Seizure outcome in patients with surgically treated cerebral arteriovenous malformations

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A series of 280 cases of cerebral arteriovenous malformations (AVM's) treated surgically between June, 1970, and June, 1989, is reviewed with particular focus on the preoperative seizure history and follow-up seizure status. Follow-up evaluation (mean duration 7.5 years) was achieved in 98% of cases and was accomplished through re-examinations, telephone interviews, and written questionnaires. Overall, 89% of the surviving patients with a follow-up period of greater than 2 years were free of seizures at last examination.

Of the 280 patients in this series, 163 had experienced no seizures preoperatively. A recent follow-up study (with a minimum duration of 2 years or to death) was available in 157 of these 163 cases; 21 patients had died. Of the 136 surviving patients, only eight (6%) were having new ongoing seizures. In the 128 (94%) who had remained seizure-free, 73% were receiving no anticonvulsant agents while 27% were taking anticonvulsant prophylaxis. The 2-year minimum follow-up study in 110 of the 117 patients with preoperative seizures revealed that eight (7%) had died. Of the 102 surviving patients, 85 (83%) were seizure-free (with 48% no longer receiving anticonvulsant therapy), while 17 (17%) still suffered intermittent seizures. However, of these 17 patients, 13 reported their seizures to be improved compared to preoperatively; the seizures were the same in two patients and were worse in two patients.

An actuarial analysis was conducted comparing the life expectancy of patients following surgery for AVM's with the expected survival of a general white population of the same age and sex in the West Northcentral region of the United States. No statistically significant difference was found. There were seven perioperative deaths (three from cerebral hemorrhage, two from pulmonary emboli, and two from obstruction of venous drainage) and 22 deaths during the follow-up period. Of these 22 deaths, the cause was unknown in four patients, apparently unrelated to the AVM in 13, and directly or indirectly related to the patient's neurological condition prior to surgery or due to surgery performed for resection of the AVM in five.

There was a statistically significant relationship between the size and location of the AVM and the clinical presentation. Patients with small AVM's (< 3 cm) were more likely to present with hemorrhage whereas those with large AVM's were more likely to present with seizures.

Conclusions from this study are: 1) there is a low incidence of a new seizure disorder following surgery; 2) chances for resolution or control of a pre-existing seizure disorder are good; 3) although resolution of seizures or seizure control was achieved postoperatively in AVM's of all sizes, this benefit was highest in smaller as opposed to larger AVM's; and 4) ultimately, there is a good capacity for recovery from pre-existing neurological deficits or those resulting from surgery.

Key Words: arteriovenous malformation • seizure • outcome

Recent studies have confirmed that cerebral arteriovenous malformations (AVM's) carry a lifelong risk of significant morbidity and mortality due to hemorrhage. This risk can be eliminated with complete removal of the AVM. With the modern techniques of preoperative embolization and microsurgery and advances in neuroanesthesia, surgical resection is proving to be increasingly safe for these patients. In analyzing risk/benefit ratios attendant to AVM resection, neurologists and neurosurgeons must consider not only the surgical risks of death and new neurological deficits versus the benefit of the elimination of future hemorrhage, but also the risk of inducing or aggravating a seizure disorder and the benefit of eliminating or significantly improving seizures that exist secondary to the AVM.

The results of surgical treatment for AVM's and subsequent long-term seizure follow-up study have been only sparsely documented. The conclusions regarding the efficacy of this operation for seizures are mixed. 

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Since we found it difficult to determine the prognosis for new seizure development or improved seizure control following AVM resection based on the reports in the literature, we reviewed a series of surgically treated AVM's specifically to determine the effect of surgery on seizures and neurological outcome relative to AVM location, size, preoperative hemorrhage, and seizure history. The primary operative objective (80%) in our series was not seizure control, but resection of the AVM to prevent rebleeding or to lessen the risk of future hemorrhage. Accordingly, in most cases there was no attempt to localize or remove a seizure focus other than the AVM itself.

