (17). Other methods include electroencephalography, somatosensory-evoked potentials and brain stem-evoked potentials (3), transcranial Doppler (TCD) ultrasonography (18) and induced hypotension (19). The aim of these techniques is to enhance the predictive value of a successful BOT. In certain cases, numerous assessment methods have been employed in conjunction with clinical examinations to determine in which patients PVO is safe and to thereby reduce the incidence of ischemic complications (20).

The neurological examination assessment is the most useful and widely applied method during BOT to determine whether a patient is able to tolerate PVO (21). When the BOT procedure is performed for clinical assessment, the patient is asked a series of questions to assess their motor, sensory, speech and memory capacity, as well as their analytical or calculation skills (3). Although the clinical assessment is the basis for all BOT paradigms, certain disadvantages exist. For instance, a clinical examination may increase the risk of thromboembolic complications, which may require a prolonged balloon inflation time. In addition, patients must be fully conscious and the occlusion procedure must be performed under local anesthesia to facilitate the clinical examination (3).

Table I. Clinical characteristics of the 38 patients.

Sex	n	Carotid aneurysm	Extensive cervical tumor	Traumatic carotid cavernous fistulae
Female	20	13 (65)	5 (25)	2 (10)
Male	18	9 (50)	7 (39)	2 (11)
Total	38	22 (58)	12 (31)	4 (11)

Values are expressed as n (%).

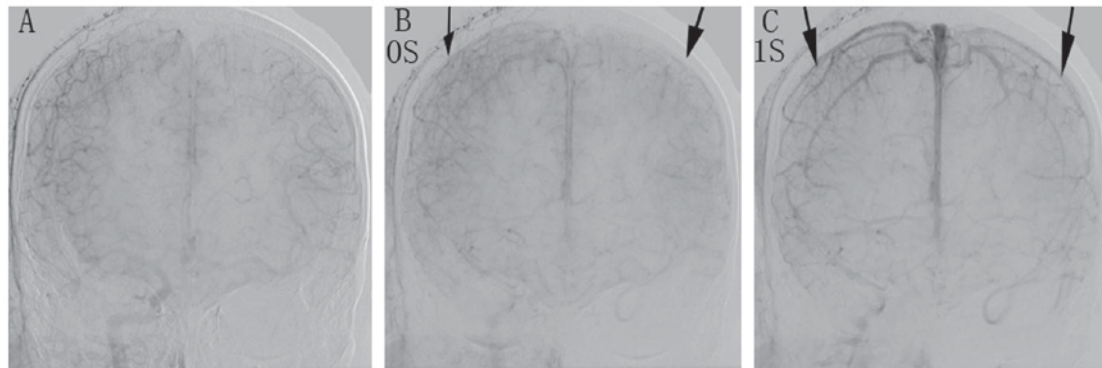


Figure 1. Angiogram displaying a BOT of the right internal carotid artery in a 52-year-old male patient with a cervical tumor. (A) Significant cross-filling of the Circle of Willis in the late arterial phase. (B) The early venous phase is displayed one sec after the first image; defined as 0S. Cortical vein opacification is observed in the left and right hemispheres (black arrows). (C) One sec later (1S), the venous phase synchrony is more evident in the left and right hemispheres (black arrows). This patient represents an example of perfect symmetry of venous phase delay during a BOT. BOT, balloon occlusion test; 0S, 0 sec; 1S, one sec.

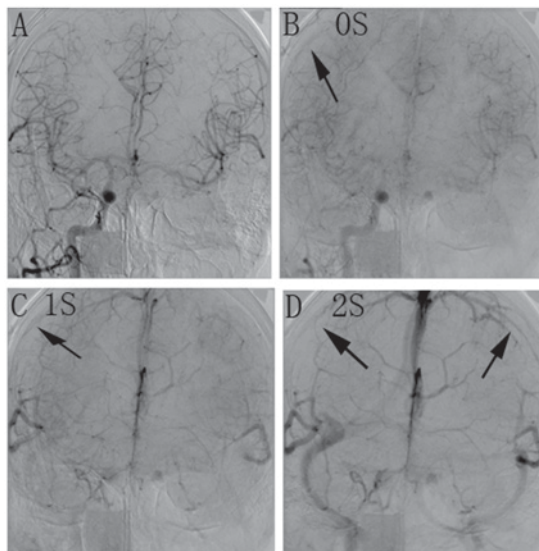


Figure 2. Angiogram displaying a BOT of the right internal carotid artery in a 47-year-old male patient with a cervical tumor. (A) Significant cross-filling of the Circle of Willis in the late arterial phase. (B) The beginning of the venous phase on the right hemisphere (black arrow) and certain cortical arteries in the left hemisphere are visible one sec after the first image; defined as 0S. (C) One second later (1S), the cortical arteries on the left hemisphere and veins on the right hemisphere (black arrows) are more visible. (D) One second later (i.e., the venous phase at 2 S), the veins were filled in the left and right hemispheres (black arrows). This patient had a 2 sec venous drainage delay. BOT, balloon occlusion test; 0S, 0 sec; 1S, one sec; 2S, two sec.

