In carefully selected cases of arterial aneurysms and deep-seated arteriovenous malformations (AVM), when direct attack may be dangerous or impossible, the authors advocate stereotaxic clipping. A special device and technique for its application are described. The instrument is introduced through a trephine opening and clipping is monitored by angiography. Successful results have been obtained in 10 operations performed on eight patients, three of whom had arterial aneurysms (two internal carotid and one anterior cerebral-anterior communicating) and five with AVM's.

**Key Words**  
aneurysm surgery  
arteriovenous malformation  
stereotaxic surgery  
artrial aneurysms  
stereotaxic clipping

In spite of remarkable advances in the surgery of cerebral arterial and arteriovenous aneurysms, the intensive search for new methods of operative treatment is continuing in an effort to reduce the rate of serious complications and mortality. Stereotaxic techniques have undergone outstanding development during the last two decades. One of the most important advantages of the stereotaxic method is that it avoids manipulation of blood vessels and retraction of the brain, which leads to vasospasm, brain edema, and the danger of aneurysm rupture.

In the literature we found no description of stereotaxic clipping of arterial or arteriovenous aneurysms through an ordinary burr hole. Development of such a technique was prompted by the feasibility and accuracy of modern stereotaxic surgery and the discrete angiographic target made by an aneurysm or an artery located deep in the brain. After our special device for stereotaxic clipping was constructed in 1972, we performed many experiments on technical models, animals, and cadavers. The preliminary reports describing our method of stereotaxic clipping have been published previously. The first operation on a patient with a previously giant, inoperable hemispheric arteriovenous aneurysm was performed in 1973. To date we have carried out 10 operations on eight carefully selected patients. It is the purpose of this paper to present details of the instrumentation, operative technique, and clinical results of the stereotaxic clipping of arterial and arteriovenous aneurysms.

**Instrumentation**

Our special device for stereotaxic clipping (Patent No. 452336) was constructed for use with our previously described stereotaxic apparatus (Fig. 1). The device was made in two models differing only in the size of the outer diameter of the tube (2.9 and 3.6 mm, respectively). The surgeon chooses a suitable device before the operation depending on the measurement of the diameter of the artery or the neck of the aneurysm as seen angio-
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Fig. 1. *Left:* Stereotaxic clipping device in assembly with stereotaxic apparatus. *Right:* The clipping device is shown unassembled (*right*), and with open clip on the tip and first pivot (*left*). Three clips of different sizes are shown (*center*).

graphically. If the artery or neck is 3 mm in diameter, the thinner device with the 5-mm clip opening must be used; if the artery diameter is about 5 mm, the device with the 7-mm clip opening should be used.

The device is a stainless steel tube 17 cm long with a conical narrowing at one end. At the other end is a special structure for controlling clip movements and disconnecting the clip from the device. There are also two metal pivots for inserting into the tube. One has a thin terminal segment that protrudes from the tip of the tube for several millimeters. This pivot is inserted into the tube before its stereotaxic introduction into the brain. The thin tip must reach the target point and its location must be angiographically verified.

The second pivot carries on its tip a special clip and replaces the first one through a collet designed for this purpose.

The special removable stainless steel clips of different sizes (Fig. 1 *right*) permit the clipping of vessels from 1 to 7 mm in diameter. The chosen clip is easily attached to the tip of the second pivot before its insertion into the cannula. The clip passing the conical narrowing at the tip of the cannula is consecutively squeezed and opened.

Operative Technique

Careful study of both projections of the preoperative angiograms is essential. The target point must be chosen in accordance with several factors. The afferent artery (or arteries) must be clipped far enough from the arteriovenous aneurysm to avoid dangerous contact with angiomatous tissue or large draining veins. It is necessary to check the orientation of the target vessel in frontal, sagittal, and horizontal planes, because the insertion of the tube and the clip perpendicular to the vessel or the aneurysmal neck is of utmost importance. The site for the burr hole is selected to avoid insertion of the device through a functionally important brain area.

The operation is carried out under neuroleptanalgesia or general or local anesthesia with routine premedication. The patient's head is placed supine in the stereotaxic frame and fixed by two sharp pins. A 25-mm burr
A hole is made by coronal trephine; the burr hole can be placed at any point, but we prefer to make it near the coronal suture. The stereotaxic apparatus with clipping device attached is fixed in the burr hole. Because repeated intraoperative angiography is essential, a needle or catheter is inserted percutaneously into the carotid artery.

