Approaches for Arteriovenous Malformation Management:
How to Combine Intravascular, Radio, and Direct Surgery

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Summary: We started gamma knife surgery on May 28, 1991 and have treated 24 cases of AVM
during nine months. Based on our experience, various therapeutic policies for AVM management
have been assessed. Radiosurgical procedures were quite safe and patients could return to preopera-
tive activities the day after treatment. However, we had two patients whose malformations ruptured
during and after radiosurgery. As the ideal goal of AVM management is complete obliteration of
the nidus as soon as possible, direct surgery and intravascular surgery remain excellent treatments,
especially for ruptured AVMs with intracranial hematomas. For the treatment of large AVMs in
functional areas, combination therapies can be performed and intravascular embolization may be
considered in order to reduce the volume of the nidus. However, the risk of embolization is still
appreciable for AVMs in functional areas. Compartment irradiation using independent isodose lines
of 50% may be useful for such high risk AVM patients, though a two stage radiosurgical procedure
may also be considered. Selective angiography and MR imaging are useful for the dose planning
of these radiosurgical procedures.

Key words:
- arteriovenous malformation
- embolization
- gamma knife surgery
- surgical excision

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Introduction

The development of microsurgical, interventional neuroradiological, and radiosurgical techniques provide multiple options for arteriovenous malformation (AVM) management. Nowadays experienced neurosurgeons can extirpate small AVMs not only in critical cortical areas and deep in a hemisphere adjacent to a lateral ventricle but also around the brain stem; without worsening the neurological status. For large AVMs, especially the so-called "high-flow AVM", with enlarged feeding arteries, endovascular surgery such as embolization or balloon occlusion of feeders has been performed as a preoperative procedure or as an alternative to surgery and conservative treatment. In cases of small AVMs, especially in the basal ganglia, the thalamus and the brain stem, gamma knife surgery has become an important therapeutic modality because of its efficacy and safety. However, each of these various procedures suffers from fundamental difficulties. These difficulties include normal brain dissection for direct surgery, ischemic complications for intravascular surgery and recanalization after embolization. Finally there is the latent period before complete obliteration of AVMs occurs following radiosurgery. Moreover, large AVMs in functional areas are difficult to manage irrespective of the technique employed. Not only the development of combination therapy but also the technical advancement of each procedure should be considered.

We started gamma knife surgery on May 28, 1991 and have treated 24 cases of AVMs with or without combination therapies over a period of nine months. Based on this experience, we will discuss therapeutic policies for AVM management for the development of combination therapies and for the technical advancement of the radiosurgical procedure.

Clinical Material and Methods

With the exception of two dural AVMs, all cases were referred for gamma knife surgery because of unacceptable risks for the development of new neurological deficits with other forms of treatment. There were 13 females and 11 males. Twenty-two patients were treated using the 201-source cobalt-60 gamma knife. Eleven patients had at least one prior attempt at surgical removal. Intravascular embolization had been performed in 5 patients and feeder clipping had been performed in 3 patients in an attempt to reduce the AVM volume.

We divided the patients into 4 groups (deep-seated, cerebral hemisphere, cerebellar, and dural) according to the locations of the lesion (Table 1). All deep-seated AVMs were small (under 3 cu cm) and ruptured at least once. One patient with a thalamic AVM had undergone direct surgery, however, part of the nidus was still present at postoperative angiography. All these AVMs received gamma knife surgery. The hemispheric group contained 4 small (under 3 cu cm), 7 medium (3–10 cu cm), and one large (more than 10 cu cm) AVMs. Three patients with unruptured AVMs had convulsive seizures. Of these 2 were medium sized and one was large. The others were ruptured AVMs. Eight of 12 patients underwent open surgery (removal in 5 and feeder clipping operation in 3 cases) and 2 of these were operated a second time. Nevertheless, remaining nodules were observed after surgery. Intravascular embolization, with particles or glue was performed in 3 patients, to reduce the size of the AVM. All 12 patients underwent gamma knife surgery. Three cerebellar AVMs had ruptured. One patient was operated in an attempt at direct removal and 2 patients received intravascular embolization with coils or glue. Gamma knife surgery was performed in all 3 patients. Three patients with dural AVMs had exophthalmus, chemosis and congestion of the bulbar conjunctiva. All were dural AVM of the cavernous sinus and were managed with Matas maneuver (carotid compression) for several weeks. One AVM supplied from branches of the external carotid artery disappeared completely and another one, supplied from both external and internal carotid artery decreased the size. No change was observed in the third patient. Intravascular embolization with

<table>
<thead>
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<th>Location</th>
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<tr>
<td>deep-seated</td>
<td>6</td>
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<tr>
<td>thalamus</td>
<td>3</td>
</tr>
<tr>
<td>splenium</td>
<td>1</td>
</tr>
<tr>
<td>hippocampus</td>
<td>1</td>
</tr>
<tr>
<td>CP angle</td>
<td>1</td>
</tr>
<tr>
<td>cerebral hemisphere</td>
<td>12</td>
</tr>
<tr>
<td>parietal</td>
<td>6</td>
</tr>
<tr>
<td>frontal</td>
<td>3</td>
</tr>
<tr>
<td>temporal</td>
<td>2</td>
</tr>
<tr>
<td>occipital</td>
<td>1</td>
</tr>
<tr>
<td>cerebellar</td>
<td>3</td>
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<tr>
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Table 1 Location of 24 cases of arteriovenous malformations
glue was performed in this patient and the AVM disappeared. The second patient was accepted for gamma knife surgery because of a progressing decrease in visual acuity, due to the residual AVM.