In reviewing our series and presenting this report, we have tried to answer the following four questions: What is the likelihood of new onset of seizures after AVM resection? Will AVM resection change the frequency and severity of seizures that were present preoperatively? Is there a difference in postoperative seizure occurrence in individuals with no seizures versus single or multiple seizures preoperatively? Do the factors of AVM size, location, and previous hemorrhage affect the seizure prognosis?

Clinical Material and Methods

Patient Population

Between June, 1970, and June, 1989, 321 cerebral, cerebellar, and brain-stem parenchymal AVM's were surgically treated at the Mayo Clinic. Of these, 41 were thombosed or occult and 280 were angiographically demonstrable. We retrospectively surveyed the angiographically demonstrable intraparenchymal AVM's only. Of these 280 cases, five patients were counted twice since their lesions were determined to be separate or recurrent, with a second operation for AVM resection performed 1.5 to 4.5 years after the first. The total series included 141 males and 139 females. The age at presentation for surgical treatment ranged from 5 months to 81 years (mean 33 years).

Recent patient follow-up evaluation was accomplished through re-examinations, telephone interviews, and written questionnaires. The mean follow-up period for the 280 cases was 7.5 years (range 1 month to 20.3 years). However, a recent seizure history was unobtainable for six patients and seven had a follow-up duration of less than 2 years and were not counted in the final seizure analysis; therefore, the final analysis was based on the 267 cases with a follow-up period greater than 2 years or to death.

The primary symptom that led to the diagnosis of the AVM in the 280 cases was hemorrhage in 156 (56%), seizures in 70 (25%), and headache or focal neurological deficits as well as other symptoms in 54 (19%). Clinical or subclinical hemorrhage was found to have occurred preoperatively in 207 patients (74%), both seizures and hemorrhage in 69 (25%), seizures without hemorrhage in 48 (17%), and neither seizures nor hemorrhage in 25 (9%).

Of the 163 patients who experienced no preoperative seizure, the general preoperative status was classified as excellent in 47%, good in 18%, and poor in 35%. Of the 117 patients who had suffered preoperative seizures, 66% were classified as in excellent condition, 19% good, and 15% poor. Patients who were in poor condition preoperatively were usually disabled because of recent hemorrhage.

The seizure history of the 280 angiographically demonstrable AVM's is summarized in Table 1. The seizure history in patients with AVM's in adjacent areas of perceived similar epileptogenic potential were analyzed. Particular attention was paid to AVM's in the temporal, frontal, frontoparietal, sylvian, and parietal regions. These sites represented 164 (61%) of the 267 AVM cases with 2-year minimum follow-up period. The anatomical distribution of the AVM's is illustrated in Fig. 1.

Terminology

The following definitions were applied for the purposes of this study. Neurological function was classified as: excellent, no or minimal deficit, including visual field defect; good, mild to moderate neurological deficit but able to work; poor, major deficit, unable to work; and dead. Eloquent areas of the central nervous system included the primary sensorimotor regions, the primary visual cortex, the primary language cortex, the hypothalamus, the thalamus, basal ganglia, and internal capsule, and the brain stem.
Seizure outcome after surgery for AVM’s

Surgical Approach

A detailed description of the surgical techniques utilized in the resection of the AVM’s in these 280 cases has been reported previously. All patients were operated on under general anesthesia with standard microsurgical techniques. Ligation of major feeders and/or staged embolization was used selectively. Excision of the AVM was undertaken with preservation of as much normal parenchyma as possible. In cases with a previous hemorrhage, the hematoma was evacuated along with grossly injured brain tissue. Hemosiderin-stained but otherwise normal-appearing brain parenchyma was not resected. Intraoperative electrocorticography was not utilized because the primary goal of surgery was resection of the AVM in its entirety and not resection of the seizure focus.