The target point is transferred from the angiograms to the plain films and stereotaxic calculation is made for the correct orientation of the clipping device. The calculated angles of correction are checked on the protractors of the stereotaxic device. All operations are made under the control of an image amplifier with television monitoring.*

After coagulating the cortical point, the first pivot is inserted through the cannula into the brain until it touches the target point. This movement is checked by consecutive angiography using Polaroid film. The first pivot is replaced by the second, which carries the squeezed clip. By turning a special ring of the control structure on the outer end of the device, it is possible to open the clip and check the degree of the opening in millimeters. Careful and slow introduction of the clip a little deeper permits accurate application upon the vessel or aneurysmal neck.

Before clipping, blood pressure is lowered by intravenous Arfonad to 60 to 70 mm Hg. If the next angiogram verifies the correct position of the clip, turning of the ring squeezes the clip until its full closure. Another angiogram is performed to show the effective clipping of the aneurysm or the afferent artery. Immediately after clipping, the patient is awakened so that normal function of the contralateral extremities can be confirmed. If function is satisfactory, neuroleptanalgesia is repeated and blood pressure is increased gradually. The clip is released from the pivot by pushing a button on the outer part of the device. Under television control the tube is withdrawn from the brain.

If it is necessary to clip two or more vessels, the entire procedure is repeated. In case of failure such as partial or wrong clipping, or development of hemiparesis, the clip may be opened and withdrawn into the tube by slightly turning the ring on the outer end of the device. The duration of the clipping operation is between 1½ and 2 hours.

**Summary of Cases**

Each of the eight patients in this series was examined preoperatively by bilateral axillary and carotid angiography and, when necessary, by angiography in oblique projections and with cross compression. Cerebral blood flow (CBF) was investigated in five patients before and after operation using the Kety-Schmidt method as modified by us.*

**Arterial Aneurysms**

Four stereotaxic clipping operations were carried out on three patients aged 44, 46, and 49 years. In the initial stage of our study we selected three types of arterial aneurysms to investigate the possibilities offered by the new method: a supraclinoid aneurysm, an anterior communicating aneurysm, and an anterior cerebral artery aneurysm.

The supraclinoid aneurysm of the internal carotid is the most common type of aneurysm. The narrow necks of the majority of these aneurysms make them particularly suitable for stereotaxic clipping, as the following case illustrates.

**Case 1.** This 49-year-old woman was admitted after two severe subarachnoid hemorrhages (SAH's) 17 months and 1 month respectively before admission. After admission her general condition was satisfactory. She had paralysis of the left third nerve, light hemiparesis of the right side, and signs of sensorimotor aphasia. A four-vessel angiographic study demonstrated a bilobed supraclinoid saccular aneurysm (14 X 7 mm in lateral projection) arising from the left internal carotid in the region of its junction with the posterior communicating artery (Fig. 2 A). The aneurysmal neck was narrow. There was mild spasm of the carotid.

In April, 1974, stereotaxic clipping of the aneurysm neck was carried out under general anesthesia. A trephine opening was made 3 cm posterior from coronal suture and 3 cm to the left of the midline. The stereotaxic apparatus with clipping device was installed, and a catheter was percutaneously introduced into the left common carotid artery. The target (aneurysmal neck) was transferred from angiograms to the plain films (two views) and stereotaxic calculations were

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Fig. 2. Case 1. Angiograms showing a supraclinoid internal carotid aneurysm before operation (A), during stereotaxic clipping (B, C) and 2 weeks after operation (D, E).
made. The tip of the first pivot reached the target point at a depth of 76 mm. The pivot was then replaced by another with a compressed clip. It was put on the aneurysm neck and its position was confirmed by control angiography (Fig. 2 B and C). Arterial pressure was lowered to 70 mm Hg.

The patient was awakened for several minutes for a check of movements, but no changes were noted. The clip was closed slowly by means of the button on the external part of the device. One more control angiogram showed that the aneurysm neck had been clipped and that there was non-filling of the aneurysm. The clip was then released and the device was withdrawn. The operation was performed under continuous television monitoring. The bone button was then put in place. The duration of the operation was 1 hour and 40 minutes. There were no postoperative complications and no neurological changes. The patient could walk 3 days after surgery.

Control angiography 2 weeks later demonstrated the elimination of the aneurysm (Fig. 2 D and E). The lumen of the internal carotid artery at the level of the clip was not changed. At 16 months postoperatively the patient's condition was good, and she returned to work. Aphasia and third nerve paralysis have disappeared completely.

In spite of a remarkable improvement in the results of direct attack on anterior communicating artery aneurysms, the technical difficulties and rate of complications remain serious unsolved problems. Logue and Ahmed and Sedzimir proposed the open clipping of the dominant anterior cerebral artery for thrombosis of aneurysms of the anterior communicating artery. We believe that the stereotaxic clipping of the neck of such an aneurysm may be done in exceptionally rare cases, but that clipping of the dominant anterior cerebral artery is also technically possible. This point of view is confirmed by the following case.

