Interhemispheric approach for the surgical removal of thalamocaudate arteriovenous malformations

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A series of 250 surgically treated cerebral arteriovenous malformations (AVM's) is presented, in which 22 lesions were located primarily in the thalamus and caudate nucleus. A standardized interhemispheric approach through the posterior corpus callosum and into the atrium of the lateral ventricle was utilized for the surgical removal of these AVM's. Total removal was confirmed by angiography in 18 patients; removal was subtotal in four cases. There were no deaths in this group of patients. Disturbances of recent memory pre- and postoperatively were seen in half of the patients, but most of these deficits were temporary. Other complications included: postoperative homonymous hemianopsia (six cases), transient hemiparesis (three cases), hemisensory loss (two cases), Parinaud's syndrome (one case), and recurrent hemorrhage 2 years after surgery (one case). All 22 patients returned to their previous occupations and are leading independent lives. The results of this experience indicate that thalamocaudate AVM's can be effectively treated by resection.

Key Words • arteriovenous malformation • caudate nucleus • thalamus • surgical approach

arteriovenous malformations (AVM's) that involve the deep nuclei of the brain have always represented a dilemma for neurosurgeons. Surgery for these lesions involves considerable risk to critical areas of the nervous system. However, rupture of an AVM in this location can lead to catastrophic parenchymal or intraventricular hemorrhage. Thus, an untreated diencephalic AVM must be considered a hazardous entity.

In our series of 250 surgically treated intracerebral AVM's, 22 patients harbored malformations located primarily within the thalamus and basal ganglia. A standardized surgical approach was used in this group of patients. The presentation, surgical techniques, and outcome in these 22 patients are summarized and three illustrative cases are presented in fuller detail. The results of this experience indicate that these deep AVM's can be effectively treated by resection.

Representative Cases

Case 1

This 41-year-old man experienced a sudden intraventricular hemorrhage. Nine months after this episode, he came to the Neurological Institute for evaluation of short-term memory loss, a right homonymous quadrantanopsia, and mild clumsiness of the right hand. Angiography demonstrated a small AVM medial to the trigone of the left lateral ventricle and extending into the splenium of the corpus callosum. The malformation was fed by branches of the posterior and anterior cerebral arteries. The venous drainage was into the straight sinus and vein of Galen.

Surgery was performed via a left parietal craniotomy with the patient in the semisitting slouch position. An interhemispheric approach was used to expose the AVM. A cortical incision was made in the cingulate gyrus and the superior surface of the malformation was followed laterally. An area of old hemorrhage facilitated dissection around the anterior margin of the malformation into the thalamus. The lateral and posterior aspects of the AVM were defined and the malformation was rolled medially on its venous pedicle, which was divided.

Postoperatively, the patient had a homonymous hemianopsia. The remainder of the neurological findings were unchanged. Angiography confirmed complete removal of the AVM. At his 6-month follow-up examination, he had returned to full employment and his recent memory was improving.
FIG. 1. Case 2. Preoperative vertebral angiograms, anteroposterior (left) and lateral (right) views. Solid arrows point to the nidus of the malformation, and open arrows point to the medially draining vein.

FIG. 2. Case 2. Postoperative vertebral angiograms, anteroposterior (left) and lateral (right) views, showing complete removal of the malformation (compare with Fig. 1).

FIG. 3. Case 3. Preoperative contrast-enhanced coronal computerized tomography scan showing the location of the malformation (arrow).

Case 2

This 29-year-old woman was 3 months pregnant when she experienced a sudden severe headache associated with vomiting. A computerized tomography (CT) scan showed a small hemorrhage into the right trigone of the ventricle. Except for meningismus she had no neurological signs. An angiogram demonstrated a small AVM in the right pulvinar region with feeding vessels from the anterior and posterior choroidal arteries (Fig. 1). The pregnancy was terminated and the patient was transferred to the Neurological Institute for surgery 2 months later.

The operation was performed through a right parietal craniotomy with the patient in the semisitting slouch position. Via the interhemispheric route, a 1-cm opening was made in the posterior aspect of the corpus callosum and the right lateral ventricle was entered. The AVM was encountered on the floor of the lateral ven-
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FIG. 4. Case 3. Preoperative angiograms showing the malformation (arrows) after lateral internal carotid artery injection (left), after lateral vertebral artery injection (center), and after anteroposterior vertebral injection (right).

The choroid plexus just lateral to the choroid plexus. A circumscribing incision was made around the malformation. The dorsal aspect of the pulvinar was resected, and the dissection was carried deep into the dorsal medial region of the thalamus and anteriorly to about 3 to 4 mm posterior to the foramen of Monro. In this fashion the malformation was removed.