For most types of BOT assessment, certain challenges prevail, as the systemic pressure is affected by several factors.

General anesthesia, patient mood and even environmental conditions may affect stump pressure assessment (20). In addition, although previous studies have identified a significant correlation between stump pressure and cerebral perfusion (22), the usefulness of stump pressure assessment remains controversial, as other studies did not identify a correlation with cerebral perfusion (23). If perfusion scanning assessment is performed, the patient must be transferred to a CT, MRI or SPECT scanning room. The balloon is placed in the ICA during transportation, which may increase the risk of carotid artery injury (13-15). The disadvantage of NPM is that the result is not reliable due to the high false-positive and -negative rates (17). Although TCD ultrasonography has the advantage of being non-invasive, it does not provide a consistently stable result (18). The correlation between cerebral blood flow and mean middle cerebral artery velocity is not linear, as the mean velocity may be affected by the hematocrit, viscosity and vessel caliber (14). A previous study indicated that the induced hypotension assessment was not superior to the traditional BOT (19). Dare *et al* (19) suggested that the false-negative rate of the induced hypotension assessment may be increased due to the direct vasodilator effect of nitropruside on the cerebral circulation.

The venous phase delay assessment is based on the assumption that an adequate intracranial collateral circulation exists to confirm the symmetry of the two hemispheres when one ICA is occluded during a BOT (6). Venous phase delay is a simple angiographic BOT assessment performed under general anesthesia removing the need for any further neurological examination. This type of evaluation is rapid and

Table II. Results of the clinical examination and venous phase assessment.

Clinical examination	n	Venous phase delay (sec)		
		<2	2-4	>4
Negative	30	28 (93)	2 (7)	0 (0)
Positive	8	1 (12.5)	2 (25)	5 (62.5)
Total	38	29 (76)	4 (11)	5 (13)

Values are expressed as n (%).

straightforward (6). A reduced balloon inflation time in the ICA thus indicates a reduced risk of thrombus formation associated with an occluded ICA (3). Even though venous phase delay has several advantages and has recently attracted extensive attention, neurological examination remains the most commonly used method to assess a patient's ability to tolerate PVO (21). Neurological examination is straightforward, practicable and does not require any specialized equipment. Accordingly, in the present retrospective study, the results of the venous phase delay assessment were compared with those of a neurological examination during a BOT of the ICA to investigate a preliminary comparison between the two types of assessment.

In the present study, for most patients with a negative neurological examination, the venous phase delay was <2 sec. Therefore, patients with a venous phase delay <2 sec were identified as having the ability to tolerate PVO. This result was consistent with that of a study by Abud *et al* (6), which demonstrated that patients with a venous phase delay <3 sec were identified as having the ability to tolerate carotid occlusion without developing neurologic deficit. For most patients with a positive neurological examination, the venous phase delay was >2 sec, and all patients with a venous phase delay of >4 sec had a positive neurological examination. Therefore, a venous phase delay of >2 sec, which is associated with a positive neurological examination during BOT, may be used to indicate patients which cannot tolerate PVO. Furthermore, patients with a venous phase delay of >4 sec will definitely not be able to tolerate PVO. Accordingly, if the venous phase delay is 2-4 sec, the BOT result requires to be determined by additional factors along with the venous phase delay.

In conclusion, according to the present retrospective study and previous studies, venous phase delay assessment is a reliable method for evaluating a BOT of the ICA. In addition, a delay <2 sec should be considered to indicate that PVO of the ICA is safe.

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Availability of data and materials

All datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

EX and HZ designed the study. ZC and LH performed the examinations and analyzed the data. ZC and LH prepared the manuscript. EX and HZ read and approved the final manuscript.

Ethical approval and consent to participate

The present study was approved by the Ethics Committee of the Second Xiangya Hospital of Central South University (Changsha, China). All patients provided informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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