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ABSTRACT: THE MICROSURGICAL EXCISION of arteriovenous malformations located in the thalamic region in eight patients is reported. Six were located in the posterior aspect of the thalamus and two were located in the anterior. Hemorrhage occurred in all of the cases. Hemiparesis, hemianesthesia, and consciousness disturbance were the most typical clinical features. The supine position with the anterior transcallosal approach was used for anterior dorsal lesions, and the sitting position with the posterior interhemispheric approach was used for posterior dorsal lesions. Total removal was confirmed by angiography in seven patients, and incomplete removal was noted in one patient. There was one death in this group of patients. Memory disturbance was the most common postoperative complication. This complication showed considerable improvement with time. Other complications included homonymous hemianopsia (three patients), hemisensory loss (six patients), and transient hemiparesis (one patient). All survivors (seven patients) were able to return to their occupation after surgery. The vascular input, the location of the malformation, and clinical history are the contributory factors concerning operability. With the modern neurosurgical and anesthesiological facilities, surgical removal of thalamic malformations in selected cases is advisable.

KEY WORDS: Arteriovenous malformation; Intracerebral hemorrhage; Surgical excision; Thalamus

Arteriovenous malformations (AVMs) in the thalamus have been considered inoperable. However, rupture of an AVM in this location can lead to catastrophic parenchymal or intraventricular hemorrhage. Thus, an untreated thalamic AVM is considered a hazardous entity. Having gained experience from operating on callosal, parasplenic AVM and having familiarity with the topographic anatomy of the thalamic region, surgical intervention for the thalamic AVM was done in selected cases. The presentation, surgical technique, indication, and outcome of these cases are detailed.

SUMMARY OF CASES

This series of eight patients includes three males and five females. Their ages ranged from 9 to 38 years (mean, 25.6 yr). Clinical symptoms and signs

are summarized in Table 1. Hemorrhage occurred in all patients; it occurred twice in one patient and three times in two patients. One patient also had focal seizures when the bleeding occurred. Clinical findings of hemiparesis, hemianesthesia, and consciousness disturbance appear to be the most typical features of this lesion (Table 2).

LOCATION OF THE ARTERIOVENOUS MALFORMATION

All of these AVMs were primarily located in the thalamus: four on the right side and four on the left side. The majority of AVMs (n = 6) were located on the posterior aspect of the thalamus. Two AVMs were located in the anterior aspect of the thalamus (Table 1).

VASCULAR ANATOMY

Although most malformations in this series were supplied by two or more major arteries, the thalamoperforator is the primary vascular supply (Table 3). All malformations were fed by the thalamoperforator. Four of those also received input from the anterior choroidal artery, and the posterior choroidal artery was involved in seven patients. The lenticulostriate artery was angiographically demonstrated to supply only two malformations.

The venous drainage from these malformations was always toward the midline. In three patients, the primary draining vein was into the basal vein of Rosenthal. In the remaining five patients, the venous drainage was directly into the internal cerebral vein.

SURGICAL TECHNIQUE

The supine or sitting position is used depending on the exact site of the lesion. The supine position with anterior transcallosal approach is used for anterior dorsal AVMs, and the sitting position with posterior interhemispheric approach is used for posterior dorsal AVMs. For the anterior transcallosal approach, the patient is positioned in the recumbent supine position, with the head flexed so that the junction of the coronal and sagittal sutures is parallel to the horizontal. An ipsilateral procedure is used. A free bone flap is elevated, making the superior margin just to the left of the midline so that the sagittal sinus is exposed. The anteroposterior position of the flap is situated so that two-thirds will be anterior to the coronal suture and one-third will be posterior. The dura is then opened in a U-shaped fashion, with the base along the sagittal sinus. When the medial margin of the hemisphere is free, gentle retraction is applied to separate it from the falx. The gyri of the right and left cingulate region often adhere to each other and must be separated. The corpus callosum is divided over a distance of about 2 to 3 cm. The ipsilateral ventricle is then entered. At this point in the operation, some aspect of the malformation with hemorrhage may be visualized (Fig. 1). The thalamus will then be explored lateral or medial to the choroid plexus depending on the position of the drainage vein and on the surface of the thalamus. If a local hematoma is evident, the hematoma is removed first and then the pathological vessel is dissected along the

cleavage plane of the malformation. The elimination of the feeders always causes some difficulties, which can be overcome with patient stepwise dissection, coagulation, separation, and further dissection.