Perioperative Management

Perioperative anticonvulsant agents were routinely administered for seizure prophylaxis. The duration of postoperative anticonvulsant therapy was variable and dependent upon the preoperative history of seizures, the occurrence of postoperative seizures, and the follow-up electroencephalogram.

Statistical Analysis

Cases were analyzed statistically using the chi-squared method. It should be made clear that difficulty arises in assessing the statistical significance of several factors, especially those related to the fact that follow-up evaluation does not occur at an identical time for all patients. We conducted an actuarial analysis comparing the life expectancy of patients following surgery for AVM’s with the expected survival of a general white population of the same age and sex in the West North-central region of the United States.

Results

In reviewing the results of surgery for AVM’s in order to determine the prognosis for new seizure development or improved seizure control, we selected for consideration the patient’s preoperative clinical condition and seizure history, the location and size of the AVM, and the presence of preoperative hemorrhage.

Preoperative Condition vs. Clinical Status at Follow-Up Examination

Table 2 compares the preoperative clinical status of the patients without and with a history of seizures to their clinical status at last follow-up examination.

Seizure History

Patients With No Preoperative Seizures. Of the 280 patients with angiographically demonstrable AVM’s, 163 experienced no preoperative seizures. At last follow-up evaluation (duration > 2 years or to death), 128 (94%) of the 136 surviving patients were seizure-free. Of these, 93 patients were receiving no anticonvulsant medications while 35 remained on anticonvulsant prophylaxis. Only eight patients (6%) had ongoing seizures while receiving anticonvulsant therapy (Fig. 2 left).

Table 2

<table>
<thead>
<tr>
<th>Preoperative Clinical Status</th>
<th>No. of Cases</th>
<th>Clinical Status at Last Follow-Up Examination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td>cases without preop seizures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>excellent</td>
<td>74</td>
<td>76%</td>
</tr>
<tr>
<td>good</td>
<td>28</td>
<td>64%</td>
</tr>
<tr>
<td>poor</td>
<td>55</td>
<td>45%</td>
</tr>
<tr>
<td>cases with preop seizures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>excellent</td>
<td>73</td>
<td>86%</td>
</tr>
<tr>
<td>good</td>
<td>21</td>
<td>52%</td>
</tr>
<tr>
<td>poor</td>
<td>16</td>
<td>43%</td>
</tr>
</tbody>
</table>

* For neurological function status definitions, see text.
† Includes all deaths regardless of cause.

Fig. 2. Pie charts showing seizure status at last follow-up examination in 136 surviving patients with no preoperative seizures (left) and in 102 surviving patients with preoperative seizures (right). Follow-up period was greater than 2 years in all patients.

Patients With Preoperative Seizures. A total of 117 patients had a history of preoperative seizures. At last follow-up evaluation, 85 (83%) of the 102 surviving patients remained seizure-free. Of these, 41 patients (48%) were no longer receiving anticonvulsant therapy (Fig. 2 right).

In analyzing the 49 patients with a single or few (one to three) seizures preoperatively, follow-up monitoring for greater than 2 years or to death was completed in 47 patients. Three patients had died. Of the surviving 44 patients, 41 (93%) remained seizure-free through the last follow-up examination, with 56% no longer receiving anticonvulsant agents. In two patients (5%) seizures were worse and in one patient (2%) seizures were improved compared to preoperatively.

Sixty-eight patients suffered four or more seizures preoperatively. Follow-up study of at least 2 years’ duration or to death was available in 63 patients. Five patients (8%) had died. Of the remaining 58 patients with multiple seizures preoperatively, 44 (76%) were seizure-free at last follow-up evaluation, with 41% no longer receiving anticonvulsant therapy. In 12 patients (21%) seizures were improved, and in two patients (3%) seizure status remained unchanged; no patients experienced worsening of their preoperative seizures.

