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Temporary and Permanent Occlusion of Cervical and Cerebral Arteries

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Permanent occlusion of cervical vessels is a solution to many vascular diseases and has been practiced for almost 200 years. John Hunter pioneered ligation as a therapeutic technique by ligating the popliteal artery to treat an aneurysm. Carotid occlusion was initially used to treat penetrating injuries of the carotid artery. In 1804, Abernethy ligated the common carotid artery after trauma; unfortunately, the patient died from a subsequent stroke [1]. Astley Cooper (1768–1841) described his experience with carotid ligation for aneurysms in 1836, with the first successful procedure being performed in 1808. Victor Horsley made the diagnosis of a giant carotid aneurysm at surgical exploration and successfully ligated the carotid artery a few days later [2]. The later developments of cerebral angiography by Egas Moniz in the 1920s, surgical clipping of aneurysms by Dandy in the 1930s, and gradual vascular occlusion of the carotid and other vessels by the use of adjustable clamps [1,3] as well as by endovascular techniques in the 1970s stimulated interest in the use of endovascular balloon occlusion as a minimally invasive alternative to open ligation of a parent vessel and using endovascular techniques to test cerebral reserve [3]. The development of Hunterian strategies to treat unclippable aneurysms of posterior and anterior cerebral circulations was pioneered by Drake et al [4].

Approximately 80% of patients tolerate carotid occlusion or the loss of a nondominant or codominant vertebral artery [5,6]. The issue of determining which patients can safely tolerate a permanent occlusion led to the evolution of balloon test occlusion (BTO) as a pretreatment test [7–9]. Temporary endovascular balloon occlusion to test cerebrovascular reserve before cervical or cerebral artery sacrifice is a relatively recent diagnostic test [5], the sensitivity and specificity of which are still under review [10]. The primary indications for this procedure are surgically untreatable aneurysms [7,11,12,26,27]; control of hemorrhage associated with trauma, aneurysm rupture, or tumor invasion [3,8]; skull base or cervical tumors intimately associated with arteries [1,8,13–15]; traumatic or nontraumatic arterial fistulae (not otherwise manageable); and dissection (Box 1). In addition, BTO, combined with other adjunctive tests, such as CT angiography (CTA), magnetic resonance angiography (MRA), digital subtraction angiography (DSA), CT or magnetic resonance perfusion [16] studies, clinical examination, induced hypotension [14], acetazolamide challenge test [9,14], transcranial Doppler ultrasonography and electroencephalogram (EEG) monitoring, carotid stump pressure

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Box 1. Indications for temporary or permanent balloon occlusion

1. Surgically untreatable aneurysms
   - Giant
   - Fusiform
   - Cavernous
   - Petrous
   - Cervical carotid aneurysms
2. Head and neck cancer: carotid or vertebral artery sacrifice required for en bloc resection or devascularization
3. Control of hemorrhage
4. Arteriovenous fistulae (not otherwise manageable)
5. Assessment presacrifice of injured vessel (eg, dissection)

measurement, and xenon-cerebral blood flow (CBF) or single photon emission computed tomography (SPECT) quantitative CBF measurement, can provide useful information about the cerebral arterial anatomy and physiology of a particular patient [4,5,7,8,17,18]. These tests, when properly performed and interpreted, can provide a high degree of certainty that permanent occlusion of a given vessel will or will not result in a deficit related to hypoperfusion or ischemic infarction [7,8,19,20]. If the occlusion is not tolerated, consideration must be given to the abandonment of permanent arterial sacrifice or preocclusion revascularization via a surgical bypass procedure.