For the posterior interhemispheric approach, the patient is placed in the sitting position. Through a parasagittal, parieto-occipital craniotomy, exposure continues in an interhemispheric plane along the parasplenial region, with splitting of the ipsilateral paramedian corpus callosum for 1 cm anterior to the splenium and entering into the trigone (Fig. 2). The exploration may also extend through the posterior part of the trigone; then, the same technique for the excision of anterior thalamic malformations is continued.

SURGICAL OUTCOME

Two patients in this series underwent the anterior transcallosal approach, and four patients received the posterior interhemispheric approach. The remaining two patients required the anterior and posterior approach in two procedures. All patients except one had total removal (Table 4). The only patient with incomplete excision died. The other seven patients were able to resume their previous occupations after surgery. The most common postoperative complication was a disturbance of recent memory. Five patients were noted to have at least transient problems in acquiring new knowledge. However, four of these patients had suffered a preoperative memory disturbance as a result of hemorrhage. All patients showed considerable improvement with time.

Three patients were found to have a contralateral homonymous field defect after the operation. All of these patients had field cut preoperatively. There were six cases of postoperative hemisensory loss, but only three persisted. One patient had transient hemiparesis, and he regained normal strength in 1 month.

All eight patients were studied with postoperative angiography. Total removal of the AVM was confirmed in five patients, and residual AVM was noted in three. Subsequent operations with total obliteration were required in two of these three patients. Unfortunately, the other did not have a chance for another operation because of continued bleeding, resulting in death 5 days after the initial operation.

ILLUSTRATED CASES

Patient 1

This 18-year-old girl experienced a sudden onset of severe headache and vomiting 8 months before the time of admission. A similar episode with consciousness disturbance brought her to our emergency service. An examination revealed that she was in a comatose state, with a Glasgow Coma Scale score of E1M4V1, isocoric pupil with normal light reflex, neck stiffness, left hemiplegia, and hemianesthesia. A generalized tonic-clonic seizure was noted in the emergency room. A computed tomographic scan showed hemorrhage in the right thalamus with rupture into the ventricle. Emergent ventricular drainage was done. She gradually

regained consciousness. A cerebral angiogram demonstrated a small AVM in the right anterior thalamic region with feeding vessels from the anterior and posterior choroidal arteries and the thalamoperforators (Figs. 3A and 4A).

The operation was performed through a right, frontoparietal craniotomy with the patient in the supine position. Via the anterior interhemispheric route, the corpus callosum was divided to about 2 cm in distance. The right lateral ventricle was then entered. An old blood clot was noted in the floor. After the clot was removed, the AVM was encountered in the anterior dorsal aspect of the thalamus. A circumscribing incision was made around the malformation, and the dissection was gradually deepened. After total occlusion of the feeder, the malformation was removed.

A postoperative angiogram revealed no residual malformation (Figs. 3B and 4B). The patient experienced progressive improvement after the operation. At her 6-month follow-up examination, she had normal neurological status except for mild hyperreflexia on the left side. She had returned to work and her usual activities.

Patient 2

This 9-year-old boy was brought to our hospital because of sudden onset of headache and vomiting associated with consciousness disturbance. An examination revealed a Glasgow Coma Scale score of E1M5V1, isocoric pupil with normal light reflex, neck stiffness, right hemiplegia, and hemianesthesia. A computed tomographic scan showed left thalamic hemorrhage with rupture into the ventricle. After conservative treatment, he regained consciousness. A cerebral angiogram was arranged and revealed an AVM in the left pulvinar region with feeders from the thalamoperforators and posterior choroidal artery and drainage to the internal cerebral vein (Fig. 5).