Case 2. This 44-year-old man began to suffer from sudden headaches and repeated vomiting in December, 1974, and on one occasion he lost consciousness for 3 hours. Initially he showed signs of meningeal irritation; he had slight pyramidal signs on the right side and bloody spinal fluid. After admission 3 weeks later, he complained of a headache, but his general condition was satisfactory.

Right-sided axillary and carotid angiography disclosed a saccular aneurysm of the anterior communicating artery. Left carotid angiography showed no filling of the aneurysm. The aneurysmal neck was not clearly visible (Fig. 3 A). Since clipping the aneurysmal neck seemed to be technically impossible, stereotaxic clipping of the dominant right anterior cerebral artery was performed (Fig. 3 B). The burr hole was made 1 cm anterior to the coronal suture and 3 cm to the right of the midline. The distance from the cortex to the target was 62 mm. The clip was placed on the artery under television control.

Postoperative carotid angiography showed that the clip had slipped and the aneurysm had refilled. A second stereotaxic operation was done 2 weeks later through the same burr hole (Fig. 3 C). The second clip was placed proximal to the first and 10 mm from the bifurcation of the internal carotid artery (Fig. 3 D). The postoperative course was free from complications. Subsequent left carotid angiography showed that the anterior cerebral artery was clipped and the aneurysm no longer filled (Fig. 3 E). The control examination 9 months postoperatively showed that the patient was in excellent condition. He is working full time and has no complaints.

It was reasonable to suppose that stereotaxic clipping of the distal branch of the anterior cerebral artery would be technically easy and less dangerous. The following case illustrates this procedure.

Case 3. This 46-year-old man was admitted in February, 1975, after a severe SAH. After slight physical strain he developed severe headaches and vomiting, followed by a generalized seizure and unconsciousness. Neurological examination showed he was confused, had severe meningeal signs, and right-sided hemiparesis. Lumbar puncture disclosed bloody cerebrospinal fluid. The patient's general condition improved, but headache, vertigo, weakness of the right extremities, and loss of memory remained. Total cerebral angiography showed a wide-necked berry aneurysm of the left frontopolar artery.

Stereotaxic clipping of the feeding frontopolar artery was performed under neuroleptanalgesia. A burr hole was placed 1 cm
FIG. 3. Case 2. Angiograms showing an anterior communicating artery aneurysm before operation (A), after clipping of the anterior cerebral artery (B), and during the second operation (the first clip slipped) (C). Right (D) and left (E) carotid angiograms show the result of a second, more proximal clipping of the anterior cerebral artery. The aneurysm did not fill.
TABLE 1
The CBF in five patients with AVA's before and after clipping feeding vessels

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Total CBF* (ml/min)</th>
<th>Local CBF† (ml/100 gm/min)</th>
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<tr>
<td></td>
<td>Preoperative Value</td>
<td>Preoperative AVA Hemis.</td>
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<td>% of Normal</td>
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<tr>
<td>6</td>
<td>980.7</td>
<td>130.8</td>
</tr>
<tr>
<td>7</td>
<td>1647.8</td>
<td>219.7</td>
</tr>
<tr>
<td>8</td>
<td>1015.0</td>
<td>135.3</td>
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*The normal total CBF was 750 ml/min.
†The normal local CBF was 55 ml/100 gm/min.

arteriovenous Aneurysms

It is known that only approximately 50% of hemispheric arteriovenous aneurysms (AVA's) can be totally removed. The radical extirpation of the remaining 50% is impossible because of their size or deep-seated location. It is widely accepted that by diminishing the blood flow to the AVA and thus its volume, the risk of intracranial hemorrhage and the rate of seizures may be reduced. For this purpose several techniques have been successfully applied during the last decade, including artificial embolization, and the introduction of special balloon catheters.

During the last 3 years we performed six operations of stereotaxic clipping of hemispheric AVA's in five patients ranging in age from 13 to 45 years. The dominant signs were subarachnoid-parenchymatous hemorrhages, seizures, pyramidal tract signs, pulsating bruit in the head, and headaches. The aneurysms were located in the right hemisphere in three cases, in the left in one, and in the region of the corpus callosum and third ventricle in one. Four aneurysms were of large or giant size: in three, volumes varied from 42 to 190 cu cm and one had a volume of 23 cu cm.

Four widespread AVA's were supplied by several arteries and two by arteries from both sides. Only one relatively small aneurysm was supplied by a branch of the middle cerebral artery.

