Balloon catheterization and occlusion of major cerebral vessels

F. A. SERBINENKO, M.D.

N. N. Burdenko Institute for Scientific Research in Neurosurgery, USSR Academy of Medical Sciences, Moscow, USSR

A balloon catheter technique for catheterization of human cerebral blood vessels is described. Temporary occlusion of different cerebral vessels was successfully accomplished in more than 300 cases, including investigations of collateral blood flow, intraarterial pressure, brain temperature, the vital staining of tumors, and the introduction of chemical agents. Temporary occlusion of the internal carotid artery makes possible angiography of the external carotid, while occlusion of separate branches of the external carotid permits selective angiography of its functioning branches. The balloon catheter is valuable in investigating arteriovenous and carotid-cavernous fistulas. With the help of a detachable balloon it is possible to occlude the cavity of arterial aneurysms or the afferent vessels of arteriovenous aneurysms; it is also useful as a means to shut off the blood flow to arterial aneurysms and carotid-cavernous fistulas when access is difficult. A method for reconstruction of the cavernous part of the carotid artery in cases of carotid-cavernous fistulas is described.

KEY WORDS • balloon catheter • temporary arterial and venous occlusion • selective angiography • arteriovenous aneurysm • carotid-cavernous fistula

When studying the problems of vascular neurosurgery in dealing with arterial and arteriovenous aneurysms and carotid-cavernous fistulas, one can trace two independent trends, namely, the extravascular and intravascular approaches. Both trends arose at approximately the same time, but the latter has been intensively developed during the last 10 years. When Dandy in 1935 first put a metallic clip on the carotid artery for a carotid-cavernous fistula, he became the first proponent of the extravascular trend in neurosurgery. It was Brooks in 1930 who laid the foundation of intravascular surgery by inserting a piece of muscle into the carotid artery to embolize a carotid-cavernous fistula.

The scope of intravascular approaches is being steadily expanded; artificial thrombosis of an aneurysm to encourage coagulation, the introduction of anticoagulants when the blood flow appears to be too slow, embolization of aneurysms with diverse plastics, stereotaxic anodic thrombosis, and thrombosis of aneurysms by means of magnetic fields are all being practiced. It has the special advantage of avoiding intracranial operative procedures.

For 40 years Brooks' operation has had both violent antagonists and energetic supporters. In 1964 his methods were improved by Arutiunov and Burlutsky so that the operation became more reliable and controlled. Tamponade of the carotid-cavernous fistula...
One of the first cases in which a balloon was used to occlude the carotid artery. Angiography of the external carotid a. carried out during temporary occlusion of the internal carotid a. in the study of an external carotid cavernous sinus fistula. 1 = balloon; 2 = external carotid; 3 = internal maxillary; 4 = middle meningeal; 5 = cavernous sinus; 6 = superior ophthalmic vein.

Selective angiography of a branch of the middle cerebral a. 1 = catheter; 2 = balloon.

FIG. 1. One of the first cases in which a balloon was used to occlude the carotid artery. Angiography of the external carotid a. carried out during temporary occlusion of the internal carotid a. in the study of an external carotid cavernous sinus fistula. 1 = balloon; 2 = external carotid; 3 = internal maxillary; 4 = middle meningeal; 5 = cavernous sinus; 6 = superior ophthalmic vein.

FIG. 2. Selective angiography of a branch of the middle cerebral a. 1 = catheter; 2 = balloon.

segment by muscle embolization became almost essential in the surgical treatment of carotid-cavernous fistulas; muscle emboli could be transported to the fistula hydraulically or by means of the Fogarty catheter. In 1969 we applied the technique of muscle embolization to fistulas formed by meningeal arteries and the cavernous sinus. Earlier Luessenhop, et al., reported x-ray contrast plastic-ball embolization of hemispheric arteriovenous aneurysms; this technique is now being applied to specific arterial embolization in arteriovenous aneurysms.

The use of an inflated balloon to occlude vessels in cardiovascular surgery opened still another phase of cerebrovascular surgery. In 1963 Fogarty, et al., used this technique to keep thrombi and emboli out of large vessels like the carotid, and Le Veen and Curruti and Jates used balloon catheters for the surgical treatment of arteriovenous aneurysms of the subclavian and femoral arteries. A few cases of artificially made carotid-cavernous fistulas have been described; these were the result of puncture of the cavernous segment of the carotid artery with a Fogarty catheter during attempts to shut thrombi out of the internal carotid artery.

Luessenhop and Velasquez have described the reaction of cerebral vessels to Silastic balls or an inflated balloon. In a case of arteriovenous aneurysm combined with supraclinoid arterial aneurysm, they demonstrated temporary obturation of the orifice of the arterial aneurysm with an inflated silicone balloon; isolation of the aneurysm from the circulating blood was visualized angiographically. Transfer of the plastic embolus or balloon catheter from the external into the internal carotid artery was facilitated by the current of the circulation. Despite the fact that these methods were not put into common practice, the investigation demonstrated the feasibility of the technique and the absence of related spasmogenic reactions in the cerebral vessels. Several methods of permanent occlusion of the internal carotid artery with a balloon have been reported. Electromagnetic techniques for the delivery of a silicone catheter into cerebral vessels may also prove useful, but will not be discussed in this paper.