The first operation was performed by an anterior interhemispheric approach. After the corpus callosum was divided, the left lateral ventricle was entered. An area of old hemorrhage facilitated the identification and dissection of the malformation. The malformation was located in the posterior dorsal aspect of the thalamus. It was excised circumferentially. We found it difficult to give adequate management of the entire malformation through this approach. The follow-up angiogram disclosed some residual AVM (Fig. 6). The second procedure was performed 3 weeks later. The occipital interhemispheric approach with the patient in the sitting position was used. The occipital lobe was retracted laterally. After identification of the splenium, the corticotomy was made on the precuneus. The trigone was then entered, and the malformation could be identified through the floor of the trigone. By use of an operating microscope, the malformation was dissected around the margin. The lesion was easily excised. The postoperative angiogram revealed complete obliteration of the malformation (Fig. 7). The patient's postoperative recovery was uneventful. Six months after the operation, only mild hyperreflexia over the right arm

and right homonymous hemianopsia were present. He had returned to his previous occupation as a student.

DISCUSSION

Operative resection of AVMs in the thalamus is a great 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 be expected that surgery for these lesions may lead to profound and disabling neurological sequelae. Solomon and Stein (11) and Shi and Chen (9) have reported good success, but the AVMs in the basal ganglion and ventricle are included in their series. The AVMs reported here are primarily located in the thalamus. This retrospective analysis also indicated that the AVMs in the thalamus can be safely removed in selected cases by current surgical techniques.

The preoperative preparation for these patients requires detailed neuroradiological studies. High-resolution computed tomographic scanning and, more recently, magnetic resonance imaging have proved invaluable for the precise localization of the AVMs and for defining their relationship to the tentorium, the brain stem, and the ventricular system. Cerebral angiogram is indispensable when planning the surgical approach, and it is essential to understand the vascular anatomy.

The primary input in all of the AVMs in this series was from the thalamoperforators; this is characteristic of AVMs involving the thalamus. The patients reported by Solomon and Stein (11) had primary vascular supply from the choroidal arteries. The thalamoperforating arteries were angiographically demonstrated to supply only three malformations. The majority of cases reported by Shi and Chen (9) received input from the anterior choroidal artery and the lenticulostriate artery. The perforating branches of the posterior cerebral artery and the posterior communicating artery were noted in only one patient. The AVMs in the basal ganglion and ventricle are also included in their series. We suggest that the primary input of AVMs in the thalamus is restricted to the thalamoperforating arteries.

Embolization has been a useful adjuvant to the surgical treatment of large, supratentorial AVMs (13); however, the malformations in the thalamus are generally not suitable for this procedure. These malformations are primarily supplied by the thalamoperforating arteries, choroidal arteries, and lenticulostriate arteries. These vessels generally have small intraluminal diameters and arise from parent vessels at right angles. These factors make embolization hazardous and not usually indicated for these malformations.

The interhemispheric transcallosal approach was first described by Dandy (1) for removing posterior third ventricle tumors. It had been applied for treating vascular malformations in the medial hemisphere (12) and following the tentorial ring (10). We used the same approach but put the craniotomy more anteriorly. We found it ideal for treating vascular malformations in the region of the anterior thalamus. The AVMs can be easily localized after the hematoma in the floor of the

ventricle is identified. For vascular malformation in the posterior thalamus, the posterior interhemispheric approach was used. The patient was placed in the sitting position. The exposure was then done in the interhemisphere plane through a parasagittal, parieto-occipital craniotomy. The trigone can be entered after the paramedian corpus callosum has been split anterior to the splenium. The malformation can also be localized after the hematoma in the floor of the ventricle has been identified.