Patients With Perioperative Seizures. Of the 163 patients with no preoperative seizures, 16 (10%) experienced perioperative seizures. At last follow-up evalu-
ation, 14 of these 16 patients were seizure-free, whereas in only two were the seizures ongoing. Of the 117 patients with a history of preoperative seizures, six (5%) had worsening of seizures during hospitalization. At last follow-up examination, five of these six patients remained seizure-free and seizures were improved compared to preoperatively in the remaining patient.

Location of Arteriovenous Malformations

Overall, 180 (64%) of the 280 AVM’s involved eloquent areas of the brain. The relationship between the location of the AVM and the history of preoperative seizures was examined and is detailed in Table 3. There was, as expected, a greater representation of AVM’s in “epileptogenic” cortex in the group having preoperative seizures. Specifically, while AVM’s in the anterotemporal, posterotemporal, posterofrontal, and sylvian regions accounted for 132 (47%) of the lesions in this series, they represented 73 (62%) of the patients with preoperative seizures. This was statistically significant (p < 0.001). An examination of the risk of ongoing postoperative seizures revealed that, of the eight patients who developed seizures postoperatively, four patients (50%) with ongoing seizures after surgery had AVM’s in the temporal, posterofrontal, or sylvian region. Of 17 patients with a history of preoperative and ongoing seizures, 10 (59%) had AVM’s located in the temporal, posterofrontal, or sylvian region (Fig. 3).

Size of Malformations

Arteriovenous malformation size was categorized as small (< 3 cm), medium-sized (3 to 6 cm), or large (> 6 cm). Twenty-five percent of the 106 patients with small AVM’s and 53% of the 125 patients with medium-sized AVM’s had preoperative seizures. In the group of 49 patients with large AVM’s, 45% experienced preoperative seizures. The risk of seizures in patients with small AVM’s was significantly less than in the other two groups (p < 0.001).

The variable time of follow-up evaluation precludes a statistical analysis relative to the occurrence of postoperative seizures compared to the size of the AVM prior to surgery. However, it was noted that at last follow-up examination in the group of surviving patients with small AVM’s, 96% were seizure-free. This can be compared to 87% in the group with medium-sized AVM’s and 82% for those with large AVM’s. Tables 4 and 5 compare AVM size and seizure status at last follow-up evaluation.

Presence of Preoperative Hemorrhage

While it was discovered that patients with large AVM’s were more likely to have experienced preoperative seizures, the opposite appeared to be true regarding preoperative hemorrhage. Clinical or subclinical hemorrhage was found to have occurred in 207 of our 280 patients. Subclinical hemorrhage was defined as either an unsuspected hemorrhage discovered on computerized tomography or magnetic resonance imaging or evidence of previous hemorrhage found at surgery.

In analyzing the size of the AVM’s, it was determined that a statistically significant number of patients with small AVM’s had no preoperative seizures and were more likely to have sustained a preoperative hemorrhage (p < 0.001). Ninety-six (91%) of the 106 patients with small AVM’s had suffered preoperative hemorrhages while 81 (65%) of the 125 patients with medium

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TABLE 3

<table>
<thead>
<tr>
<th>Location of AVM</th>
<th>No. of Cases</th>
<th>% With Prop Seizure</th>
<th>% With No Prop Seizure</th>
</tr>
</thead>
<tbody>
<tr>
<td>anterofrontal</td>
<td>18</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>posterofrontal</td>
<td>53</td>
<td>57%</td>
<td>43%</td>
</tr>
<tr>
<td>anterotemporal</td>
<td>20</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>posterotemporal</td>
<td>50</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>sylvian/parietal</td>
<td>23</td>
<td>39%</td>
<td>61%</td>
</tr>
<tr>
<td>parieto-occipital/occipital</td>
<td>49</td>
<td>22%</td>
<td>78%</td>
</tr>
<tr>
<td>basal ganglia</td>
<td>9</td>
<td>33%</td>
<td>67%</td>
</tr>
<tr>
<td>brain stem/cerebellum</td>
<td>39</td>
<td>8%</td>
<td>92%</td>
</tr>
<tr>
<td>corpus callosum</td>
<td>11</td>
<td>36%</td>
<td>64%</td>
</tr>
<tr>
<td>intraventricular</td>
<td>8</td>
<td>37%</td>
<td>63%</td>
</tr>
<tr>
<td>totals</td>
<td>280</td>
<td>42%</td>
<td>58%</td>
</tr>
</tbody>
</table>