Twenty-two patients had application of the Leksell stereotactic G frame under local anesthesia supplemented by intravenous sedation (pentasocin 15 mg and diazepam 5–10 mg). The application was usually performed in the sitting position until October 3, 1991. Thereafter the lying position with continuous monitoring of blood pressure and pulse rate, was used. Biplane stereotactic angiograms were obtained to define the AVM nidus and to determine target coordinates (Fig. 1A). In cases with several feeders from different major arteries, selective angiography was performed using a microcatheter and a digital subtraction method for exact delineation of the nidus. C: MR imaging used for the three-dimensional evaluation of arteriovenous malformations.

Table 2 Radiosurgical dose administered for 22 AVMs

<table>
<thead>
<tr>
<th>Dose Data</th>
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<tr>
<td>isodose (%) at AVM margin</td>
<td></td>
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<tr>
<td>85</td>
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<td>70</td>
<td>3</td>
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<td>50</td>
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<td>25</td>
<td>3</td>
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<tr>
<td>20–24.5</td>
<td>13</td>
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<tr>
<td>16.5–19</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
</tr>
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Results

1) Radiation Dosimetry

The results of radiation dose planning are summarized in Table 2. A peripheral isodose line of 50% or greater was utilized in 21 patients (95%) which permits a steep fall-off in radiation dose beside the lesion. One patient was treated with the 30% isodose line at the AVM edge because of the location and size of the lesion. Single isocenters of irradiation were used in 6 patients and multiple isocenters (range 2 to 7) were used in 16 patients in order to produce precise cover of the irregular margins of the nidus, even in cases of small AVMs.

The mean dose delivered to the AVM margin was 20.4 Gy (range 12 to 25 Gy), and that delivered to the center was 38.9 Gy (range 29.5 to 50 Gy). A dose of 20 Gy or more to the edge of the AVM was the aim in each case. However, 6 patients were treated with the marginal dose of 12 Gy to 19 Gy (mean 16.9 Gy) in order to protect critical areas adjacent to the AVM.

2) Location and Size of AVM and Dose

All patients with deep-seated AVMs were treated with a peripheral isodose line of 50% or greater. All except one thalamic AVM were irradiated with a marginal dose of 20 Gy or higher. One patient with a thalamic AVM was treated with the marginal dose of 19 Gy because of the proximity of the internal capsule. The average numbers of irradiation isocenters were 3.3 (range one to 7). One thalamic AVM had two separated niduses and required two independent dose volumes using the 50% isodose in each instance (Fig. 2).

Patients with hemisphere AVMs received an average of 2.9 irradiation isocenters (range one to 5). Four
patients were treated with a marginal dose under 20 Gy (range 12 to 18 Gy). Two of these patients had AVMs located in the frontal lobe and parietal lobe partially including the motor cortex. The other two AVMs were situated in the occipital lobe and anterior frontal lobe. Three AVMs (one large and two medium size) were treated with two or more independent isodose lines of 50% based on the results of selective angiography. Two of these had received prior embolization in order to reduce the volume of the nidus. A second radiosurgical procedure may be considered to treat the residual AVM nidus in these patients.

Three patients with cerebellar AVMs were treated with a peripheral isodose line of 50% or greater. One of these received a marginal dose of 16.5 Gy because the AVM was close to the brain stem. A patient had two separated residual niduses after direct surgery and treated with two independent dose volumes using the 50% isodose line at the edge in each instance.

One of three dural AVM patients had residual niduses in both cavernous sinuses after Matas maneuver. The niduses were irradiated with a marginal dose of 20 Gy.

3) AVM Rupture during the Application of the Leksell Frame

A patient with a cerebellar AVM complained of headache just after the application of the stereotactic frame and then became unconscious. A CT scan showed a high density mass in the posterior fossa extending into all the ventricles (Fig. 3). Though her respiration became irregular, emergency operation was performed under glyceol drip infusion in order to remove the hematoma. Fortunately, the patient recovered after ventricular drainage and partial resection of the malformation.

We thought that the elevation of blood pressure possibly induced the AVM rupture during the frame application. Since this accident, we have used a continuous monitor of blood pressure and pulse rate in cases of AVM patients, who are placed in the supine position during application of the frame and angiography.