Solomon and Stein (11) used the interhemispheric transcallosal approach for treating vascular malformations in the region of the atrium of the lateral ventricle. The hemisphere retraction was usually on the parietal lobe. The bridging vein represents a hazard of this approach, and it may be necessary to take one or two sizable draining veins. We put the hemisphere retraction on the parieto-occipital region for treating lesions around the posterior thalamus. The bridging veins usually are lacking around there. The transcortical, transventricular approach for the excision of the thalamic malformations has also been reported. Different corticotomies via the parietal lobe (4), the superior temporal gyrus (2), the middle temporal gyrus (15), or the inferior temporal gyrus (3) have been applied. The major drawback to those approaches is that normal functioning brain must be traversed before the malformations are reached. In addition, the exposure is usually away from the deep arterial supply.

The surgical indications for thalamic malformations are still controversial. We restricted the operative cases to those who had a history of bleeding. Problems in localizing the vascular malformation will be met in those without a history of bleeding, and surgery could result in disastrous sequelae. The vascular input also contributes to the indications. Primary vascular input from the anterior thalamoperforator may not be a good candidate because of the high possibility of hypothalamus involvement. Primary input from the posterior thalamoperforator, choroidal, or lenticulostriate arteries are more optimal. Dorsal, posterior, or lateral locations are easier to approach. Lesions located mainly on the ventral region involve more risk because of deep position and possibility of hypothalamus involvement. All of the cases reported here fitted these criteria.

The most common postoperative complication was a disturbance in recent memory. Five of the patients with thalamic malformations in this series were found to have problems in acquiring new knowledge. However, four of these patients had suffered a preoperative memory disturbance consequent to AVM rupture. Those malformations were all located on the left side. Only one additional patient with right thalamic AVM displayed memory disturbance after surgery. Solomon and Stein (11) had the same findings, and they suggested that the left fornix, thalamus, and/or caudate nucleus are critical for recent memory function.

Gamma-beam irradiation for the treatment of small AVMs has been advocated by Steiner (14). The

successful treatment of a large group of patients has been reported with complete obliteration of the malformations. The major drawback to this method is the long latent period between the treatment and obliteration of malformations and the risk of hemorrhage during that period. Additionally, the long-term deleterious effect of this high-energy radiation is unknown. Therefore, radiosurgery can only be considered in patients with AVMs that have not ruptured and that are situated in a location unfavorable for surgical removal.

There are no reports of thalamic malformations that can clarify the relative merits of surgical excision versus conservative treatment, nor are there specific elements in individual cases that would suggest a good or bad prognosis. On the other hand, patients with deep-seated angiomas appear to be prone to recurrent hemorrhage⁽⁶⁻⁸⁾. Surgical intervention seems advisable, provided that operative mortality and morbidity can be expected to be lower than that expected from the natural course. Compared with the risk of morbidity due to an untreated AVM, which approaches 50%^(5,13), only one patient in this series died. Surgical excision of ruptured thalamic malformation is warranted. In conclusion, with the use of modern operative and anesthesiological facilities, the surgical treatment of thalamic malformations in selected cases has become not only possible but even advisable in view of the low morbidity when compared with the risk of alternative or conservative treatment.

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COMMENTS

The author presents a timely article that discusses the microsurgical obliteration of deep (thalamic) arteriovenous malformations (AVMs). Currently, there is raging discussion about the benefits of radiosurgery for these lesions as opposed to microsurgical removal. Solomon and Stein⁽¹⁾ have previously discussed the microsurgical treatment of small AVMs, including those located in the thalamus. We had approximately an 85% cure rate in these lesions, with no mortality and no major neurological permanent deficits. Lee has approximately an 88% cure rate but unfortunately a 12% mortality. It is interesting that in order to salvage this cure rate, further operations were necessary on two patients for residual malformations left at the time of the first surgery. Without including the mortality rate in this article, the cure rates of Solomon and Stein and Lee are higher than those obtained by radiosurgery.

