Dysplastic Vessels After Surgery for Brain Arteriovenous Malformations

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Background and Purpose—The cause and clinical significance of residual dysplastic vessels after surgery for brain arteriovenous malformations (AVM) are unclear. We studied predictors and frequency of residual dysplastic vessels on cerebral angiography after AVM surgery.

Methods—The 240 prospectively enrolled surgical patients from the New York AVM Databank underwent 269 AVM-related surgical procedures. Reported postoperative brain angiographic findings were classified post hoc as showing (1) persistent dysplastic vessels, (2) a residual AVM, (3) focal hyperemia in the surgical bed, (4) other changes, or (5) a normal angiogram. Univariate and multivariate models were applied to test for an association between residual dysplastic vessels and patient age, sex, preoperative AVM size, anatomic AVM location, number of embolization procedures before surgery, and the time interval between AVM surgery and the postoperative angiogram.

Results—Of the 224 documented postoperative angiograms, 78 (35%) showed dysplastic vessels, 24 (11%) had evidence for a residual AVM, 16 (7%) showed focal hyperemia, 6 (2%) revealed other findings, and 100 (45%) were normal. The number of cases showing angiographic evidence for dysplastic vessels was significantly associated with increasing size of the AVM (in millimeter increments; \( P = 0.0001 \)); the mean diameter of AVMs in patients showing dysplastic vessels after surgery was significantly larger (41 mm, SD \( \pm 14 \)) than in those without residual dysplastic vessels (27 mm, SD \( \pm 13 \); \( P < 0.001 \)). Symptomatic postoperative intracerebral hemorrhage occurred in 4 patients (1%), in 2 of whom dysplastic vessels were seen on the postoperative angiogram.

Conclusions—The findings suggest that persistent dysplastic vessels may be found in approximately one third of angiograms after AVM surgery. Preoperative AVM size was found to be an independent predictor for the occurrence of dysplastic vessels on the postoperative angiogram. (Stroke. 2002;33:1053-1056.)

Key Words: angiography ■ cerebral arteriovenous malformations ■ surgical treatment

Surgery for brain arteriovenous malformations (AVMs) may be complicated by postoperative hemorrhage arising from residual AVM nidus or from other bleeding sources in the surgical bed. Whether or not persistent dysplastic vessels after AVM removal constitute a risk for postoperative intracranial hemorrhage (ICH) is currently subject to debate.1,2 The frequency of dysplastic vessels and other postoperative angiographic changes has not been reported from larger AVM patient cohorts, and no predictors for their occurrence have been determined thus far.

Our aim was to determine the frequency and predictors of residual dysplastic vessels on cerebral angiography after AVM surgery.

Subjects and Methods

Study Subjects and Data Collection

The Columbia AVM Databank is an ongoing prospective database collecting demographic, clinical, morphological, and treatment data on consecutive AVM patients admitted to the New York Presbyterian Hospital of Columbia University since 1989. All brain AVMs are proven by brain imaging and cerebral angiography. Other types of intracranial fistulas (such as dural arteriovenous fistulas and vein of Galen–type malformations) are not included in the study cohort. Patients enrolled are drawn from the New York metropolitan area as well as from distant referral sites. Further details on the study cohort, design, variable definitions, and methods have been described in prior publications.3,4 Overall, 240 consecutive patients underwent 269 AVM-related surgical procedures between July 1, 1989, and June 30, 2000. Demographic, clinical, and morphological baseline characteristics of all surgically treated patients are summarized in Table 1. Twenty-seven patients had 2 surgical interventions and 2 patients had 3 surgical interventions, including 14 who underwent elective 2-step AVM removal, another 10 with residual AVMs, an additional 4 suffering postoperative ICH requiring hematoma evacuation, and 1 example of a recurrent AVM in a 12-year-old subject documented 2 years after initial AVM removal.
Variable Definition and Statistical Analysis
Baseline morphological characteristics as used in this study were AVM nidus size (measured as maximum diameter in millimeters) and anatomic AVM location stratified into lobar (any frontal, parietal, temporal, and/or occipital location), deep (the basal ganglia, internal capsule, thalamus, and/or corpus callosum), and infratentorial (brain stem and/or cerebellar location).

Postoperative cerebral angiography was performed by the transfemoral arterial catheterization technique. Both the anterior and posterior circulations were visualized in at least 2 projections with the same technique used in all patients. All angiograms were performed in the conventional angiography suite with standardized contrast dye injection techniques and digital subtraction angiography imaging, allowing optimal visualization of the brain vasculature.

All angiographic studies were read by the senior radiology house staff. For the purpose of our analysis, the reported findings were classified post hoc as follows: (1) dysplastic vessels (irregularly shaped, “corkscrew,” or “kinky hair”–like arterial branches in absence of early veins) (Figure); (2) residual AVM (distinct AVM nidus with early draining vein); (3) hyperemia (capillary blush in the surgical bed without evident AVM nidus); (4) other (sluggish flow, slow filling, or enlargement of previous feeding arteries); or (5) normal (ie, no abnormalities other than rarefaction of arterial filling in the surgical bed, ligated arterial branches, presence of surgical clips). Symptomatic postoperative ICH was defined as any clinically symptomatic event (sudden-onset headache, seizure, and/or focal neurological deficit) with signs of fresh parenchymatous hemorrhage on CT brain imaging within 1 week after surgery.