This report describes our method of catheterization of cerebral vessels and the feasibility of their temporary or permanent oc-
Fig. 3. Investigation of collateral cerebral blood flow during temporary occlusion of cervical part of internal carotid a. by balloon. Left: Blood flow through anterior communicating a. 1 = balloon; 2 = anterior cerebral a.; 3 = middle cerebral a. on side of fistula; 4 = cavernous sinus. Right: Blood flow through posterior communicating a. 1 = catheter; 2 = balloon; 3 = vertebral a.; 4 = basilar a.; 5 = posterior communicating a.; 6 = carotid a.; 7 = cavernous sinus.

TABLE 1
Temporary diagnostic occlusion of major cerebral arteries

<table>
<thead>
<tr>
<th>Artery Ocluded</th>
<th>No. of Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>internal carotid</td>
<td>187</td>
</tr>
<tr>
<td>for external carotid</td>
<td>80</td>
</tr>
<tr>
<td>investigation*</td>
<td>15</td>
</tr>
<tr>
<td>for investigation of blood flow through posterior comm. artery</td>
<td>10</td>
</tr>
<tr>
<td>for investigation of blood flow through anterior comm. artery for occlusion of the siphon</td>
<td>82</td>
</tr>
<tr>
<td>ophthalmic</td>
<td>3</td>
</tr>
<tr>
<td>anterior cerebral (A1)</td>
<td>5</td>
</tr>
<tr>
<td>anterior cerebral (A2–A3)</td>
<td>23</td>
</tr>
<tr>
<td>middle cerebral (M1)</td>
<td>15</td>
</tr>
<tr>
<td>branches of middle cerebral</td>
<td>34</td>
</tr>
<tr>
<td>posterior cerebral</td>
<td>3</td>
</tr>
<tr>
<td>first section of external carotid</td>
<td>3</td>
</tr>
<tr>
<td>lingual</td>
<td>3</td>
</tr>
<tr>
<td>occipital</td>
<td>8</td>
</tr>
<tr>
<td>internal maxillary</td>
<td>10</td>
</tr>
<tr>
<td>middle meningeal</td>
<td>8</td>
</tr>
<tr>
<td>basilar</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>304</td>
</tr>
</tbody>
</table>

*Complications occurred in two cases.

Our past experience now permits elaboration of many diagnostic and therapeutic applications related to cerebral circulation. We started angiographic investigations with the help of an inflated silicone balloon in 1963. On February 8, 1964, we performed angiography of the external carotid artery after temporary occlusion of the internal carotid artery (Fig. 1). Since then we have designed balloons which can be used with ordinary angiographic needles; balloons 0.5, 0.7, 1.2, and 1.5 mm in diameter are now in use. The anterior, middle, and posterior cerebral arteries and their branches can be probed with the smallest balloon catheters, and the internal carotid artery can be occluded with larger sizes.

**Method**

Under local anesthesia the carotid artery is punctured with an angiographic needle.* The balloon catheter is then introduced into the

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*The author is preparing a separate paper describing in detail the operative techniques involved. For purposes of this paper, each use of the technique is briefly summarized in connection with the specific application under consideration.
artery through the needle. The balloon is filled with a contrast medium (0.05 to 0.1 cm³ triotраст, верографин, etc.) and then is directed under television monitoring into the proper vessels. Catheterization of the anterior cerebral artery is carried out with the help of a second balloon which occludes the trunk of the middle cerebral artery, or by compression of the contralateral carotid artery. In some cases the occlusion of one of the branches of the middle cerebral artery by one balloon allows catheterization of the functioning branches by another. The balloon is passed into the cerebral arteries exclusively by the flow of blood.

For probing vertebral and basilar systems and the posterior cerebral artery, either the Seldinger method of transfemoral catheterization of the vertebral artery or the Maslovski method of puncture of the horizontal section of the vertebral artery should be used. In almost all cases in both adults and children, a needle 1.5 mm in external diameter with a lumen of 1.3 mm is employed. Such a needle permits the simultaneous introduction of three 0.5 mm balloon catheters into different cerebral vessels.

Neither the two cervical loops of the carotid artery nor the largest curves of its siphon need be considered a serious obstacle to probing of the cerebral vessels. The only problem is withdrawal of the catheter from the carotid artery, especially when the balloon has been placed far from the puncture site, as in the anterior, middle, or posterior cerebral arteries.

Two types of balloon are used; one is used exclusively to occlude the vessel, and the other not only occludes but also allows passage of various liquids and contrast materials through a separate lumen in both directions.

Vessels may be temporarily or permanently occluded. Temporary occlusion of an arterial lumen makes the following possible:

1. Clinical and electro-physiological study of the collateral blood supply of a vascular system distal to the occluded vessel
2. Angiographic investigation of the collateral blood flow from systems adjacent to that of the occluded vessel
3. Trial of the therapeutic effect of occluding a vessel functioning as a shunt or the afferent vessel of an arteriovenous aneurysm
4. Study of the effect of reducing or eliminating blood flow in a vessel.