I found the surgical judgment and discussion

thereof as well as the approaches to be well founded and solid. He points out many of the nuances of the surgical approach to these lesions and the anatomical angiographic evaluation before surgery.

I was particularly interested in the discussion of recent memory difficulties after this surgery, some of which were present before the operation. He pointed out, as we did, that this is more apt to occur when the lesion is located on the left side, suggesting some dominance in the acquisition of facts or recent memory. This lends further credence to that theory of a dominance of this system. In general, I agree with everything that was presented but am chagrined by the relatively high mortality figure.

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Dr. Lee is to be commended for managing this group of thalamic AVMs with very acceptable morbidity and mortality. This article promises to provoke controversy in an era when more and more ruptured thalamic lesions are being referred for stereotactic radiotherapy. The surgical principles described in this report are anatomically based and appear to be quite sound. I would disagree with two specific points articulated by the author.

The first point concerns the delay in definitive surgical resection after an initial incomplete surgical procedure that did not result in complete removal. The only mortality of this series occurred 5 days after the first procedure because of a subsequent bleeding episode. I also noted that in Patient 2, a second operation was delayed 3 weeks. It has been our experience that the initial surgical procedure invariably alters the dynamics of the venous drainage, and if the resection is incomplete, immediate risk is imposed by this dangerous de-efferentation. Our policy of definitive immediate postoperative angiography with the patient under anesthesia, with a return to the operating room if residual is noted, was born from such catastrophes. The second point concerns the value of superselective embolization in thalamic and other eloquently located malformations. These are the very malformations in which a relatively dry and thoroughly embolized dissection plane is the most desirable, as one dissects tightly along the margin using generous coagulation to withdraw the AVM from vital tissue. If robust feeding to the malformation is left intact at the time of operation, the tiny fragile vessels at the periphery rupture easily and require transgression into important tissue to secure hemostasis. Although there are technical difficulties in accessing some of these