There is no doubt, however, that despite the satisfactory outcome of provocative tests, a few patients treated with a Hunterian strategy are at risk of stroke or neurologic deficit because of hypoperfusion or postocclusion thromboembolism [8]. Our institution therefore uses a selective revascularization protocol (Table 1) unlike some other institutions, which advocate a universal revascularization approach [21]. Briefly, a selective approach involves using provocative testing and performing revascularization based on the results of the provocative testing, and the universal approach involves distal revascularization for all vessels requiring sacrifice. The assessment of cerebrovascular reserve before a contemplated parent artery sacrifice or an extended temporary occlusion (eg, as may be necessary in the reconstruction of a giant aneurysm) at our institution has been previously described [7]. Essentially, cerebrovascular reserve is assessed using four modalities: neuroclinical, hemodynamic, neurophysiologic, and provocative. These modalities are assessed together in an effort to predict tolerance to parent artery sacrifice. Neuroclinical assessment involves examination of the awake patient for any corresponding deficits during BTO. Hemodynamic assessment during temporary occlusion involves observation of cross-flow on DSA from the contralateral to ipsilateral hemisphere and radionuclide CBF studies (^{99m}Tc-hexamethylpropyleneamine oxime–SPECT) with maintenance of normotension. Neurophysiologic testing involves EEG assessment for any changes during occlusion. Provocative testing involves pharmacologically reducing the patient's mean arterial pressure to approximately two thirds of baseline during temporary occlusion and a neuroclinical reassessment [7,14,22]. This testing has been associated with a high correlation to tolerance of permanent sacrifice of the carotid artery in 18 of 19 patients [22].

Van Rooij et al [23], in a study of 17 patients who underwent successful BTO of the cervical internal carotid artery with neurologic and neurophysiologic monitoring (no complications noted) followed by permanent occlusion of the carotid artery, demonstrated that not a single patient had suffered an ischemic event at the 21-month follow-up. Mathis and colleagues [8], in their extensive experience of 500 temporary internal and common carotid artery balloon occlusions, found a 0.4% permanent neurologic complication rate. Overall, in the literature, the

Table 1
Indications for bypass from temporary balloon occlusion: institutional protocol

Clinical	EEG	SPECT	Hypotension	Intervention
Pass	Pass	Pass	Pass	PO
Pass	Fail	Fail	Fail	PO + low-flow bypass (STA-MCA)
Fail	Fail	Fail	Fail	PO + high-flow bypass (venous/radial artery bypass)
Pass	Pass	Fail	Fail	PO + low-flow bypass (STA-MCA)

Abbreviations: PO, permanent occlusion; STA-MCA, superficial temporal artery to middle cerebral artery.

complication rate associated with BTO is approximately 1.5% [7]. The generally good outcome in patients who have permanent occlusion is evident when considering the Cooperative Study of Intracranial Aneurysms and Subarachnoid Hemorrhage [24], in which 100 of 129 patients with unruptured aneurysms had a good outcome with a Hunterian strategy with no provocative testing. Echoing these results are those of Drake et al [4], who reported ischemic complications in 3 of 114 patients who underwent parent artery occlusion (all complications were thought to result from thromboembolism rather than hypoperfusion—this may represent a technical failure), again, with no provocative testing. Graves et al [25] found a permanent neurologic complication rate of 1 of 19 patients in their endovascular internal carotid occlusion series.

The techniques of parent vessel test occlusion have also been refined to place the balloon immediately proximal to the lesion to be occluded, even quite distally in the cerebral circulation, so as to minimize the column of thrombus that develops beyond the balloon; reduce the risk of recanalization related to collaterals to the arterial segment just proximal to the lesion; and minimize trauma and ischemia to proximal collaterals, perforators, and end arteries [7]. This more selective approach may also result in a better occlusion rate and improved resolution of giant aneurysms because of greater relative flow reduction within them [7]. In addition, the technique can be used to assess collaterals during occlusion of posterior circulation vessels, such as the posterior cerebral artery P1 segment, the distal vertebral artery, the posterior inferior cerebellar artery, and even the proximal basilar artery [7,21,25]. The issues of collateral flow, perforator occlusion, and ischemia are particularly relevant in these regions.