Postoperatively, the patient complained of numbness of the left side of the face and body. Testing revealed decreased pain sensation on the left side but preservation of two-point and stereognostic sensation. These minor deficits cleared within days of the operation and the patient was discharged home in normal condition. Angiography revealed no residual malformation (Fig. 2). At her 3-month follow-up examination, she had returned to work and her usual activities.

Case 3

This 28-year-old woman was in good health except for a 1-year history of generalized headaches and episodic numbness in the left arm. The neurological examination was completely normal. Radiological studies showed an AVM with no evidence of hemorrhage. The malformation was 2 cm in diameter, was located in the posterior cingulate gyrus and corpus callosum, and extended to the floor of the lateral ventricle on the right (Fig. 3). The AVM was supplied by a large anterior cerebral artery, the posterior cerebral artery via a posterior callosal artery, and the right lateral posterior choroidal artery (Fig. 4).

An operation was performed via a right parietal craniotomy with the patient in the semisitting slouch position. Via an interhemispheric approach the corpus callosum was exposed and feeding vessels to the malformation were divided. The malformation was then followed laterally to the forceps major of the corpus callosum and inferiorly into the floor of the lateral ventricle at the location of the pulvinar and right fornix. The vascular supply from the choroidal vessels was secured and the entire malformation was rolled out on the medial venous pedicle and removed.

Postoperatively, the patient had no neurological deficits. Angiography and CT scanning (Fig. 5) showed no evidence of residual AVM. Detailed psychometric testing done both pre- and postoperatively failed to demonstrate any change in language or memory function.

FIG. 5. Case 3. Postoperative contrast-enhanced coronal computerized tomography scan showing a hypodense area corresponding to the site of arteriovenous malformation resection.
Summary of Cases

This series of 22 patients includes 13 males and nine females. Their ages ranged from 14 to 42 years (mean 28 years). A summary of these cases is presented in Table 1.

Clinical Presentation

Twenty-one patients presented with sudden intraventricular or intracerebral hemorrhage as the first manifestation of their AVM. One patient (Case 3) presented with sensory aberrations and headaches, and was the only patient in this series to come to medical attention for reasons other than a hemorrhagic event. Initially, many of the patients had profound neurological deficits, such as coma and hemiplegia. All patients showed dramatic improvement in their neurological status so that within 1 month after hemorrhage all patients were alert, oriented, ambulatory, and capable of independent lives. Three patients had a mild residual hemiparesis, two had hemianopsia, and six had some disturbance of recent memory function. Five of the six patients with a preoperative memory disorder bled from lesions involving the left pulvinar, caudate, and fornix.

Location of the AVM

Two patients had bilateral involvement of diencephalic structures; one of these malformations extended infratentorially. The remaining patients had supratentorial AVM's that were lateralized: 14 were on the right side and six were on the left side.

Twenty of the 22 malformations in this series were located adjacent to the atrium of the lateral ventricle. One patient had a malformation situated anteriorly in the septal region extending into the anterior aspect of the right thalamus, and one had an extensive AVM that followed the entire corpus callosum, the septal region, fornice, and roof of the third ventricle.

Vascular Anatomy

Although most malformations in this series were supplied by two or more major arteries, the choroidal arteries form the primary vascular supply to AVM's situated near the atrium of the lateral ventricle. Thirteen malformations were fed by the posterior choroidal arteries, and four received input from the anterior choroidal artery. The posterior pericallosal artery as well as other penetrating branches from the posterior cerebral artery in the region of the fusiform gyrus supplied 13 of the AVM's. The distal segment of the anterior pericallosal artery was involved in nine cases. Although thalamoperforating arteries were angiographically demonstrated to supply only three malformations, small penetrating vessels supplying the deep aspect of the malformations were encountered during surgery in almost all cases.

The venous drainage from these malformations was always toward the midline. In one case, the primary draining vein ascended in the interhemispheric fissure to reach the superior sagittal sinus. In the remaining 21 cases, the venous drainage was into the deep venous system of the brain: internal cerebral veins, the basal vein of Rosenthal, the vein of Galen, and the straight sinus.