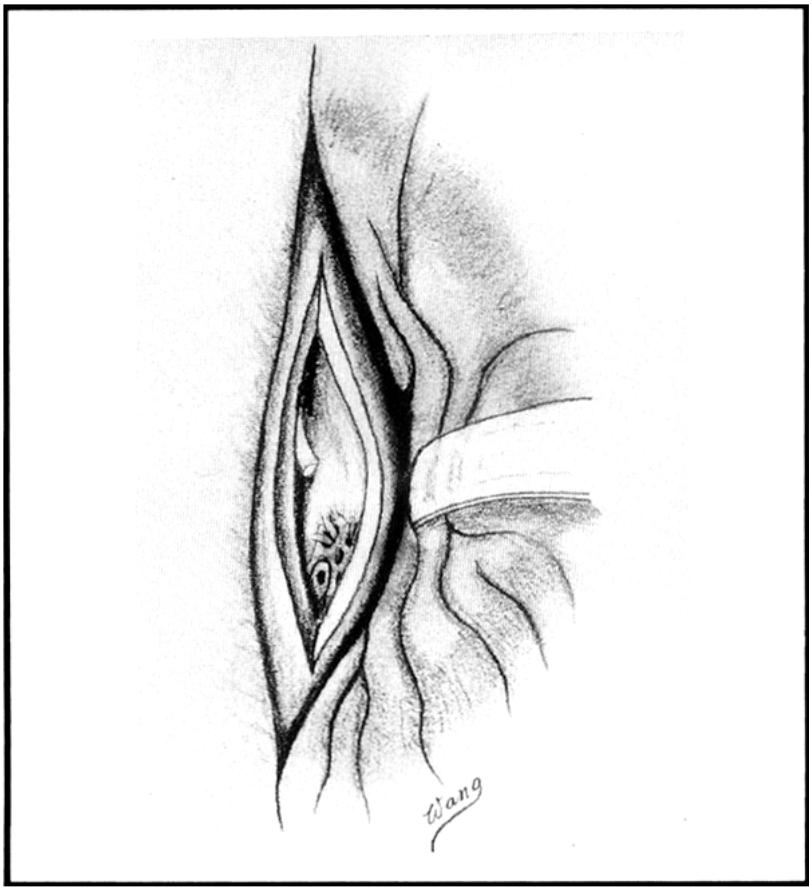


Figure 1. Artistic drawing of the anterior interhemispheric approach to the ventricle through the division of the corpus callosum. Retractor is shown on the medium surface of the frontal lobe. The vascular malformation can be seen beneath the ependyma of the ventricle.

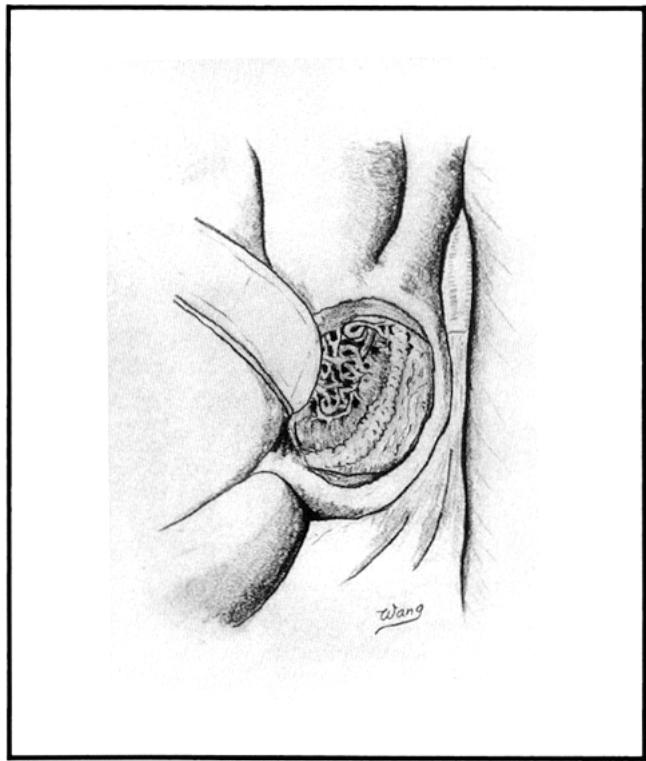


Figure 2. Artistic drawing of the left posterior interhemispheric approach to the trigone through an incision in the precuneus. The vascular malformation can be identified beneath the floor of the trigone

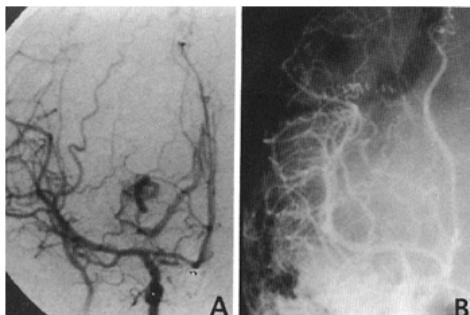


Figure 3. A, anteroposterior carotid angiogram of Patient 1 preoperatively, showing an AVM fed by the anterior choroid artery and drained by a vein to the basal vein of Rosenthal. B, postoperative angiogram showing no evidence of residual AVM.