Technique and devices for balloon test occlusion

The following is a description of the protocol used at our institution. Before the procedure, the patient is assessed medically, particularly from a cardiovascular reserve point of view (in terms of evaluation of fitness for induction of hypotension). An anesthesiologist is in attendance for hemodynamic monitoring and supervision of induced hypotension. The patient is examined for femoral and leg pulses. A baseline neurologic examination is performed. An arterial line, intravenous line, electrocardiogram (EKG) monitor, EEG monitor, and Foley catheter are placed. The patient is given antibiotics (cephalothin or oxacillin). Femoral line sheaths (6.5-French right and 5.5-French left) of appropriate lengths are then placed via micropuncture access and a modified Seldinger technique. Once the sheaths are in position, a loading dose of heparin (60 U/kg) is intravenously administered to achieve an activated coagulation time (ACT) of 300 seconds. At our institution, it is also routine practice for a diagnostic cerebral angiogram to be performed before BTO is attempted. Bilateral external carotid angiography is also performed to assess the anatomy of the superficial temporal arteries, should these vessels be required for bypass surgery. If angiography has been performed, we start with an arch run to image the cervical and intracranial vessels. This serves as a baseline anatomic reference, which is repeated after trial balloon occlusion. After diagnostic angiography, the vessel to be occluded is selected with a 6-French guide catheter using over-the-wire and roadmap techniques. If access is particularly difficult (eg, because of an anomalous origin of the left common carotid artery [ie, the so-called "bovine arch"]), an exchange length wire can be left in the vessel of interest along with the diagnostic catheter. The guide catheter is then navigated to the vessel of interest over the exchange length wire. It is our practice to keep all catheters that might be exchanged during the procedure connected to a heparinized saline drip via rotating hemostatic adapters so as to avoid thromboembolic complications. Once the guide catheter is in an appropriate position proximal to the target occlusion site, contrast is gently injected to ensure that placement of the guide catheter did not cause a dissection. The diameter of the target vessel is then measured using standard calibration techniques. With modern three-dimensional (3D) noninvasive imaging (MRA and CTA), a measurement can also be obtained before BTO. It is our practice to confirm the measurements of any previous angiographic study with those obtained during this study. The appropriate balloon is then prepared in standard fashion as outlined by the particular manufacturer. It is critical to avoid air pockets in any balloon system and to study diameter and volume curves of the balloon carefully. Balloons used for extracranial BTO are compliant balloons (Figs. 1 and 2). One example of a compliant balloon is the HyperForm nondetachable balloon

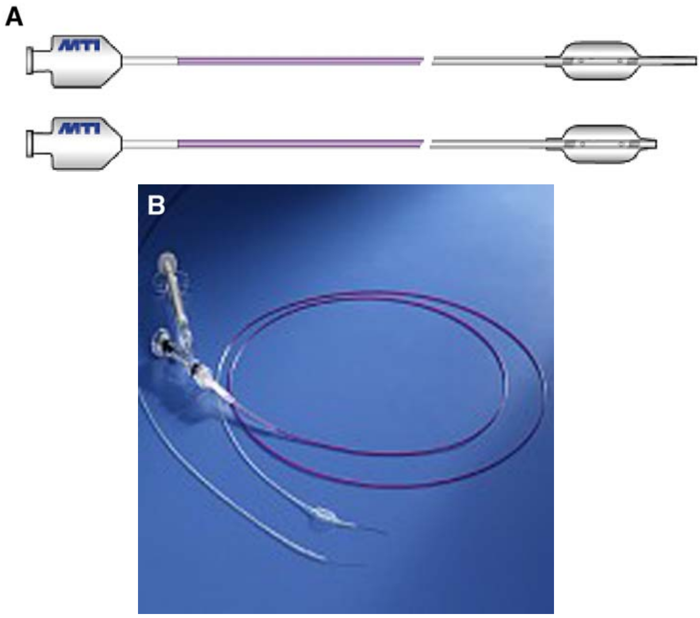

Fig. 1. HyperForm temporary occlusion balloon catheters (Micro Therapeutics, Irvine, California).