Surgical Technique

Surgery was performed on all patients in this series via an interhemispheric route ipsilateral to the malformation (Fig. 6). A spinal drainage catheter is inserted and the patient is placed in a semisitting slouch position. The head is straight and maximally flexed to bring the curved portion of the parietal bone parallel to the floor. A 4 x 4-cm bone flap is formed to the right or left including the midline. The medial burr holes are placed slightly to the opposite side of the superior sagittal sinus with the posterior hole adjacent to the lambda. A dural flap is created along the sinus, and medially draining veins are preserved whenever possible. Retractors are placed on the falx and on the parietal lobe to expose the posterior aspect of the corpus callosum. At this point in the operation some aspect of the malformation may be visualized. When the malformation lies entirely in the floor or wall of the lateral ventricle, the corpus callosum must be divided before the AVM can be appreciated. Resection of the malformation is begun, based on the CT scan, magnetic resonance imaging

### TABLE 1

<table>
<thead>
<tr>
<th>Feature</th>
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<tr>
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<td>recurrent hemorrhage</td>
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* AVM = arteriovenous malformation.
† Five patients had two operations.
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(MRI), and angiographic information as well as defined principles of AVM surgery that have been outlined elsewhere.\(^9-12\)

In all cases in this series, the corpus callosum was divided over a distance of about 1 to 2 cm, and the fornix, which lies just deep to the corpus callosum, was sectioned ipsilaterally. These maneuvers were necessary to gain access to the atrium of the ventricle. In some patients, the malformation actually involved the corpus callosum and the ipsilateral fornix.

Five patients in this group required two operations. One patient had incomplete removal and required reoperation. One patient underwent a suboccipital infratentorial approach to remove residual malformation in the region of the quadrigeminal plate. One patient had a subtemporal operation to resect residual malformation extending into the fusiform gyrus. One patient required two interhemispheric operations for a large AVM extending from the anterior third ventricle to the splenium of the corpus callosum. The fifth patient was first operated on by a subfrontal approach to eliminate feeding vessels entering the malformation through the anterior perforated substance. His second operation was an interhemispheric exposure of the anterior right lateral ventricle where the malformation was removed from the head of the caudate and the septal region.

Surgical Outcome

There were no operative deaths in this series, and all 22 patients were able to resume their previous occupations after surgery. The most common postoperative complication was a disturbance of recent memory. Eleven patients were noted to have at least transient problems in acquiring new knowledge. However, six of these patients had suffered a preoperative memory disturbance as a result of hemorrhage, and only three of these were believed to be worse after surgery. All patients showed considerable improvement with time.

Six patients were found to have a contralateral homonymous field defect after the operation. Two of these patients had field cuts preoperatively. Only two of these six patients had visual loss in the dominant hemisphere; neither displayed a disabling disconnection syndrome and both were capable of reading and naming colors postoperatively.

There were three cases of postoperative hemisensory loss: one cleared completely within 1 week and two are persistent. Three patients had transient hemiparesis, and all of these regained essentially normal strength in 2 to 12 months. One patient with an AVM extending into the quadrigeminal region developed a profound eye-movement disorder after surgery. Another patient who was neurologically normal developed a sterile ventriculitis and required prolonged steroid therapy.

All 22 patients were studied with postoperative angiography. Total removal of the AVM was confirmed in 18 cases, and residual malformation was noted in four. Reoperation in one of these four patients again failed to obliterate the malformation. This patient rebled from the AVM 2 years after the second surgery, and a third operation at that time removed the residual lesion.

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**Fig. 6.** Drawings of the surgical approach. CC = corpus callosum; C = caudate nucleus; T = thalamus; LV = lateral ventricle; F = fornix; IC = internal capsule.  
Left: Coronal section of the brain in the region of the atrium of the lateral ventricle demonstrating the operative exposure of the thalamocaudate arteriovenous malformations (AVM's) in this series.  
Right: Operative exposure of the thalamocaudate AVM's as seen during surgery. Retractors are shown on the medial surface of the right parietal lobe.
Discussion

Operative resection of AVM's in the thalamus and caudate region constitutes a formidable challenge for the neurosurgeon. These vascular malformations are located deep within the brain substance adjacent to several vital structures of the central nervous system. It can therefore be anticipated that surgery for these lesions might produce profound and disabling neurological sequelae. However, the retrospective analysis presented in this report indicates that these lesions can be safely removed with current neurosurgical techniques.

The preoperative preparation of these patients requires sophisticated neuroradiological studies. High-resolution CT scanning and, more recently, MRI have proved invaluable for the precise localization of the AVM's, and for defining their relationships to the tentorium, brain stem, and ventricular system. Stereoangiography has been useful in appreciating the three-dimensional vascular anatomy, which is often critical for planning the surgical approach.