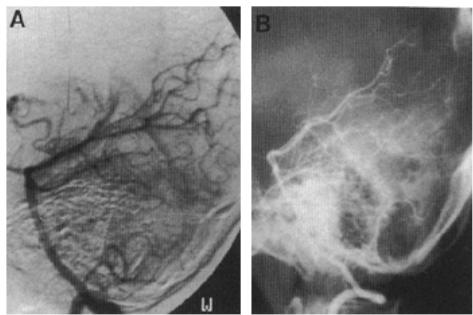


Figure 4. *A*, lateral vertebral angiogram of Patient 1 preoperatively, showing prominent vascular supply by posterior choroidal arteries and thalamoperforators. *B*, postoperative angiogram showing total occlusion of the AVM

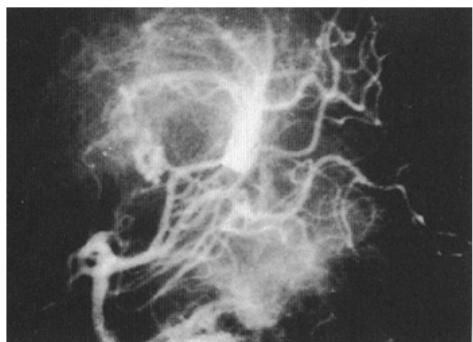


Figure 5. Lateral vertebral angiogram showing prominent vascular supply by thalamoperforator and posterior choroidal arteries and the draining vein to the internal cerebral vein



Figure 6. Lateral vertebral angiogram (performed postoperatively) showing some residual AVM.

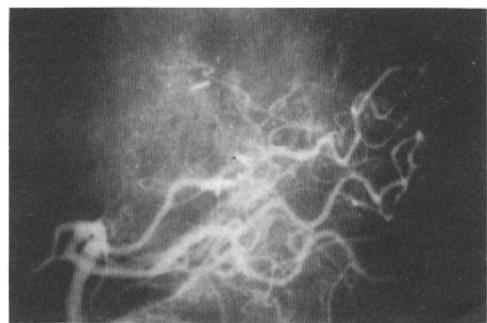


Figure 7. Lateral vertebral angiogram (after second operation) showing no evidence of residual AVM.

Patient No.	Age (yr)/Sex	Symptoms	Site	Location	Approach ^a
1	9/M	Hemorrhage	Left	Posterior	Supine, occipital
2	18/F	Hemorrhage	Left	Posterior	Occipital
3	30/F	Hemorrhage, 3 times; seizure	Right	Posterior	Occipital ^b
4	38/M	Hemorrhage	Left	Posterolateral	Occipital
5	21/F	Hemorrhage, 3 times	Left	Posterolateral	Occipital, supine
6	33/F	Hemorrhage	Right	Posterior	Occipital
7	38/M	Hemorrhage	Left	Anterior	Supine
8	18/F	Hemorrhage, 2 times	Right	Anterior	Supine ^b

^a Supine, anterior transcallosal approach; Occipital, posterior interhemispheric approach.

^b Ventricular drain before definitive surgery.

Table 1. Summary of Eight Patients with Thalamic Arteriovenous Malformations

	No. of Patients	
	Preoperative	Postoperative
Hemiparesis	6	7 ^a
Hemianesthesia	6	6 (3) ^b
Consciousness disturbance	5	1 ^c
Memory impairment	4	5
Hemianopsia	3	3
Seizure	1	0

^a One additional patient had transient hemiparesis but regained normal power in 1 month. All of the patients can walk without support at 6-month follow-up.

^b Only three of six had persistent hemisensory loss.

^c One patient died 5 days postoperatively because of subsequent bleeding.

Table 2. Symptoms and Signs of Patients with Thalamic Arteriovenous Malformations

	No. of Patients
Feeder	
Thalamoperforator	8
Anterior choroidal artery	4
Posterior choroidal artery	7
Lenticulostriate artery	2
Drain vein	
Basal vein of Rosenthal	3
Internal cerebral vein	5

Table 3. Vascularization of Eight Patients with Thalamic Arteriovenous Malformations

	No. of Patients
Total removal	7 ^a
Mortality	1
Return to premorbid occupation	7
Memory disturbance (new)	1
Homonymous hemianopsia (new)	0
Sustained sensory loss	3
Subsequent bleeding	1
Transient hemiparesis (new)	1

^a Two patients had two operations.

Table 4. Operative Results of Eight Patients with Thalamic Arteriovenous Malformations