The use of a balloon provided with a lumen permits:

1. Selective angiography of a vessel located either distal or proximal to the occluded section (Fig. 2)
2. Injection of fluid-hardening plastics into an aneurysm
3. Injection of radiopaque materials for tumor staining
4. Supplying chemotherapeutic agents to a tumor.

Permanent occlusion of a vessel may be accomplished by injecting a solidifying filler into the balloon.

The duration of temporary vessel occlusion depends on the collateral blood supply of the system of the vessel occluded. We have found that the longest time during which temporary occlusion of the internal carotid artery can be maintained is 80 minutes.

General Results

From 1969 to 1972 more than 300 temporary diagnostic balloon occlusions of various cerebral vessels were carried out (Table 1). Complications arose in two cases; the patients were 50 and 20 years old and both died because of unexplained thrombosis of the middle cerebral artery. All our investigations were accomplished under local anesthesia. The balloon was repeatedly set in different sections of the artery. In spite of this, there was no instance of complications. In our search for a shunt opening, repeated occlusions were made particularly often in the cavernous section of the carotid artery. None of our patients showed evidence of local or generalized spasm of cerebral vessels, either clinically or angiographically.

Since the introduction of this method into clinical practice, all our cases of carotid-cavernous and arteriovenous aneurysms or fistulas located in the brain, scalp, face, or orbit have been studied by temporary occlusion of specific arteries. Table 1 shows that the internal carotid artery was the one most frequently occluded, probably because it is in this arterial distribution that vascular pathology is most commonly observed.
Balloon catheter occlusion of cerebral vessels

Fig. 4. Angiographic investigation of AV aneurysm by temporary occlusion of afferent vessels of aneurysm by balloons. Upper Left: General view of aneurysm fed by large branches of anterior and middle cerebral arteries. 1 = aneurysm; 2 = anterior cerebral a.; 3 = middle cerebral a. Arrow indicates branch of middle cerebral a. to be occluded; single crossed arrow indicates anterior cerebral a.; double crossed arrow indicates middle cerebral a. Upper Right: Balloon occlusion of a large branch of middle cerebral a. which was feeding aneurysm at site of balloon in upper left figure. Branches of anterior cerebral a. feeding aneurysm are clearly defined. 1 = balloon; 2 = anterior cerebral a.; 3 = middle cerebral a.; 4 = aneurysm; 5 = electrode. Single crossed arrow indicates anterior cerebral a. Lower Right: Skull film showing balloons in anterior and middle cerebral arteries. 1 = balloons; 2 = catheters. Single crossed arrow and double crossed arrow indicate anterior cerebral and middle cerebral arteries, respectively.

Fig. 5. Selective angiography of ophthalmic a. feeding AV aneurysm in the orbit during occlusion of supraclinoid part of carotid a. 1 = balloon; 2 = internal carotid a.; 3 = ophthalmic a.; 4 = branches of cavernous carotid feeding aneurysm; 5 = aneurysm.
Temporary Diagnostic Occlusion of Major Cerebral Vessels

Angiography of Vessels Distal to Occlusion

Matas Test and Collateral Circulation. In clinical practice the Matas test has served a fundamental role in evaluating the collateral blood circulation through the circle of Willis. However, the technique of applying digital pressure to the carotid artery in the neck has many shortcomings that challenge the reliability of this test. There is no clear notion of whether the common or internal carotid artery is being compressed. Moreover, the carotid artery and internal jugular vein are being compressed simultaneously. The role of the ophthalmic artery in the cerebral blood supply is reduced when the common carotid artery is compressed. Finally, the technique can produce undesirable reflex reactions from the carotid sinus.

Balloon occlusion of the internal carotid artery has none of these faults. The artery can be selectively occluded in its cervical, bone, cavernous, or supraclainoid segments. The balloon is usually positioned at the level of C1–3 where it contrasts well against the background of the soft tissues of the neck. With the first indications of an insufficient cerebral collateral circulation the artery is deoccluded. Repeated blood flow release ultimately demonstrates a collateral blood supply adequate for the cerebral hemisphere. Clinical and electrophysiological evaluations of the collateral blood circulation can be correlated with the angiographic study that usually accompanies the occlusive procedure. The method is particularly useful in patients who apparently cannot tolerate compression of the carotid artery. Intolerance to a Matas test occasionally gives the erroneous impression of an inadequate collateral hemispheric circulation due to hyperactivity of the carotid sinus. Balloon occlusion of the internal carotid artery permits a logical resolution of this problem. The following case illustrates this point.

