Evaluating brain tolerability to carotid artery occlusion

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An objective and practicable method to evaluate the brain tolerance to unilateral carotid artery occlusion was attempted. Ten consecutive cases were studied. Endovascular trial balloon occlusion of the unilateral carotid artery in conjunction with single-photon emission computed tomography (SPECT) as well as digital subtraction angiography (DSA) and clinical neurological evaluation was routinely performed for those patients who might undergo permanent occlusion of the internal (ICA) and/or common carotid artery (CCA). The result of SPECT was analyzed semi-quantitatively and compared with the baseline data as well as the data from contralateral side. The relative symmetry index (rS) of side-to-side radioactivity counts relevant to the baseline was calculated. One subject failed the balloon occlusion test (BOT), even though an angiographically adequate collateral circulation was observed. The rS of the patient was 74.5%. The remaining patients passed the 45-min BOT without any neurological deficiency induced. Their value of rS was 97.8% ± 4.4%. Based the BOT results, the left ICA, CCA and external carotid artery were excised in one patient, CCA–ICA reconstructions after carotid occlusions were performed in three. The carotid arteries were saved in five. For one patient, the ICA was occluded spontaneously during the BOT. There were no neurological impairments developed after the surgery. With this BOT technique, clinically silent areas of decreased perfusion might be detected. We suggest it be a routine preparatory to carotid manipulations.


Keywords: Carotid artery occlusion; brain tolerability; balloon; SPECT

INTRODUCTION

Advances in skull base surgery have resulted in the ability to perform large scale en bloc resections of neoplasms affecting the clivus, sphenoid wings, and other deep structures. Such tumors frequently involve the internal carotid artery (ICA), and complete resection may require dissection or sacrifice of the ICA. The major complication of this procedure is cerebral infarction. Over years, attempts have been made to determine which patients could safely sacrifice unilateral carotid artery without the threat of disaster. Nowadays, endovascular temporal balloon occlusion test (BOT) has been recommended. However, some patients who pass BOTs may subsequently develop neurologic deficits when the carotid artery is permanently occluded.

The purpose of this paper is to report our experience with BOT. We try to establish a practicable and objective method to evaluate the brain tolerability to unilateral carotid artery occlusion.

PATIENTS AND METHODS

Patients

Ten consecutive cases were investigated. For patients who might have carotid artery surgery, endovascular balloon test occlusion of the carotid artery (left side, n = 7; right side n = 3) was performed (Table1).

Interventional technique

With the patient sedated but awake, a standard four-cerebral-vessel digital subtraction angiography (DSA) was first performed using the Seldinger technique. A double lumen balloon occlusion catheter (OB/5/100/035, Medi-tech®, Boston Scientific) was then fluoroscopically introduced into ICA. The level of C1–3 is recommended where it contrasts well against the neck. Following, another catheter was brought to the ipsilateral common carotid artery (CCA) proximal to the balloon via the opposite femoral artery; the balloon was gradually inflated. The occlusion was checked by injection of contrast through the other catheter to reveal stagnation of flow, rather than by watching for distortion of the balloon. A documentary film was obtained. The balloon was rapidly deflated and the test was ended immediately, whenever a neurologic deficit was elicited at any stage during the BOT, and this patient was consequently considered to have failed the BOT. Otherwise, the test occlusion would have continued for a period of 45 min. At 15 min, DSA through the contralateral CCA and the vertebral artery of either side should be performed in order to evaluate the patency of the circle of Willis. Thirty minutes after the occlusion, each patient was injected intravenously with 25 mCi (925 MBq) of technetium-99m-ethyl cysteinate dimer (99mTc-ECD). At the termination of the test procedure,
the catheter was withdrawn into the CCA and a repeat control angiography was performed over the entire intracranial distribution of this vessel to evaluate the possibility of distal embolization as well as the condition of the carotid artery at the point of occlusion (i.e., where the balloon was). Finally, all the catheters were removed and the patient was then transferred for cerebral SPECT.

**Clinical neurologic testing**

A battery of neurologic and cognitive tests was performed repeatedly before and during the procedure. The most commonly used parameters are sensori-motor testing, ability of speech and calculating and status of consciousness as well as the patient’s complaint and Babinski’s sign. Any alteration of one of these parameters should be interpreted as evidence of ischemia and should result in immediate deflation of the balloon.