Study of CBF appears to be the objective criterion for the evaluation of clipping operation in AVA's. Five of our patients were investigated before and after surgery by our modification of the Kety-Schmidt nitrous oxide method. It is well known that total and hemispheric CBF in the presence of an AVA is substantially increased. In our five cases, total CBF consisted respectively of about 131%, 135%, 219%, 259%, and 322% of normal volume (750 ml/min) (Table 1). As previously described, the rate of increase has correlated well with the volume of the AVA. The hemispheric CBF was greatly increased mostly in the hemisphere in which the AVA was located. In cases of giant and large AVA's, the opposite hemispheric CBF was also increased. After stereotaxic clipping of afferent vessels, total CBF decreases markedly in all cases — ranging from 23.1% to 154.4% (mean 72%). In three cases CBF became practically normal; in two cases, although reduced, it remained very high. One of these two cases, Case 4, had a giant AVA.

Because there is still no definite solution to the problem of inoperable AVA's we concentrated our efforts on the clipping of feeding vessels as a mode of palliative treatment of large and giant aneurysms. Three cases briefly described below illustrate this point. The first case (Case 4, which was our first such operation, done in 1973), may be of particular interest because bilateral clipping was carried out.

Case 4. For about 30 years this 45-year-old man had suffered from pulsating headaches,
which had become continuous and severe several years before admission. He had suffered seizures for about 10 years. At first they were local but later became generalized and more frequent. Slight left-sided hemiparesis developed 2 years before admission.

Four-vessel angiography showed a giant AVA (193 cu cm), occupying the right parietal, temporal, and occipital lobes. It was supplied by greatly enlarged arteries from both sides, by right middle and left anterior cerebral arteries and to a lesser extent by branches of right anterior and posterior cerebral arteries (Fig. 4 A). The aneurysm was evaluated as absolutely inoperable.

In January, 1973, through a burr hole near the coronal suture, stereotaxic clipping of the enlarged (6 mm) branch of the right middle cerebral artery was carried out. Two clips were applied. There were no complications after surgery. Control angiography showed a marked decrease of the aneurysm volume (Fig. 4 B) and of the total and hemispheric CBF (Table 1). The headaches became less severe.

Six months later stereotaxic clipping of the large branch of the anterior cerebral artery (Fig. 4 C) was performed on the other side. No complications were noted. Correct clipping was confirmed angiographically and consequent substantial decrease in volume was achieved (Fig. 4 D). After the second operation there was a marked clinical improvement: severe headaches and seizures disappeared completely in the 2½-year follow-up period.
Case 5. This 25-year-old man had a history of two severe subarachnoid-parenchymatous hemorrhages with consequent long-lasting, right-sided hemiparesis. He also had up to three seizures per month. Four-vessel angiography indicated a very large AVA (153 cu cm) deep in the left temporal lobe and fed mainly by the left middle and posterior cerebral arteries (Fig. 5 A). It was decided that total removal of the lesion was technically impossible.

In April, 1974, stereotaxic clipping of the large feeding branch of the left middle cerebral artery was performed and confirmed angiographically. After clipping, the AVA was not visualized by angiography (Fig. 5 B). The CBF decreased by two thirds on the aneurysmal side and by half on the other side and has become near normal. There was no complication after operation.

At 1½ years after surgery there have been no seizures or signs of intracranial hemorrhage. The neurological deficit has diminished markedly and the patient's general condition is good.

Case 6. This 42-year-old man had an SAH 1 month before admission. For 16 years he had suffered from frequent seizures. Angiography showed a large arteriovenous malformation (128 cu cm) located in the mediobasal part of the right temporal lobe and supplied by enlarged branches of the right middle and posterior cerebral arteries. Because of its size and location the aneurysm was evaluated as inoperable. In May, 1974, stereotaxic clipping of the large branch of the middle cerebral artery was carried out. Remarkable reduction of the aneurysm volume and substantial decrease of CBF (Table 1) were achieved.

During a 1-year follow-up period there have been no intracranial hemorrhages and no seizures. The patient's general condition is good and he is working full time.

The next case illustrates the possibility of stopping flow to a middle-sized AVA deep in a poorly accessible region of the brain.

Case 7. This 13-year-old boy had sustained four severe intraventricular hemorrhages during a period of 4 years. He was admitted 3 weeks after the last bleed. Bilateral angiography showed a middle-sized (42 cu mm) arteriovenous malformation, involving deep medial structures, the corpus callosum, and the third ventricle. The aneurysm was supplied mainly by the right pericallosal artery and, to a lesser extent, by branches of the right middle and both posterior cerebral arteries (Fig. 6 A). The deep bilateral location of the aneurysm made it inoperable.