Case 1. This 42-year-old man was being investigated for a suspected carotid-cavernous fistula. During a standard Matas test involving digital compression of the right carotid artery in the neck, a 5- to 7-second cardiac arrest was recorded on the electrocardiogram. Right carotid angiography indicated thrombosis of the cavernous sinus with a nonfunctioning fistula; blood flow in the internal carotid artery had been reversed so that the right external carotid arterial system was being supplied with blood from the circle of Willis (steal syndrome) through the internal carotid artery. Diagnostic exclusion of the internal carotid artery by balloon occlusion was undertaken. The internal carotid artery was punctured under local anesthesia; digital carotid pressure for 5 to 7 seconds again produced electrocardiographic evidence of a 7- to 10-second cardiac arrest. A balloon was introduced into the artery to produce occlusion at the C3–4 level and in the cavernous section of the artery. The patient tolerated the occlusion for 10 minutes without any clinical symptoms or EKG abnormality.

If a carotid-cavernous fistula is functioning, compression of the carotid artery in the neck may indicate an insufficient collateral hemispheric blood supply that may be genuine or artificial. Genuine insufficiency is a consequence of extreme emptying of the circle of Willis’ blood flow into the cavernous sinus; at times this evacuation can be so complete that the total blood flow in connecting arteries is directed into the cavernous sinus, thus leaving the middle cerebral artery exsanguinated. In these cases balloon occlusion of the cavernous segment and occlusion of the shunting foramen result in a redirection of adequate blood flow through collaterals to the blood supply of the cerebral hemisphere. It is worth noting that in the presence of a carotid-cavernous fistula, the ophthalmic artery may play an important role in the supply of blood to the middle cerebral artery.

Among 50 patients examined by this technique because of a suspected carotid-cavernous fistula, insufficiency of the collateral hemispheric blood supply was observed 10 times; all of these cases were found to have an “artificial” insufficiency. The following case was typical.

Case 2. A 30-year-old man had been recurrently hospitalized for traumatic carotid-cavernous fistula on the right side. When examined in 1968, squeezing the right carotid artery in the neck for 1 to 2 minutes resulted in loss of consciousness and an epileptic seizure; the patient was discharged for a period of systematic digital compression of...
the carotid at home. However, he could not proceed with his "training" and was hospitalized again in January, 1971. Cervical compression of the right carotid artery produced signs of depletion of the blood supply to the right cerebral hemisphere. Angiographic investigation showed poor development of the right posterior communicating artery; the anterior portion of the circle of Willis was normal. Under local anesthesia the right carotid artery was punctured; the cavernous segment and the shunting orifice were then occluded with a balloon. There were no signs of inadequate blood supply. Permanent occlusion of the cavernous segment and that of the shunting foramen were accomplished. At the time of discharge the patient was asymptomatic and the fistula nonfunctioning.

Angiographic Investigation of the Sources of Collateral Cerebral Blood Supply. The occlusion of the cervical internal carotid artery permits angiographic determination of the collateral role of the anterior and posterior communicating and ophthalmic arteries and to ascertain any competitive interrelations among these arteries. The technique also makes it possible to investigate all the collateral sources during a single angiographic study; with this purpose in view we perform vertebral angiography as part of the same diagnostic procedure (Fig. 3 and cover).

With carotid-cavernous fistulas the collateral hemispheric blood circulation is investigated during occlusion of the internal carotid artery. However, these are not equivalent investigations. In one instance the anterior and posterior portions of the circle of Willis, the ophthalmic artery, the suprafistulous portion of the internal carotid artery, and the blood flow to the cavernous sinus are under study; in the other, occlusion of the carotid-cavernous segment and that of the shunting foramen will accurately preview the postoperative state of the collateral blood supply to the cerebral hemisphere, as well as further delineate the position of the ophthalmic artery.

Investigation of the Collateral Blood Flow into the Ophthalmic Arterial System. This study, conducted from the external carotid artery, is of paramount importance if a trapping procedure is anticipated or if it is desirable to exclude the ophthalmic artery. The problem can be solved by temporary balloon occlusion of the internal carotid artery and the orifice of the ophthalmic artery or by specific occlusion of the orifice of the ophthalmic artery. This is the most useful method to permit examination of eye function, ophthalmotonus, arterioretinal blood pressure, etc., in 10 or 15 minutes.

Temporary Occlusion of Anterior, Middle, and Posterior Cerebral Arteries and their Branches. These applications of the procedure contribute additional details regarding the collaterals serving the system of the vessels occluded.

The anterior cerebral artery can be occluded both proximal and distal to the anterior communicating artery. In the former case, blood flow to the anterior cerebral artery through the anterior communicating artery is under study; in the latter, blood flow through anastomoses from the middle and posterior cerebral arteries to the system of the anterior cerebral artery is being investigated. Occlusion of the middle cerebral artery permits investigation of anastomosis in the gray matter with the anterior and posterior cerebral arteries. Occlusion of the posterior cerebral artery can be accomplished both proximal and distal to the posterior communicating artery.

Temporary occlusion of the specific vessels is of great prognostic importance in estimating the consequences following surgical exclusion, or in anticipation of embolization of afferent vessels to arteriovenous aneurysms, especially those located in functionally important areas. The following is a typical case.