**SPECT studies**

SPECT imaging was accomplished after removal of catheters and stabilization of the patient using a dual detector gamma camera (Helix SPX-6D, Elscint®, Israel) equipped with a low-energy general parallel hole collimator. The reconstructed slice thickness was 10 mm in the coronal planes. A baseline SPECT was performed three days before BOT. Both baseline and BOT scans were obtained under the resting condition with the patient’s eyes covered and ears plugged without any acoustic, visual or motor stimulation. Semiquantitative analysis was performed by means of mirror technique. Fifteen symmetric pairs of rectangle region-of-interest (ROI) consisting of 1274 pixels on each side were defined. The degree of side-to-side relative symmetry index (\( rS \)) was then obtained using the following equation:

\[
\frac{St}{Sb} = \frac{97.93}{100} \times 100\%\,
\]

where \( St \) is the ROIs count ratio of affected/opposite side during BOT; while \( Sb \) is the one taken three days before.

**RESULTS**

Although DSA demonstrated that all the subjects possessed adequate collateral circulations, one out of the 10 subjects failed the BOT. The \( rS \) of this patient was 74.52%. The remaining patients in this study passed the 45-min BOT without neurologic deficit developing. The \( rS \) of the asymptomatic group was 97.76% ± 4.39%.

**Table 2** shows the detailed SPECT outcome. According to the BOT outcomes, the ICA, CCA and external carotid artery (ECA) were excised in one patient; CCA–ICA reconstructions were performed in three; the carotid artery was spared in five. For one patient, the ICA was occluded during the BOT. No neurological impairment developed post-operatively in all the patients (Table 1).

**Illustrative case**

**Case LWY**

A 49-year-old man was admitted for a giant mass in his left neck. Iconography delineated that the spinal canal was effaced and the left CCA, ICA and ECA were encroached. The patient had been operated on four times in the past five years for the same reason, and his left vertebral artery had been ligated during the first surgery. Fortunately, this patient passed the 45-min BOT with 97.9% of \( rS \). As a result, we believed that the carotid artery could be scarificed safely. The ICA, CCA and ECA were then removed in the operation and no cerebral ischemia developed post-operatively.

**Case WCQ**

A 60-year-old woman with a diagnosis of post-operative recurrence of parotid adenocarcinoma was referred for tolerance evaluation due to severe involvement of the carotid artery. Twenty minutes after the balloon inflation in the right ICA, we noted that the patient was somewhat apprehensive, yet the orientation and calculation abilities were normal at the time. Fourteen minutes later, the patient complained of numbness in her left hand, though an angiographically adequate collateral circulation was observed. The
clinical examination showed a suspicious Babinski’s sign on her left side with degree II muscular power of the left extremities. By deflating the balloon promptly, the symptom remitted subsequently. The SPECT imaging showed that the nuclear density on the right cerebral during the BOT was definitely decreased compared to the baseline. Her rS was 74.5%. Accordingly, the patient underwent 37-min temporary bypass during the resection of the tumor, followed by CCA–ICA reconstruction with artificial vessel (Gore-Tex®). No neurologic impairment occurred postoperatively.

**DISCUSSION**

Elective occlusion of the ICA has been performed since the 1900s for the management of traumatic arterial lesions, inoperable ICA aneurysms or pseudoaneurysms and for the management of skull-base and cervical tumors. Since the risk of stroke after iatrogenic carotid occlusion in unselected patients varies between 30% and 54%, pre-operative knowledge of whether or not a patient can safely tolerate such a procedure can have a significant impact on surgical planning. In clinical practice the Matas test has served a fundamental role in evaluating the collateral. However, the technique of applying digital pressure to the carotid artery in the neck has many shortcomings that challenge the reliability of this test. At present, modern techniques have dramatically enhanced the Matas approach. The use of inflatable balloons establishes a more ‘physiologic’ temporary occlusion that is more effective and safe than digital compression or occlusion with Silverstone clamp. Theoretical advantages of gradual occlusion with ligatures or clamps versus abrupt occlusion with the balloon catheter have not been borne out.

When BOT is clinically tolerated, the morbidity and mortality of permanent arterial occlusion is reduced but, unfortunately, not eliminated. Since the report of endovascular temporary arterial occlusion presented by Serbinenko, a variety of adjunctive methods have been tested to improve the sensitivity and specificity of clinical neurologic evaluation alone for the detection of insufficient cerebral blood flow (CBF) to allow safe permanent arterial occlusion. Cerebral ischemia during test occlusion is most simply assessed by the level of consciousness, but this merely detects those with no cerebrovascular reserve and does not indicate patients with impaired reserve who are at risk if the circulation is further challenged by increased metabolic demands, hypotension or surgery. It appears that 5%–20% of the patients will be at risk of cerebral ischemia if neurologic tests are employed alone. Hereby, various endeavors were made to validate additional techniques for improving the pre-operative risk assessment.