It was decided to clip the main feeder of the aneurysm, the pericallosal artery. Successful stereotaxic clipping of the artery was performed in December, 1973. Control angiography showed that the AVA no longer filled through the artery (Fig. 6 B). The CBF was markedly decreased (Table 1). There were no postoperative complications. During a 20-month follow-up period there have been...
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Fig. 6. Case 7. Angiograms of a middle-sized AVA supplied mainly by pericallosal artery. A: During the operation. B: After stereotaxic clipping of the artery the aneurysm did not fill.

no hemorrhages. The boy is in good condition and continues to attend school.

The next case is important for the evaluation of the clipping method. In this case the method has been used for the management of an AVA that undoubtedly could have been completely removed by classic open surgery. It is well known that AVA's supplied by one feeder are rare. Their total extirpation may usually be achieved without great technical difficulties. Nevertheless, to study the possibilities of stereotaxic clipping we decided to employ it in a case of operable AVA. It should be emphasized that surgery totally eliminated the aneurysm from the circulation.

Case 8. This 26-year-old man was admitted several hours after a single subarachnoid-parenchymatous hemorrhage. The marked post-bleeding hemiparesis gradually disappeared. Angiography showed a small AVA (23 cu mm) in the right parietotemporal region. There was only one thin feeding branch from the middle cerebral artery (Fig. 7 A). In November, 1973, this branch was clipped without complications (Fig. 7 B). Control angiography showed the complete exclusion of the malformation from the circulation (Fig. 7 C). Postoperative CBF investigation demonstrated a return to normal (Table 1).

About 2 years after surgery the patient is in good condition without neurological deficit. Intracranial hemorrhage has not recurred.

Discussion

Early attempts to apply the stereotaxic technique to deep-seated and poorly accessible arteriovenous malformations (AVM’s) were made by Guiot, et al., and Riechert and Mundinger. These authors used a combination of stereotaxic technique and the classic direct approach. After ordinary flap craniotomy a stereotaxic device was installed and directed through a small cortical incision toward the aneurysm. In this way Guiot, et al., could either coagulate small AVM’s or clip middle cerebral artery aneurysms. Riechert and Mundinger reported four cases with deep AVM’s successfully operated on by this method.

Alksne and Rand developed the technique of magnetic thrombosis of intracranial aneurysms. A magnetic cannula 6 mm in diameter was placed stereotaxically at the dome of the aneurysm and after the puncture of its wall with a fine needle, a suspension of iron was introduced into the aneurysm, causing thrombosis.

Mullan reported wide experience in producing stereotaxic intraaneurysmal thrombosis by means of several fine steel needles inserted into the aneurysmal sac, after which positive direct electric current was applied. The results were satisfactory in most cases, but in a series of 61 patients there were four postoperative deaths directly attributed to the procedure, while eight cases showed incomplete obliteration.
Four patients with anterior communicating-anterior cerebral arterial aneurysms were operated on by Samotokin and Hilko, who stereotaxically introduced thin electrodes into aneurysms followed by anodal electrolysis for 1 to 3 hours. This operation was combined with intravenous infusion of coagulants. In all cases aneurysm volume was reduced by 30% to 40%, but complete thrombosis was not achieved. One case of successful stereotaxic thrombosis of an anterior communicating arterial aneurysm and another case of stereotaxic electrocoagulation of a single vessel feeding a small AVM in the frontal lobe of an 8-year-old child have also been reported.

Despite these encouraging results the stereotaxic method of managing arterial and arteriovenous aneurysms has not been common neurosurgical practice.

The main purpose of this study was to reach a higher degree of safety in the performance of surgery of arterial and arteriovenous aneurysms. In this connection it is important to note that after 10 operations of stereotaxic clipping there was no mortality and in only one case was there hemiparesis lasting several days. It should be emphasized that patients as a rule endured the operation very easily and were able to walk 2 to 3 days after surgery. Brain trauma secondary to stereotaxic clipping is less than during classic open surgery.

Our experience with stereotaxic clipping is relatively limited, but it is possible to draw the preliminary conclusion that this new...
method may be rational and advisable in the following instances:

1. In carefully selected cases of arterial aneurysms in which direct attack is too dangerous or technically impossible
2. In giant and deep-seated AVM's as a palliative operation for the diminution of the aneurysm volume
3. In selected cases of AVA's fed by a single artery, as a method of radical treatment.

It is reasonable to suppose that the future development of the method will offer new technical possibilities and will be useful in vascular neurosurgery.

References


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