4) Radiosurgery and Embolization or Feeder Clipping

Seven patients received embolization and/or feeder clipping before gamma knife surgery. Following these procedures, larger AVM could be adequately treated by radiosurgery. Even in cases of smaller
lesions, radiation dose planning was facilitated. All patients could be treated with a peripheral isodose of 50% or greater and with a marginal dose of 18 Gy or more.

5) Clinical Evaluation

The mean follow-up period of the patients treated with gamma knife surgery was 8.5 months (range 3 to 12 months). Seventeen patients have been followed for more than 6 months.

One patient (27-year-old man) suffered a hemorrhage 7 months after radiosurgery and became comatose. He received direct surgery at the hospital in which intravascular embolization had been performed prior to radiosurgery. He recovered well after operation and moved to another hospital for rehabilitation. His AVM was treated with four isocenters of irradiation using the 18-mm collimator (18 Gy at the 50% isodose).

Nineteen patients had no clinical changes during the follow-up period of 3 to 12 months. Two patients with neurological deficits before radiosurgery complained of some deterioration of vertigo and sensory disturbance. MR imaging or CT scan showed no additional changes at the follow-up time of 6th month after radiosurgery.

6) Neuroradiological Examination

MR imaging or CT scan was performed in 7 patients 6 months after radiosurgery. No additional changes were observed in these patients. Cerebral angiography was performed in 5 patients (4 patients: 6 months after radiosurgery and 1 patient: 12 months after radiosurgery). In 3 patients, the size of AVM nidus decreased without neurological deficits. AVMS of these patients were small (less than 1 cu cm) and/or low-flow.

7) Complication

Immediate postsurgical complications included partial seizures in two patients. Nausea and vomiting occurred in one patient. These complications resolved within 12 hours. Late complications were a small bald spot in one patient and frontal neuralgia due to nerve injury by an aluminium pin in one patient. These complications resolved within several months. In addition AVM rupture during the application of the frame and some deteriorations of vertigo and sensory disturbance in two patients were described above.

Discussion

The ideal goal of AVM management is complete obliteration of the nidus as soon as possible. Open surgery is an excellent treatment for cerebral AVMs located in surgically accessible locations, especially for small ruptured AVMs with intracranial hemorrhage. The goal of AVM management might be reached at once in these cases. For large AVMs located in non-functional areas, combination treatment with intravascular and direct surgery is reasonable and useful, especially for high-flow AVMs. In our series two patients suffered a rupture of an AVM during or after radiosurgery. Both patients received emergency operation and recovered afterwards, though they sustained neurological deficits due to the location of the AVM. These complications emphasize the need for speedy total obliteration of an AVM. Thus open surgery and intravascular surgery remain excellent treatment for AVMs.

On the other hand, gamma knife surgery is also excellent treatment for deep-seated small AVMs. The procedure itself is quite safe and patients can return to preoperative activities the day after. The efficacy of gamma knife surgery has been reported from several centers. Moreover there is a tendency today for patients not to want direct surgery (craniotomy) even in a case of a relatively easy operation. It is to be expected that the desire for non-invasive treatment, such as radiosurgery, will increase as the techniques involved become more sophisticated. However, a latency interval is unavoidable before complete obliteration of AVMs occurs and there is about 4% risk for intracranial hemorrhage during this period. If we are to develop the radiosurgery method, we must consider how to shorten the latency interval. We are using MR imaging routinely and selective angiography sometimes for exact evaluation of each nidus. Even in cases of smaller AVMs, decreasing the volume of the nidus is desirable. For smaller high-flow AVMs, intravascular embolization might be considered if it can be considered a low risk procedure for the individual patient.

We treated 7 patients with gamma knife surgery after intravascular embolization and/or feeder clipping operation. The volume of the AVM nidus decreased after embolization. However, in cases with large AVMs, some niduses became irregular in shape or separated into several compartments. The separated niduses were treated with independent dose
volumes using the 50% isodose at the edge of each component. As the risk of recanalization remains in these cases, a second radiosurgical procedure may be required. On the other hand, two cases with a prior feeder clipping operation showed decreased size of the nidus without separation into individual compartments. These were treated with only one dose volume with the 50% isodose at the edge. Nevertheless risk of recanalization also remains in these cases.

Management of large AVMs in functional regions is difficult even with combined procedures. Intravascular embolization might be considered first nowadays in order to reduce the size of the nidus, followed by direct surgery or radiosurgery depending on the size and location of the remaining nidus. The usefulness of the combined therapies has been reported to be associated with limitations and problems. The risk of intravascular embolization is still not negligible even using an amobarbital test during the procedure. It is especially true for AVMs in functional regions. Recently we experienced two large AVMs in the posterior fossa where it was not possible to reduce the volume of the nidus sufficiently by intravascular procedures. In some cases it was necessary to treat the AVMs using independent dose volumes for individual niduses using the 50% isodose after proper radiological definition of the niduses. Each compartment was covered with a marginal dose of 20 Gy. This compartment irradiation may be useful in such cases, though second radiosurgical procedure should also be considered.

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References