For many years, the electroencephalogram (EEG) has been the landmark for monitoring during carotid ligation, endarterectomies and temporary clipping. It was showed that when CBF was less than 11.5 ± 1.4 ml 100 g⁻¹ min⁻¹, 50% of patients would occur EEG evidence of cerebral ischemia. For decades, it has been the only diagnostic tool that could show early changes in electrical potentials in the brain and correlate them with the function and possible clinical outcome, but it may not be so reliable for the prediction of long-term outcomes. Transcranial Doppler ultrasonography (TCD) allows an estimate of the capacity to recruit collateral perfusion to the depleted artery territory through the circle of Willis. According to the literature, the threshold velocity reduction of middle cerebral artery varied from 30%–70%. However, a fundamental limitation of TCD is the fact that, like most diagnostic ultrasound studies, its accuracy is intrinsically operator-dependent. Recently, it was reported that a noninvasive bedside technology, near-infrared spectroscopy, could detect cerebral hypoxia–ischemia. It can determine hypoxic–ischemic thresholds for cerebral oxygen saturation in terms of EEG, brain ATp, and lactate concentrations, and compared these values with CBF and sagittal sinus oxygen saturation. Regional cerebral oxygen saturation has been found to correlate with TCD measurement.

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<th>Patient</th>
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<th>Cb₀</th>
<th>Sb (%)</th>
<th>C₀</th>
<th>Ct₁</th>
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Cb₁, Cb₀, the mean radioactive count obtained from baseline ROIs in the affected side and the opposite side, respectively; Ct₁, Ct₀, those obtained during BOT; Sb, St, symmetry index in the baseline and BOT, respectively; rS, relative symmetry index.

Table 2: The radioactive count of SPECT and symmetry index.
of cerebral artery blood flow velocity. In a recent BOT study in 24 subjects, it was noted that change in regional cerebral oxygen saturation after ICA occlusion was +3.5% to −4.2% in the good collateral circulation group, −1.2% to −3.2% in the moderate group, and −2.4% to −10.2% in the poor group.

Although cerebral angiography provides extensive information about cerebral vasculature, this information does not reflect physiologic conditions. It may be possible to identify patients with marginal perfusion reserve with Xenon-enhanced CT scanning (Xe/CT) which was initially developed in the late 1970s. At the very beginning, radioactive Xenon (¹³¹Xe) was used. Lately, a method that coupled a nonradioactive xenon with the CT scan was developed. Without the limitation of half-span's period, it can be repeated immediately. A study concluded that it was a safe procedure whenever the CBF is above 40 ml 100 g⁻¹ min⁻¹ during temporary clamping and unsafe when below 20 ml 100 g⁻¹ min⁻¹. If during temporary clamping the CBF is in the range 20–40 ml 100 g⁻¹ min⁻¹, ligation is safe provided the reduction from control values is less than 25%.

An alternative method of evaluating CBF is ⁹⁹mTc–ECD SPECT. ⁹⁹mTc–ECD, stable in vitro, is a widely available radiotracer that has been used extensively for evaluation of CBF. It shows rapid brain uptake and distributes proportionally to regional CBF. The tracer is converted intracellularly to a hydrophilic compound and remains fixed in the brain for a prolonged time, allowing delayed imaging after injection. The retention of ⁹⁹mTc–ECD requires the presence of cytosolic esterase, which in turn depends on the viability of cells. Accordingly, the cerebral uptake of ⁹⁹mTc–ECD reflects not only perfusion but also the metabolic status of brain tissue. If the tracer is injected during BOT, the distribution of the radiotracer is an indicator of regional brain perfusion and metabolism. With this approach, the balloon can be deflated and the catheter withdrawn. SPECT is superior to anatomical imaging procedures in detecting cerebral ischemia during the first hours following an icterus. A pre-occlusive SPECT study, when compared to the post-occlusive study, might provide increased sensitivity for modification of left-to-right uptake ratios. It is important to detect changes of the left-to-right ratio on homologue regions so as to discriminate between normal and altered perfusion. Another important thing is the proper timing for tracer injection after inflation of the balloon. If it is injected too early, collaterals might not be completely opened and this could lead to false-positive SPECT result. According to Askienazy and co-workers, injection of the perfusion agent should not be done until at least 15 min post-inflation.

In terms of hemodynamics, when the CCA was occluded, the pressure drop in the carotid sinus distal to the site of balloon induces the arterial blood pressure rises as a reflex. Takeuchi et al. verified that CCA occlusion might cause flow reversal from the ICA to the ECA. Thus, we deemed that the balloon should be positioned in ICA and avoided placing at the bulb of the ICA because of the carotid body during inflation of the balloon. However, if you encounter difficulty when placing the balloon, the balloon can be placed just proximal to the lesion. Failing to do this may rupture the carotid artery or propagate thrombi since the artery is often involved for majority of subjects.

To identify patients who can safely tolerate sacrifice of a carotid artery is a challenge that has yet to be fully conquered, and the BOT with brain function monitoring will play an important role in meeting this challenge. With pre-operative BOTs, many neurosurgical procedures can now be performed much more safely than before.

REFERENCES