* Abbreviation: AVM = arteriovenous malformation.

TABLE 4

<table>
<thead>
<tr>
<th>AVM Size</th>
<th>No. of Survivors</th>
<th>No. of Deaths</th>
<th>Seizure-Free, Off Meds</th>
<th>Seizure-Free, On Meds</th>
<th>New Ongoing Seizures</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 cm</td>
<td>67</td>
<td>8</td>
<td>78%</td>
<td>19%</td>
<td>3%</td>
</tr>
<tr>
<td>3-6 cm</td>
<td>50</td>
<td>6</td>
<td>66%</td>
<td>28%</td>
<td>6%</td>
</tr>
<tr>
<td>&gt; 6 cm</td>
<td>19</td>
<td>7</td>
<td>42%</td>
<td>42%</td>
<td>16%</td>
</tr>
</tbody>
</table>

* Abbreviations: AVM = arteriovenous malformation; Off Meds = patient receiving no anticonvulsant medications; On Meds = patient continuing to receive anticonvulsant prophylaxis.
Seizure outcome after surgery for AVM's

<table>
<thead>
<tr>
<th>AVM Size</th>
<th>No. of Survivors</th>
<th>Seizure-Free</th>
<th>Seizures</th>
<th>Seizures</th>
<th>Seizures</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3 cm</td>
<td>25</td>
<td>2</td>
<td>52%</td>
<td>40%</td>
<td>4%</td>
</tr>
<tr>
<td>3-6 cm</td>
<td>58</td>
<td>5</td>
<td>40%</td>
<td>41%</td>
<td>3%</td>
</tr>
<tr>
<td>&gt; 6 cm</td>
<td>19</td>
<td>1</td>
<td>26%</td>
<td>53%</td>
<td>16%</td>
</tr>
</tbody>
</table>

* Abbreviations: AVM = arteriovenous malformation; Off Meds = patient receiving no anticonvulsant medications; On Meds = patient continuing to receive anticonvulsant prophylaxis.

**TABLE 6**
Clinical status in 280 patients with angiographically demonstrable AVM’s*

<table>
<thead>
<tr>
<th>Status at Discharge</th>
<th>No. of Cases</th>
<th>Status at Last Follow-Up Examination</th>
<th>Follow-Up Period &lt; 2 Yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>excellent</td>
<td>207</td>
<td>Excellent: 88% Good: 1% Poor: 5% Dead: 2%</td>
<td></td>
</tr>
<tr>
<td>good</td>
<td>42</td>
<td>Excellent: 57% Good: 19% Poor: 5% Dead: 2%</td>
<td></td>
</tr>
<tr>
<td>poor</td>
<td>24</td>
<td>Excellent: 21% Good: 25% Poor: 12% Dead: 25%</td>
<td></td>
</tr>
<tr>
<td>dead</td>
<td>7</td>
<td>Excellent: 21% Good: 25% Poor: 12% Dead: 25%</td>
<td></td>
</tr>
</tbody>
</table>

* For neurological function status definitions, see text. AVM = arteriovenous malformation.

AVM’s and 30 (61%) of the 49 patients with large AVM’s were discovered to have hemorrhaged.