(Micro Therapeutics, Irvine, California). We have also used coronary balloons for intracranial BTO because of the greater diameter precision achieved with these balloons. When the internal carotid artery is targeted for occlusion, we place the guide catheter below the petrous (C2) segment of the internal carotid artery and carefully avoid the more distal petrous segment of the carotid artery, because a greater risk of vessel dissection is associated with catheter placement in this region. Baseline blood pressure and SPECT perfusion values are obtained before the procedure. Before the balloon is inflated, a baseline neurologic examination is performed

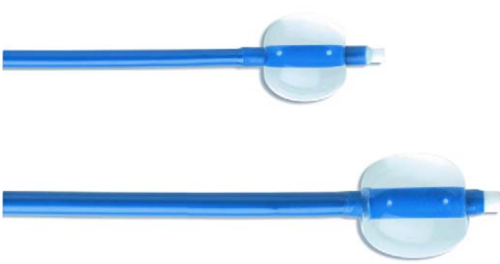

Fig. 2. The Concentric Balloon Guide Catheter (Concentric Medical, Mountain View, California), a commonly used balloon test occlusion catheter.

and an EEG tracing is obtained in the angiography suite. Sedation is given (fentanyl, no benzodiazepines). Once the guide catheter is in position and the balloon is ready for use, we navigate the balloon to the area of chosen temporary occlusion. After the balloon has been positioned, it is carefully inflated to the previously determined vessel diameter (Fig. 3). Contrast is gently injected through the guide catheter to confirm occlusion. Most compliant balloons can slowly deflate, so it is our practice to check for occlusion every 5 minutes. A contrast column below the balloon, which can be seen fluoroscopically, gives some assurance that the vessel is indeed occluded and can be followed to confirm continuous occlusion. Once occlusion has been achieved, a neurologic examination is performed every 5 minutes. At approximately 15 minutes, if the results of the neurologic examination are unchanged, the anesthesiologist is asked to reduce the mean arterial pressure to 30% below baseline. Ideally, the patient is monitored for 15 minutes at normotension and for 15 minutes with hypotension (30% below baseline mean arterial pressure). An arch angiogram of the intracranial circulation is performed to assess collateral flow while the target vessel is temporarily occluded (see Fig. 3). Alternatively, a selective angiogram of

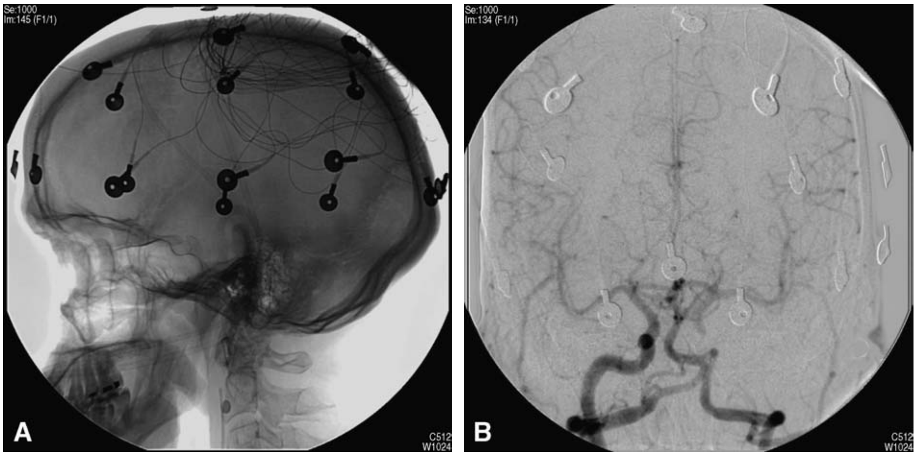

Fig. 3. A case of a patient with head and neck cancer who underwent temporary balloon occlusion of the left internal carotid artery before carotid artery sacrifice during radical resection. (*A*) MediTech (Watertown, Massachusetts) balloon in situ in the left internal carotid artery. (*B*) Arch angiogram showing good collateral flow to the left hemisphere from the right internal carotid artery via the anterior communicating artery.