Case 3. A 20-year-old patient had a history of several subarachnoid hemorrhages. An arteriovenous aneurysm located in the system of the left middle cerebral artery was identified angiographically. To explore the possibility of embolization of the aneurysm's afferent arteries, the following special investigation was carried out. The internal carotid artery was punctured under local anesthesia. Two 0.5 mm-diameter balloon catheters were introduced simultaneously into the middle cerebral artery. Each of two afferent vessels was selectively occluded for 30 to 40 minutes. Meanwhile, the blood supply to the aneurysm from neighboring systems was investigated angiographically.

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At the moment of occlusion of the arteries, no neurological defects developed. The afferent vessels to the aneurysm were then successfully embolized with plastic balls.

The following case illustrates the functional importance of the feeding vessels of an arteriovenous aneurysm as demonstrated in a preoperative investigation with balloon occlusion.

Case 4. A 33-year-old patient had angiographic evidence of a large arteriovenous aneurysm of the left temporal lobe supplied with blood by a large branch of the medial cerebral artery and by several branches of the anterior cerebral artery (Fig. 4). A balloon occlusion was carried out by introducing balloons with a diameter of 0.7 mm into the anterior and middle cerebral arteries. Occlusion of the branch of the middle cerebral artery produced no symptoms; simultaneous angiography showed that the aneurysm was also fed by branches of the anterior cerebral artery. After deocclusion of the middle cerebral artery, the anterior cerebral artery was occluded; 2 minutes later paralysis and paresthesia of the contralateral leg developed, followed by marked paresis of the arm and sensory aphasia. After 5 minutes the anterior cerebral artery was deoccluded and all the symptoms disappeared in reverse order, taking 10 minutes to 1 hour for complete regression. These data determined subsequent surgical tactics. The removal of the aneurysm could not begin with the part fed by the anterior cerebral artery, but knowledge of the location of the veins draining the aneurysm made it possible to begin the operation just outside the "forbidden" zone. The aneurysm was removed totally.

![Fig. 6. Selective angiography of carotid-basilar anastomosis during balloon occlusion of internal carotid at the level of the ophthalmic a. Investigation of blood flow through posterior communicating a. 1 = balloon; 2 = internal carotid a.; 3 = carotid-basilar anastomosis; 4 = basilar a.; 5 = posterior communicating a.](image)

![Fig. 7. Angiography of the basin of the external carotid a. in a fistula formed by arteries of the dura mater and cavernous sinus during temporary occlusion of internal carotid a. 1 = balloon; 2 = "stump" of internal carotid a.; 3 = external carotid a.; 4 = internal maxillary a.; 5 = superficial temporal a.; 6 = middle meningeal a.; 7 = supplementary middle meningeal a.; 8 = cavernous sinus; 9 = superior opthalmic vein; 10 = inferior petrosal sinus.](image)
Balloon catheter occlusion of cerebral vessels

**Fig. 8.** Carotid-cavernous fistula. After trapping operation the fistula is being fed by a dilated ophthalmic artery. *Left:* Angiography of external carotid a. 1 = “stump” of internal carotid a.; 2 = external carotid a.; 3 = internal maxillary a.; 4 = ophthalmic a.; 5 = cavernous sinus; 6 = clips on carotid a. *Right:* Angiography of middle meningeal a. during balloon occlusion of internal maxillary a. distal to middle meningeal a. demonstrating anastomosis of the middle meningeal a. with the ophthalmic a. 1 = balloon; 2 = external carotid a.; 3 = internal maxillary a.; 4 = middle meningeal a.; 5 = ophthalmic a.; 6 = clips.

**Angiography of Vessels Proximal to Occlusion**

In certain cases it is desirable to make separate angiographic studies of the internal or external carotid arteries and their branches. The needle employed in our occlusion procedure permits the simultaneous introduction of several balloon catheters into one artery and the subsequent injection of contrast material for angiographic study. Occlusion of the artery reproduces the conditions that could be expected following its thrombosis; the contrast material then flows naturally into functioning vessels proximal to the site of the occlusion. This principle is used for selective angiography of the carotid arteries and their branches, the ophthalmic artery (Figs. 5 and 6), meningeal arteries running away from the siphon, and all the branches of the external carotid artery.

**Angiography of the External Carotid Artery and its Branches.** Much scientific work has been directed toward the creation of a contrast method for study of this artery; however, this problem has not been solved satisfactorily. Temporary balloon occlusion of the internal carotid artery can be accomplished without difficulty even if the needle is placed in the common carotid artery.
When the internal carotid has been occluded the contrast material flows into the external carotid, in which the physiological conditions of blood flow have remained unchanged throughout the procedure (Fig. 7). This procedure has become comparatively simple and is now being used in all cases with angiopathology involving the external carotid artery. It is also used for investigation of collateral circulation through the ophthalmic artery for study of angiopathology in the orbit, arteriovenous aneurysms, carotid-cavernous fistulas, etc.

The need for angiographic investigation of the external carotid artery is emphasized by the data cited in Table 1; among 187 in-
Balloon catheter occlusion of cerebral vessels

Investigations of the internal carotid artery, angiography of the external carotid was done 80 times.