It was not possible to establish a clear relationship between the development of a new ongoing seizure disorder or worsening of a seizure disorder postoperatively. Of the 136 surviving patients with no seizures preoperatively, eight had ongoing seizures at last follow-up study; of those, six had sustained a preoperative hemorrhage. Of the 102 surviving patients with seizures preoperatively, only two had a worsening of their seizure disorder; both had evidence of a preoperative hemorrhage. However, a valid relationship could not be established due to the small number of patients and the variable time of follow-up evaluation.

**Mortality Rate**

An actuarial analysis was conducted comparing the life expectancy of patients following surgery for AVM’s with the expected survival of a general white population of the same age and sex in the West Northcentral region of the United States. No statistically significant difference was found in life expectancy. Twenty-nine patients in this series have died, with seven of the deaths occurring perioperatively. Causes of perioperative death were postoperative cerebral hemorrhage (three cases), pulmonary emboli (two), and obstruction of venous drainage (two). In the remaining 22 patients, the causes of death included severe preoperative hemorrhage (one case), delayed AVM-related intracerebral hemorrhage (two), intraventricular hemorrhage with gastrointestinal bleeding (two), pneumonia (three), cancer (five), motor-vehicle accident (two), cardiac disease (two), suicide (one), and unknown (four).

**Neurological Recovery**

A definite trend toward progressive postoperative improvement in neurological status was found in evaluating the case material (Table 6). Eighty-eight percent of the patients classified as having excellent neurological function at discharge remained so during the follow-up period with 4% being graded as good and only 1% as poor. In contrast, 57% of the patients who were considered in good neurological condition at discharge improved to excellent at last follow-up examination; 21% of the patients discharged with a poor status achieved an excellent status during follow-up monitoring, while 25% improved to a good clinical status.

Several of our patients presented to the emergency room following a hemorrhage with profound neurological deficits and coma but, after surgery, went on to achieve an excellent neurological recovery. As an example, one young girl from this group survived and ultimately completed a master’s degree program with a 4.0 grade point average.

**Discussion**

**Literature Review**

The symptoms of AVM’s are well described in the neurological and neurosurgical literature, and our series of surgically treated cases is similar to others in terms of location of the malformation, demographics, and incidence of hemorrhage and seizures.1,3,4,5,14,16,23 Opinions vary considerably regarding the role of surgery for AVM’s with reference to seizures. While some series have reported a significant increase in postoperative seizures and have concluded that operative intervention is the greatest risk factor in the development of seizures in patients with AVM’s, others consider intractable seizures a clear indication for operating on AVM’s.

One of the earliest studies analyzing seizures after AVM resection is that of Olivecrona and Reives15 in 1948. Almost 50% of the patients in that series presented with seizures and nearly 80% experienced some seizures prior to surgery. One-third of the patients had no seizures postoperatively while another third had only occasional seizures. The authors concluded that “the prognosis of epilepsy is best in the case of the younger persons with a short history of epilepsy, while in cases of inveterate disease with a long history of epilepsy the outlook is poor.”15 Rasmussen20 also addressed AVM’s in a review of surgery of epilepsy associated with all brain tumors. In his series of 14 AVM’s and six cavernous angiomas, approximately two-thirds of the patients with an AVM and preoperative seizures had complete resolution or significant reduction in seizure frequency postoperatively. In a more recent study by Yeh, et al.,21 it was found that more than three-fourths of the patients who had a seizure disorder due to a cerebral AVM achieved excellent seizure control after removal of the AVM and the epileptiform focus. They concluded from their results that a medically intractable seizure disorder

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is in itself an indication for surgical removal of a cerebral AVM.