the other relevant cervical vessels can be performed to assess collateral flow (Fig. 4). A ^{99m}Tc (Pertechnetate) tracer is intravenously administered at this stage. If the patient develops a deficit or EEG changes during BTO, the balloon is immediately deflated and an angiogram is performed. Embolic occlusion of distal vessels should be ruled out by observing capillary phase runs to assess the perfusion of the entire parenchyma. If no EEG or clinical change occurs during BTO, the balloon is deflated after 30 minutes; final angiography is performed of the target vessel to rule out a dissection and thromboembolic complications. As with any angiographic run to assess parenchymal perfusion, imaging is extended to the capillary and venous phases. The balloon and diagnostic catheters are then removed, followed by the sheath. The puncture site is closed with a Perclose device (Abbott, Redwood City, California), or when the ACT is less than 150 seconds, bleeding at the site can be controlled with manual compression. It is our practice not to give protamine unless a hemorrhagic complication occurs. The patient is then transferred to the nuclear medicine unit, and a repeat SPECT scan is performed. The patient is admitted to the neurointensive care unit for 24 hours after the procedure, where routine postangiography checks (eg, groin site observations, leg pulses, leg movement) and hourly neurologic examinations are performed. A postprocedure EKG is obtained.

Technique of permanent occlusion of the vertebral or carotid artery

If the BTO does not show evidence of neurologic compromise, permanent occlusion is planned via an endovascular or surgical approach. If an endovascular option is chosen, the patient is given heparin to achieve an ACT of 300 seconds after sheath placement. Patients usually receive a loading dose of clopidogrel (75 mg daily for 3 days before the procedure) and aspirin (325 mg daily beginning 10 days before occlusion).

The endovascular procedure is performed with an anesthesiologist in attendance for hemodynamic monitoring and to maintain normotension. An arterial line, intravenous lines, EKG and EEG monitors, and a Foley catheter are placed. Midazolam and fentanyl are administered for sedation. Baseline neurologic and leg pulse examinations are performed. Bilateral 6.5-French femoral sheaths are placed, and intravenous heparin (to an ACT of 300 seconds) and antibiotics (usually cefazolin) are given. The vessel to be occluded is approached using a 6-French Envoy catheter. A single-vessel cervical and intracranial injection is then performed. Because of the current limited availability of detachable vascular balloons, platinum microcoils are packed into the parent vessel until angiographic occlusion is achieved. It has been our practice to use a guide catheter capable of temporarily occluding the parent vessel, such as the Concentric Balloon