Embolization has been a useful adjunct to the surgical treatment of large supratentorial AVM's; however, malformations deep in the thalamus and the caudate region are generally not suitable for this procedure. These AVM's tend to be supplied by distal branches of the major arteries such as the choroidal, posterior cerebral, anterior cerebral, and thalamoperforating arteries. These vessels generally have small intraluminal diameters and arise from parent vessels at right angles. These factors make embolization hazardous and therefore are not usually indicated for malformations in this location.

The interhemispheric transcallosal approach to the deep paramedian lesions has been described previously in relation to medial hemisphere AVM's and AVM's that follow the tentorial ring. This approach was first used by Dandy for removing posterior third ventricular tumors, and we have found it ideal for treating vascular malformations in the region of the atrium of the lateral ventricle. These AVM's invariably drain into the deep medial venous structures of the brain, and the arterial supply derives almost exclusively from the pericallosal and choroidal arteries. With hemispheric retraction, one may reach the posterior cerebral artery as it courses around the lateral side of the brain stem and still have good visualization out to the atrium of the lateral ventricle. Therefore, a medial interhemispheric approach affords unequaled access to the arterial and venous components of these malformations.

Other surgeons have operated on AVM's in the thalamus and caudate region via a transverse incision in the parietal lobe, the superior temporal gyrus, the middle temporal gyrus, or the inferior temporal gyrus. These approaches have the disadvantage of transgressing normal functioning brain before the malformation is reached. In addition, the AVM is first visualized on its lateral surface whereas the blood supply and the venous drainage are on the medial surface. The surgeon must then work around the margins of a tense malformation to secure the arterial feeders.

The postoperative complications and the neurological sequelae of hemorrhage observed in these patients with AVM's near the atrium of the lateral ventricle provide some insight into the functional neuroanatomy of this region of the nervous system (Fig. 6). The roof and posterior face of the atrium is formed by the posterior body and splenium of the corpus callosum. The body of the caudate nucleus lies inferolaterally, while the floor is formed by the posterior thalamus. The fornix lies on the medial side in the region of the choroidal fissure. Six patients in this series bled from malformations involving these structures on the left (dominant) side. Five of these six patients developed memory problems consequent to AVM rupture. The other 16 patients had right-sided or bilateral lesions, and only one of these patients had a preoperative memory disturbance. Postoperatively, five additional patients displayed memory dysfunction, and one of these patients had a bilateral AVM that required sacrifice of both fornices and the corpus callosum.

These data imply that dominance extends to the limbic system, and that the left fornix, thalamus, and/or caudate nucleus are critical for recent memory function. Although considerable improvement in memory occurred in every impaired patient, in no instance did memory function return to normal once it had been damaged.

The experience of Drake, 2 Kunc, 5 and Yaşargil, et al., 10 in dividing the posterior corpus callosum indicates that no serious functional impairment results. Several of our patients underwent psychometric testing following partial surgical division of the splenium of the corpus callosum. In all instances a visual disconnection syndrome was demonstrable, but no patient was functionally impaired by this disconnection. Preservation of reading and naming functions, even when there was a dominant-hemisphere hemianopsia, was due to the limited section of the corpus callosum that we utilized. The splenium was never completely divided.

Gamma irradiation for the treatment of small AVM's has been advocated by Steiner, 14 who reported successful treatment of a large group of patients with complete obliteration of the malformations. The major drawback to this method is the long latency between treatment and obliteration of the malformation. In many instances, this period exceeds 2 years, during which time the patient is at risk for hemorrhage. Additionally, the long-term deleterious effect of this high-energy radiation is unknown. Therefore, patients should be chosen carefully for radiosurgery.

Four patients in this series had incomplete removal. One of these patients had two operations, both of which failed to obliterate the malformation. We have noted that many of these deep malformations have indistinct margins, and this factor indicates the increased technical difficulties that may accompany surgical removal of thalamocaudate AVM's. Only one patient rebled from...
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an incompletely removed AVM, but the possibility of incomplete removal must be factored into the equation when considering operating on malformations in this location.

Twenty-one of 22 patients in this series presented with intracerebral hemorrhage as the first symptom of a thalamocaudate AVM. This mode of presentation would be expected since these malformations were essentially all deep-seated lesions less than 2.5 cm in diameter. Larger malformations bleed less frequently, and AVM's involving cortical structures can often induce seizures as an initial manifestation. Reliable criteria to relate the surgical morbidity for thalamocaudate AVM's to their natural history will probably never be available. Nonetheless, the incidence of death or serious morbidity from hemorrhage of deep-seated AVM's is substantial, and this factor warrants surgical intervention. Compared to the risk of morbidity due to an untreated AVM, which approaches 50%, no patient in this series of 22 patients with thalamocaudate AVM's was significantly impaired by surgery.

References


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