Introduction of a balloon into the external carotid artery permits occlusion of its trunk or branches at any level, as well as study of the hemodynamics of adjoining arterial systems. In a case of fistula between the middle meningeal artery and the cavernous sinus, the middle meningeal artery was occluded with a balloon in its bone section. In another case, after a trapping procedure, the carotid-cavernous fistula functioned at the expense of blood flow from an enlarged ophthalmic artery. In a case requiring selective angiography of the middle meningeal artery, the maxillary artery was occluded more distal to the middle meningeal (Fig. 8).

Selective Angiography of Carotid Arteries.
The needle may be placed in the common carotid artery for occlusion of the first section of the external carotid artery. From this position the balloon may be directed to either the external or internal carotid arteries. The occlusion of one then permits angiographic injection of the functioning artery.

Occlusion of the Arteries of the Vertebral and Basilar Systems

Occlusion of one vertebral artery permits functional and angiographic investigation of the other. From a technical point of view it is not difficult to accomplish occlusion of the basilar artery at different levels. Occlusion of the posterior cerebral artery is also relatively easy. Figure 9 shows an arteriovenous aneurysm supplied from the right posterior cerebral artery. In this case, prior to embolization of the afferent vessels of the aneurysm, the posterior cerebral artery was occluded with a balloon for 10 minutes preceding control angiography. The balloon had been introduced into the posterior cerebral artery through the left vertebral artery, which in turn had been catheterized through the femoral artery according to Seldinger.

**TABLE 2**

Permanent therapeutic occlusion of major cerebral vessels

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Site of Occlusion</th>
<th>No. of Operations</th>
<th>Date of First Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>carotid-cavernous fistulas</td>
<td>various parts of cavernous segment of internal carotid</td>
<td>38</td>
<td>4/24/70</td>
</tr>
<tr>
<td>aneurysm of subclinoid part of carotid</td>
<td>subclinoid part of carotid at level of aneurysmal neck</td>
<td>3</td>
<td>4/29/70</td>
</tr>
<tr>
<td>nasal hemorrhages</td>
<td>anterior knee of cavernous segment of carotid</td>
<td>5</td>
<td>5/29/70</td>
</tr>
<tr>
<td>large aneurysm of cavernous section of carotid</td>
<td>internal carotid at C-1 level</td>
<td>4</td>
<td>8/19/70</td>
</tr>
<tr>
<td>AV aneurysms in ophthalmic and middle cerebral artery systems</td>
<td>ophthalmic artery &amp; subophthalmic part of carotid</td>
<td>1</td>
<td>6/16/71</td>
</tr>
<tr>
<td>AV aneurysm of pachymeninx</td>
<td>1) posterior knee of cavernous segment of carotid</td>
<td>3</td>
<td>6/16/71</td>
</tr>
<tr>
<td></td>
<td>2) extracranial section of middle meningeal artery</td>
<td>1</td>
<td>6/21/71</td>
</tr>
<tr>
<td>AV aneurysm of brain carotid-cavernous fistulas</td>
<td>feeding vessels of aneurysm</td>
<td>71</td>
<td>11/10/71</td>
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<tr>
<td>aneurysms of basilar artery fistula between basilar artery &amp; basilar plexus</td>
<td>aneurysmal cavity</td>
<td>1*</td>
<td>1/24/73</td>
</tr>
<tr>
<td>AV aneurysm of orbit aneurysm of supraclinoid part of carotid</td>
<td>basilar artery &amp; posterior communicating artery</td>
<td>1*</td>
<td>11/23/73</td>
</tr>
<tr>
<td></td>
<td>middle part of ophthalmic artery</td>
<td>1</td>
<td>11/28/73</td>
</tr>
<tr>
<td></td>
<td>aneurysmal neck</td>
<td>3</td>
<td>10/1/73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10/24/73</td>
</tr>
<tr>
<td>Total</td>
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<td>162</td>
<td></td>
</tr>
</tbody>
</table>

*Two patients died; there were no complications in the others.
Temporary Therapeutic Occlusion of Major Cerebral Vessels

Artificial clotting of arterial aneurysms has been attempted by many investigators. In 1966, Kikut and Serbinenko\(^1\) determined several zones of blood circulation in aneurysms. Reduction of the vascular lumen partially reduces the blood circulating in an aneurysm. We believe this reduction can be combined effectively with an increase in the coagulative properties of the blood and a change in the electrical charge of the intima in the aneurysm as a treatment of aneurysms.

In 1969 Khilko\(^1\) showed that it was clinically feasible to create a stable thrombus in the aneurysm by saturation with coagulants and cessation of blood flow in the aneurysm by surgical reduction of the lumen of the carotid. The technique involves narrowing the artery with a special clamp. In 1956 Logue\(^6\) clipped the anterior cerebral artery to isolate an aneurysm of the anterior communicating artery from the circulating blood; in 1970 Tindall, et al.,\(^27\) added narrowing of the lumen of the exposed contralateral common carotid artery to Logue’s procedure.