Univariate (χ² test, t test, Spearman correlation) and multivariate (logistic regression) models were used to analyze the effect of age, sex, initial AVM size, anatomic location, number of embolization procedures before surgery, and the time interval between AVM surgery and the postoperative angiogram on the occurrence of abnormalities on the postoperative angiogram. A Bonferroni correction was used for multiple contrasts.

Results
The rates of different radiological findings on postoperative angiography after AVM surgery are summarized in Table 2.

Overall, 224 postoperative angiographic studies were performed with a mean time interval of 10 days after surgery (SD ±47 days). Seventy-three (34%) of these angiograms were performed immediately after surgery while the patient was

### Table 1. Demographic, Clinical, and Morphological Characteristics of 240 Patients Undergoing AVM Surgery (n=240)

<table>
<thead>
<tr>
<th>Demographic</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at time of intervention, mean±SD, y</td>
<td>34±12</td>
</tr>
<tr>
<td>Female sex</td>
<td>120 (50%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clinical</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagnostic event</td>
<td></td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>111 (46%)</td>
</tr>
<tr>
<td>Seizure</td>
<td>70 (29%)</td>
</tr>
<tr>
<td>Headaches</td>
<td>35 (15%)</td>
</tr>
<tr>
<td>Focal deficit</td>
<td>13 (5%)</td>
</tr>
<tr>
<td>Other/unrelated</td>
<td>11 (5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Morphological</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AVM diameter, mean±SD, mm</td>
<td>32±15</td>
</tr>
<tr>
<td>AVM location</td>
<td></td>
</tr>
<tr>
<td>Lobar component (frontal, parietal, temporal, occipital)</td>
<td>214 (89%)</td>
</tr>
<tr>
<td>Deep only (basal ganglia, thalamus, internal capsule, corpus callosum)</td>
<td>4 (2%)</td>
</tr>
<tr>
<td>Infratentorial (brain stem, cerebellum)</td>
<td>22 (9%)</td>
</tr>
<tr>
<td>Endovascular embolization before surgery</td>
<td>145 (60%)</td>
</tr>
</tbody>
</table>

| Documented postoperative angiogram     | 224 (93%) |

### Table 2. Radiological Findings in 224 Postoperative Angiograms After AVM Surgery

<table>
<thead>
<tr>
<th>No. (%)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dysplastic vessels</td>
<td>78 (35%)</td>
</tr>
<tr>
<td>Residual AVM</td>
<td>24 (11%)*</td>
</tr>
<tr>
<td>Focal hyperemia</td>
<td>16 (7%)</td>
</tr>
<tr>
<td>Other</td>
<td>6 (2%)</td>
</tr>
<tr>
<td>Normal</td>
<td>100 (45%)</td>
</tr>
</tbody>
</table>

*Nine angiograms performed after first intervention in AVM patients undergoing elective 2-step surgical therapy.
still intubated, and 151 (66%) were performed 1 or more days after AVM surgery. Documented postoperative angiography data were missing in 16 patients, who were excluded from the analysis.

The number of cases showing dysplastic vessels on postoperative angiograms increased significantly with the initial size of the AVM (Spearman’s p=0.47, P=0.0001). The mean diameter of AVMs in patients reported as showing dysplastic vessels after surgery was also significantly larger (41 mm, SD ±14) than in those without residual dysplastic vessels (27 mm, SD ±13; P<0.001, t test, Bonferroni corrected). In the univariate analysis, the frequency of dysplastic vessels was also significantly associated with the increasing number of endovascular embolization procedures performed before surgery (P<0.01, χ², Bonferroni corrected). This effect, however, did not remain significant in a multivariate model controlling for AVM size, suggesting that AVM size is an independent determinant for the occurrence of dysplastic vessels after surgery (odds ratio, 1.08; 95% CI, 1.05 to 1.11; P=0.0001).

The frequency of reported focal hyperemia was significantly higher in women (n=13; 12%) than in men (n=3; 3%; P=0.009, χ²). For patients with residual AVMs or other angiographic abnormalities, no statistically significant associations were found with age, sex, AVM size, location, and presurgical embolization procedures. In an additional model, no association between any of the reported angiographic abnormalities and the time interval (in days) between AVM surgery and the postoperative angiogram was found.

Symptomatic postoperative ICH occurred after 4 (1%) of all surgical interventions, each case requiring emergency evacuation of the hematoma. No obvious cause for the bleeding could be determined, but 2 of the patients who bled after the immediate postoperative angiogram had demonstrated residual dysplastic vessels.