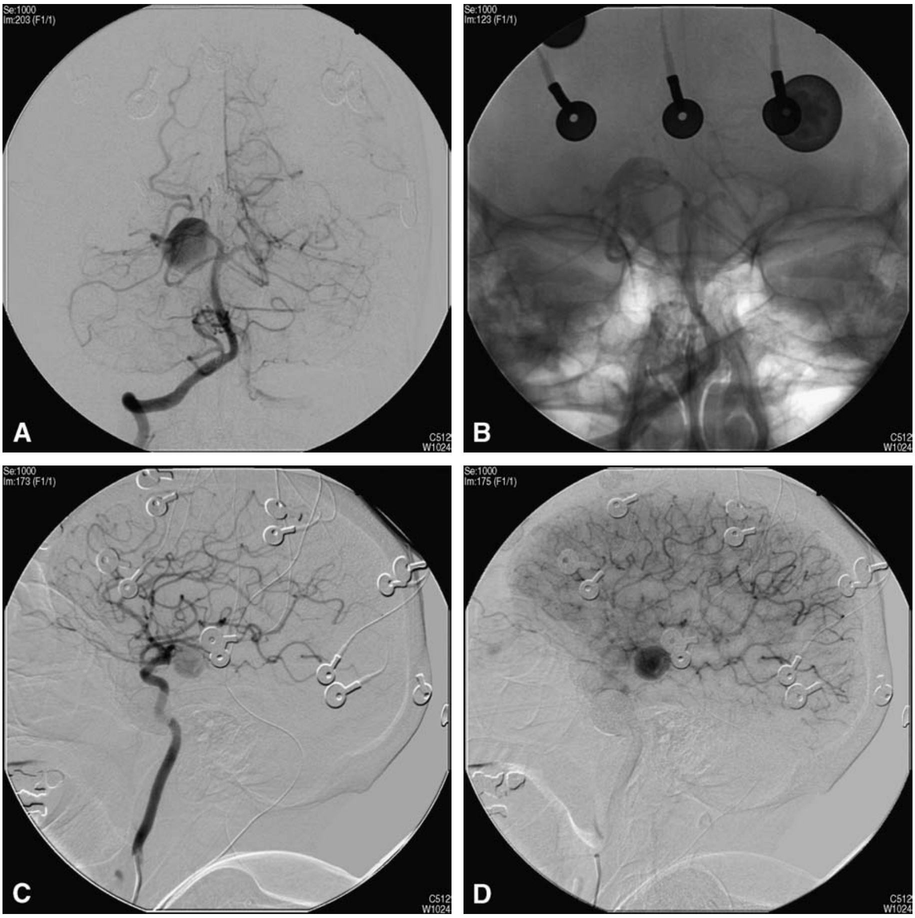

Fig. 4. A case of a patient with a large right P1 segment aneurysm incorporating the right posterior communicating artery origin. Potential P1 sacrifice with or without P1 distal bypass was planned. (*A*) Anteroposterior vertebral artery angiogram, demonstrating the P1 aneurysm. (*B*) HyperForm balloon (Micro Therapeutics, Irvine, California) in situ in the right P1. (*C, D*) Late arterial phase and capillary phase lateral right internal carotid artery angiograms with the balloon inflated showing filling of the aneurysm from the posterior communicating artery. The patient therefore required P1 sacrifice with distal bypass.

Guide Catheter (Concentric Medical, Mountain View, California). This guide catheter allows for flow arrest until a stable coil mass has been deployed and can be exchanged with the Envoy catheter. One or two oversized (relative to the parent vessel) ‘‘basket coils’’ are initially placed proximal to the aneurysm. The basket coil mass is then filled with helical detachable coils or pushable coils until vessel occlusion has been achieved (Fig. 5). A three-vessel cerebral angiogram can then be performed with an aortic pigtail catheter to assess collateral flow, or a selective study can be performed (see Fig. 5C). The sheaths are then removed, and bleeding at the puncture site is controlled with manual compression when the ACT has normalized, or the site is closed with the Perclose device. Protamine is not given. The patient is then re-examined neurologically; leg pulse and groin checks are performed, and a CT scan is obtained. The patient is admitted to the neurointensive care unit for 48 hours, where strict normotension is maintained and hourly neurologic checks are done. The patient is gradually mobilized on postprocedure day 2 and kept in the hospital for a total of approximately 5 days. A repeat CT/MRI perfusion study is performed while the patient is still in the hospital, and the results are compared with the baseline study. The

Fig. 5. Permanent sacrifice of the left internal carotid artery in a patient who previously tolerated temporary balloon occlusion. (*A*) Proximal carotid balloon occlusion with a Concentric balloon (Concentric Medical, Mountain View, California) and definitive distal coil placement. (*B*) After occlusion, stasis of contrast is seen in the left internal carotid artery with flow diversion into the external carotid artery. (*C*) Right internal carotid artery study showing effective occlusion of the left internal carotid artery and good collateral flow into the left anterior circulation via the anterior communicating artery.

clopidogrel and aspirin is continued for 1 month; thereafter, the patient is maintained on aspirin only.

Summary

We believe that temporary and permanent endovascular balloon occlusions are safe and effective procedures for the assessment and treatment of conditions for which parent vessel sacrifice is contemplated. In selected patients, BTO can predict the outcome of parent vessel sacrifice with a high degree of accuracy. This avoids the potential morbidities of a universal revascularization strategy (ie, the risks of revascularization when it may not be required) or ischemic stroke after parent vessel sacrifice when inadequate collaterals exist. In addition, in experienced hands, permanent occlusion of intracranial arteries using endovascular techniques can be done with a high degree of safety [25]. Endovascular occlusion may permit vessel sacrifice closer to the lesion than is typically possible with open surgical techniques.

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