We prefer to reduce blood flow in an artery supplying an aneurysm by inflating a balloon in the artery. For aneurysms located in the distribution of the internal carotid artery we propose the following method. The balloon is
introduced into the internal carotid artery and then inflated to a volume sufficient to shut off blood flow in the carotid; this permits exclusion of the aneurysmal blood supply. The time when the aneurysm no longer fills is determined angiographically.

The volume of the balloon that produces the required hemodynamic condition in the vessel is precisely measured. The artery is deoccluded and the original conditions of circulation in the vessel and aneurysm are restored. Substances increasing coagulation are then injected into the artery for several seconds to fill the aneurysm. Behind the coagulants a balloon is blown up to a previously determined size; this balloon serves to exclude the coagulant-filled aneurysm from the circulation. The vessel is then irrigated with the natural blood circulation. This may be repeated several times until angiography demonstrates that the aneurysmal cavity has been clotted successfully. We be-

Fig. 12. Determination of the level of rupture of the cavernous part of the carotid in a case of carotid-cavernous fistula. Left: Study of level of rupture of artery by contrasting distal part of carotid artery with contrast substance going through balloon that has occluded the artery. 1 = catheter; 2 = balloon; 3 = internal carotid a.; 4 = perforation in carotid a.; 5 = cavernous sinus. Upper Right: Study of rupture level in carotid a. and its size. 1 = balloon situated in cavernous part of carotid a.; 2 = balloon bulging through fistula. Lower Right: Balloon study of level and size of fistula. Balloon penetrated through fistula to form hourglass. Part of balloon is located in carotid a. (1), and other part in cavernous sinus (2).
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Fig. 13. Carotid-cavernous fistula eliminated from blood flow by permanent occlusion of cavernous part of carotid a. Left: Fistula before operation. 1 = internal carotid a.; 2 = ophthalmic a.; 3 = anterior cerebral a.; 4 = middle cerebral a.; 5 = posterior communicating a.; 6 = posterior cerebral a.; 7 = basilar a.; 8 = cavernous sinus; 9 = superior ophthalmic v. Right: Vertebral angiography after operation. Posterior communicating a. is feeding middle cerebral and ophthalmic arteries. 1 = catheter; 2 = balloon; 3 = vertebral a.; 4 = basilar a.; 5 = posterior communicating a.; 6 = internal carotid a.; 7 = middle cerebral a.; 8 = ophthalmic a.

Believe this method may become a practical means of creating a clot in an aneurysm. The most important feature of this method is the selective saturation of the vascular system with coagulants; only the vessel burdened with the aneurysm is treated. Moreover, the intraluminal diameter of the vessel could be reduced to exactly the desired size by repeating the procedure as many times as necessary. For aneurysms of the anterior communicating and anterior cerebral arteries, which are supplied with blood from both carotid arteries, it will probably be necessary to partially occlude both carotids temporarily with balloons or to occlude one carotid and the anterior cerebral portion of the other. Certainly variations of this idea can be adapted for use in the basilar artery system.

Permanent Occlusion of Major Cerebral Vessels

We propose the following method for permanent occlusion of blood vessels. A balloon may be introduced into the vessel through a needle to a specifically determined section of the vessel or abnormality; this may be an anatomic defect, a fistula or wound, an aneurysmal neck. This method was used for permanent occlusion of all parts of the interna carotid artery proximal to the posterior communicating artery. After checking the position, the balloon may be blown up with quickly solidifying contrast material; the catheter may then be severed by the cutting edge of the needle in the arterial lumen. Proximal parts of both catheter and needle can then be removed from the artery.

The problems encountered with permanent occlusion of major cerebral vessels deserve special consideration; in this paper we will confine ourselves to the summary of our experience (Table 2). Our permanent occlusion technique has enabled us to avoid performing complicated and protracted operations on the vessels in the neck and head. The difficulty
Fig. 14. Carotid-cavernous fistula eliminated from blood flow by balloon tamponade of cavernous sinus. Upper Left: General angiographic view. Cavernous sinus is draining all blood flow of internal carotid a. 1 = internal carotid a.; 2 = cavernous sinus; 3 = inferior petrosal sinus. Upper Right: Investigation of anterior part of circle of Willis by balloon occlusion of internal carotid a. 1 = balloon; 2 = cavernous sinus filled with contrast substance through anterior communicating a. Lower Left and Right: Postoperative skull film and angiogram showing balloon occlusion of cavernous sinus.
Fig. 15. AV aneurysm in the distribution of the middle cerebral a. Permanent occlusion of afferent vessels was accomplished by detached balloons. Upper Left: Preoperative angiogram of aneurysm. 1 = internal carotid a.; 2 = short afferent vessel; 3 = long looping afferent vessel; 4 = aneurysm. Upper Right: Postoperative angiogram, November 10, 1971. Short afferent vessel of aneurysm has been occluded by balloon (1). Long looping vessel feeds the aneurysm. Lower Left: Postoperative angiogram, November 22, 1971. Long looping afferent vessel of the aneurysm has now been occluded by the balloon (arrow). There is an insignificant blood supply to the aneurysm from the anterior choroidal a. (1). Blood flow in anterior cerebral a. has been reestablished (2). Lower Right: Control angiogram, December 7, 1971. A small part of the aneurysm (1) still is supplied by the anterior choroidal a. (2).
Balloon catheter occlusion of cerebral vessels