**Discussion**

Our data suggest that persistent dysplastic vessels may be found in approximately one third of AVM patients undergoing surgical therapy. The preoperative AVM size appears to be an independent predictor for the occurrence of dysplastic vessels after AVM surgery.

The exact pathophysiology of dysplastic vessels after AVM surgery is as yet unclear. Abnormal capillary proliferation adjacent to the AVM and a postoperative overload phenomenon have been proposed to cause dysplastic changes in brain vessels after AVM removal. No histological studies are available thus far, leaving it unclear whether the vessel wall compositions of dysplastic vessels resemble those seen in ordinary distal brain arteries, those reported from capillary telangiectasias, or those observed in distinct brain neovessels, such as moyamoya collaterals. Flow-related structural changes in the AVM-feeding vessels, a process sometimes referred to as “secondary angiopathy,” has been assumed to account for a large proportion of the perinidal angioarchitecture. In cases showing dysplastic vessels on the postoperative angiogram, a small amount of such flow-related changes may have persisted in the microvasculature despite successful surgical removal of the AVM nidus, ie, complete obliteration of the primary shunt. Whatever the mechanism of their occurrence, the association between residual dysplastic vessels and increasing preoperative AVM size, as seen in our sample, suggests at least some interaction with the initial amount of vascular supply to the malformation.

The rate of reported dysplastic vessels in our series exceeds those from earlier reports. One possible explanation is the use of postoperative digital subtraction angiography only, thereby supporting prior studies suggesting a lower sensitivity of intraoperative angiography for abnormal findings after AVM surgery. Earlier series were also based on smaller sample cohorts and often lack a uniform terminology: small “stagnating arteries,” “moyamoya-type vessels,” “modja-modja vessels,” and “perinidal hypervascular network” range among the various terms applied to dysplastic vessels, which are now considered to represent a distinct morphological entity. Therefore, operationalized diagnostic criteria for the presence of dysplastic vessels need to be validated at a multicenter level to be able to include dysplastic vessels in standardized AVM research protocols, as recently proposed.

The rate of AVM residuals in our series (11%) appears high, but the study sample included 9 of the 14 patients undergoing elective 2-step surgery who had an intermittent angiographic study before complete AVM removal (Table 2). Thus, only 15 of the 24 AVM residuals detected were unexpected lesions. On the basis of all angiograms done after single-step interventions (n=211), the actual rate for residual AVM lesions in our study may therefore be estimated to be 6%. Overall, the rate of AVM residuals was independent of the size and location of the original lesion, suggesting that the occurrence may be due to factors other than investigated in this study.

In 16 (7%) of the 240 patients, no postoperative angiographic data were available at the time of the analysis, mainly because the film material had been removed from the archives after >10 years. Therefore, a systematic error influencing our results is less likely. If we assume that the proportion of patients showing dysplastic vessels on postoperative angiography as found in our study sample (35%) remains stable, another 6 additional cases might have been detected among the missing patients. Adding the 6 hypothetical cases to our statistical model did not alter the aforementioned findings.

The higher rate of focal postoperative hyperemia in women remains unexplained and adds to prior reports suggesting sex-related differences for both natural AVM history and treatment risk. Whether our observation is related to mechanisms leading to an elevated risk for surgical therapy in women, as recently reported, remains to be determined. None of our postoperative patients showed evidence for cerebral hyperemia and postoperative brain swelling suggesting normal perfusion pressure breakthrough, which is assumed to be one mechanism leading to hemorrhage after AVM resection.

Whether persistent dysplastic vessels after AVM removal account for an increased risk of postoperative ICH is subject to current debates. In a series of 12 patients with large (>5 cm) AVMs, Takemae et al found evidence for dysplastic
vessels in 5 cases (42%) on postoperative angiograms, 4 of whom suffered intraoperative or postoperative ICH. On the basis of this preselected patient cohort, the authors concluded that dysplastic vessels may be a predictor of intraoperative and postoperative ICH. However, no comparison was made with other postoperative instances of ICH after surgery in the same AVM patient population. Most recently, Solomon et al reported experience on 6 AVM cases showing dysplastic vessels on postoperative angiography who were managed conservatively. None of the patients suffered postoperative ICH, and all vascular abnormalities resolved spontaneously over time. The authors proposed transient hypotensive therapy after surgery (10% to 20% below baseline resting mean arterial pressure) with slow liberalization to normotension after 24 to 48 hours. Our own data cannot exclude the possibility of symptomatic postoperative ICH in a setting of residual dysplastic vessels, but the low rate (1%) of postoperative ICH in our sample did not provide sufficiently high numbers to analyze associations between any of the angiographic abnormalities and postoperative bleeding complications. The postoperative presence of dysplastic arteries alone may therefore not justify surgical intervention for removal of the residual dysplastic vessels, but thus far no definite treatment recommendations can be given. The possibility of symptomatic postoperative ICH in a setting of residual dysplastic vessels, however, lends support to a careful management of affected patients throughout the immediate postoperative period.

Acknowledgments

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