There are numerous reports in the literature with a more pessimistic attitude toward surgical intervention for seizures associated with AVM's. In a series described by Forster, et al., only 14% of the patients already suffering from epilepsy showed a postoperative decrease in seizure frequency, whereas 22% had not previously suffered from epilepsy developed seizures postoperatively. Parkinson and Bachers stated that, based on their study, "patients with seizures before surgery are likely to have them after surgery, whereas 8% of patients who were previously seizure-free develop seizures from the surgery." In a series reviewing the incidence of seizures following supratentorial surgical procedures, Foy, et al. specifically commented on AVM's, reporting a 50% incidence of seizures after AVM surgery versus a 17% incidence for all patients undergoing a supratentorial craniotomy. However, this series of only 24 patients was grouped with cases of other vascular lesions, namely aneurysms and spontaneous hematomas. Crawford and coworkers concluded from their series of conservatively managed and surgically treated AVM's that "the most significant factor that appears to influence the development of epilepsy is surgical treatment, trebling the risk of 57 percent at 20 years." This study also revealed that "operations for AVM's in frontal and parietal lobes carried higher risks of epilepsy." Finally, in his study and review of the literature, Murphy found a lack of evidence of substantial improvement in seizure control after resection of an AVM. He did comment, however, that "when feasible, removal of the AVM and the intervening neural tissue would improve the remission rate."

Analysis of Current Series

The results of this study indicate that patients with an AVM and no prior seizure history have a very low likelihood (6%) of ongoing postoperative seizures and a relatively low likelihood (27%) of requiring anticonvulsant medications. Likewise, in the group of patients with a single or few preoperative seizures, only 5% developed worsening of their preoperative seizures or "postoperative seizure disorder" and 93% were seizure-free. Overall, in terms of all surviving patients with a follow-up duration greater than 2 years, 89% were free of seizures at last follow-up evaluation.

In examining whether surgical removal of an AVM is effective in controlling a seizure disorder, it was found that the vast majority (76%) of the patients with "epilepsy" related to their AVM's (that is, those patients with multiple preoperative seizures) had no seizures at last follow-up evaluation. Of the 14 patients who continue to have seizures, most (86%) reported a significant improvement in seizure frequency while two (14%) stated that their seizures remained unchanged. These findings are helpful in the preoperative counseling of patients but, admittedly, cannot be extrapolated to that subset of patients with AVM's and "medically intractable seizures."

In analyzing the relationship between early postoperative and subsequent seizure history, the occurrence of perioperative seizures did not appear to correlate with frequency of seizures postoperatively. Thus, a perioperative seizure should not be interpreted as a negative event in terms of the prognosis for postoperative seizures.

In addition to past seizure history, a statistically significant relationship was found between AVM size and occurrence of postoperative seizures. Although resolution or control of seizures was achieved postoperatively in AVM's of all sizes, the likelihood of this benefit was highest in smaller as opposed to larger AVM's. Specifically, larger AVM's have an increased risk of both pre- and postoperative seizures. This concurs with previous reports on the natural history of AVM's.

The location of the AVM does appear to play a role in preoperative seizure severity and pattern. We found that AVM's in the posterofrontal and temporal lobes were more likely to present as a seizure disorder compared to AVM's overall. This agrees with the study by Crawford, et al. which found that "the risk of developing epilepsy was greatest if the AVM involved the temporal lobe (10-year risk of 37%)." However, we found no correlation between location of the AVM and the risk of developing a postoperative seizure disorder, other than the anticipated supratentorial versus infratentorial location. In addition, no relationship could be established between the occurrence of a preoperative hemorrhage and the likelihood of causing or aggravating a seizure disorder postoperatively.

In the analysis of these 280 patients, there is not and cannot be an absolutely identical follow-up time for all patients; nonetheless, in comparing sequential follow-up results, we conclude that there is a strong tendency for patients who have undergone surgery for AVM's to achieve a significant reduction in preoperative seizures and an impressive neurological recovery.

Although it was not the primary purpose of this paper to compare neurological function during follow-up monitoring with neurological function at discharge, it became apparent that there was indeed a very significant improvement and recovery in neurological function during the follow-up period in addition to an improvement in seizure status. These findings offer optimism and hope for patients who have suffered from this devastating illness.

Acknowledgments

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