Fig. 16. AV aneurysm. Balloon occlusion of afferent supply from anterior and posterior cerebral arteries. Upper Left: Preoperative carotid angiogram. 1 = anterior cerebral a.; 2 = AV aneurysm; 3 = straight sinus. Upper Right: Carotid angiogram after permanent balloon occlusion of anterior cerebral a. 1 = balloon; 2 = anterior cerebral a. Lower Left: Vertebral angiogram 16 days after occlusion of anterior cerebral a. Lower Left: Vertebral angiogram 16 days after occlusion of anterior cerebral a. 1 = basilar a.; 2 = posterior cerebral arteries; 3 = AV aneurysm; 4 = balloon marker in anterior cerebral a. Lower Right: Vertebral angiogram after permanent balloon occlusion of posterior cerebral a. (sixth second of angiography). 1 = basilar a.; 2 = posterior cerebral arteries; 3 = balloon; 4 = balloon marker in anterior cerebral a.

of the procedure differs little from that of angiographic investigation (Figs. 10 and 11).

Occlusion of the artery is executed under local anesthesia; this is especially important because of the necessity of controlling the collateral cerebral blood supply. As a rule the artery is punctured with a needle whose lumen is 1.3 or 1.5 mm in diameter. In cases of carotid-cavernous fistula both the level and size of the carotid rupture can be determined exactly with the help of a balloon (Fig. 12). The carotid-cavernous segment is occluded precisely and locally, thus preserving the ophthalmic artery as a link between the circle of Willis and the external carotid artery (Fig. 13). Figure 14 shows a case in which exclusion of a carotid-cavernous fistula from the circulation was accomplished by tamponade of the cavernous sinus.

The patients on whom permanent occlusion was performed ranged in age from 3 to 67 years. All but two survived the procedure well and were discharged from the Institute in satisfactory condition.

A modification of our design allows us to separate the balloon from the catheter so as to leave it in place in the occluded vessel. With this modification, permanent occlusion of anterior, middle and posterior cerebral arteries and their branches and feeding vessels

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Fig. 17. Reconstruction of cavernous part of internal carotid a. in a case of carotid-cavernous fistula. Left: Preoperative angiogram of functioning carotid-cavernous fistula. 1 = internal carotid a.; 2 = middle cerebral a.; 3 = cavernous sinus; 4 = superior ophthalmic v.; 5 = inferior ophthalmic v. Right: Fistula is occluded with a balloon (1).

Fig. 18. Reconstruction of cavernous part of internal carotid a. in case of carotid-cavernous fistula with complete emptying of blood flow of internal carotid a. into cavernous sinus. Left: Preoperative angiogram shows carotid-cavernous fistula completely shunting blood of internal carotid. 1 = internal carotid a.; 2 = cavernous sinus; 3 = inferior petrosal sinus; 4 = internal jugular v. Right: Angiogram after reconstruction of carotid a. to redirect blood flow into cerebral vessels. 1 = balloon; 2 = internal carotid a.; 3 = anterior cerebral a.; 4 = middle cerebral a.; 5 = electrodes.
Balloon catheter occlusion of cerebral vessels

**Fig. 19.** Balloon occlusion of aneurysm of basilar artery. *Left:* Preoperative angiogram. 1 = basilar a.; 2 = posterior cerebral arteries; 3 = aneurysm. *Right:* Postoperative angiogram. 1 = balloon occluding aneurysmal cavity.

**Fig. 20.** Balloon occlusion of aneurysmal neck in supraclinoid part of carotid a. *Left:* Left carotid angiogram during operation. The balloon was introduced into aneurysmal cavity (note balloon marker above arrow). 1 = internal carotid a.; 2 = aneurysm; 3 = middle cerebral a. *Center:* Plain skull film after operation. 1 = balloon; 2 = fundus of aneurysm stained with contrast medium. *Right:* Postoperative angiogram after catheter was withdrawn from the balloon. 1 = internal carotid a.; 2 = balloon; 3 = fundus of aneurysm; 4 = middle cerebral a.
of arteriovenous aneurysms has become a reality (Figs. 15 and 16). Occlusion of the cavity of a cavernous sinus may be accomplished by balloons; in cases of carotid-cavernous fistula the cavernous segment of the carotid artery may also be reconstructed by these balloons (Figs. 17 and 18). Cavities of arterial aneurysms may also be occluded by balloons (Figs. 19 and 20).

The methods we have described for temporary and permanent occlusion of major cerebral vessels have been widely adopted at the Institute and the application of these methods is constantly being expanded. We have every reason to think that the balloon catheter technique will ultimately occupy an important place among neurosurgical procedures.

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Address reprint requests to: F.A. Serbinenko, M.D., N.N. Burdenko Institute for Scientific Research in Neurosurgery, USSR Academy of Medical Sciences, 5, Fadeev Street, Moscow 125047, USSR.