A Comprehensive Review of Radiosurgery for Cerebral Arteriovenous Malformations: Outcomes, Predictive Factors, and Grading Scales

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Introduction

Controversy exists regarding the optimal treatment of cerebral arteriovenous malformations (AVMs). Current management guidelines are based on case series and cohort studies, as there is yet to be a randomized trial assessing treatment modalities according to patient and AVM characteristics. Nonetheless, it is generally accepted that patients referred to radiosurgery constitute a unique AVM population.

The goal of stereotactic radiosurgery for cerebral AVMs is to obliterate the AVM nidus, decrease the risk of future hemorrhage, and improve seizure severity, headache, or other neurological deficits. Complete AVM obliteration following radiosurgery generally takes 1–3 years [2, 4, 16, 25, 30, 38, 52, 55, 62, 75, 77] and the risk of hemorrhage during this latency period remains essentially unchanged from untreated patients [17, 55, 60]. Obliteration rates following radiosurgery range from 54 to 92% [2, 4, 16, 25, 37, 38, 44, 47, 55, 60, 65, 68, 69, 81]. Angiographically confirmed obliteration, however, may not negate hemorrhage risk, particularly in cases with recanalization [35, 40, 68, 80].

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Patient stratification is important for risk-benefit analysis of treatment options and outcome prediction [47, 61]. To this end, investigations have focused on patient characteristics, AVM architecture, and treatment parameters to identify factors that are specifically predictive of radiosurgical AVM obliteration, complications, and outcomes. In this paper, we review these grading scales and predictive factors of AVM radiosurgery.

**Spetzler-Martin Grading System**

The Spetzler-Martin (SM) grading system has been widely accepted as a practical and reliable method for predicting patient outcomes after AVM microsurgery [21, 23, 24, 50, 63]. The simplified scoring system was developed to approximate potential risks based upon three categories: AVM size, location (eloquence of adjacent brain), and pattern of venous drainage (table 1). It is generally accepted that most patients with SM grades I and II should be treated with microsurgical resection [47], although some patients may be medically unfit or decline surgery [60]. Grade III lesions are typically treated with microsurgery or radiosurgery, particularly when symptomatic. An individualized, multimodal approach is recommended for select grade IV/V lesions [47].

The SM grading scale may produce errors in patient selection due to oversimplification [7]. The modified Spetzler-Martin (mSM) grading system was put forth to address the discrepancies between the SM grade and patient outcomes, specifically with regard to grade III [6]. The mSM recognizes that AVMs of grade III present different challenges according to their location/size and introduces two subgroups: grade IIIA (grade III due to size >6 cm) and grade IIIB (grade III due to venous drainage and/or eloquence). A recommended treatment plan is embolization to reduce the size of grade IIIA lesions so that they can be treated with microsurgery, and radiosurgery for grade IIIB lesions [6]. Other modifications to SM grade III patients have been suggested to better define appropriate surgical treatment [33].

Although the SM grading system is generally considered an accurate method to predict patient outcomes after microsurgery, it may be less effective in predicting radiosurgical outcomes [41, 47, 52, 54, 59, 63]. The system fails to take into account a number of prognostic factors that have been associated with successful radiosurgery, such as radiation dose, AVM volume, specific location, and patient age [45, 52, 59]. In addition, the nature, complications, and patient selection criteria of the two treatment modalities markedly differ [37]. Despite these issues, the SM and mSM grading systems are easy to use and have been shown to be relatively predictive of radiosurgical outcome in a number of studies [1, 8, 19]. Continued investigation, however, is necessary to validate the efficacy of the SM and SM-derived grading systems.

**Predictive Factors and Grading Scales**

**Obliteration**

Obliteration is the radiological hallmark of successful AVM radiosurgery. On angiography, it is defined as ‘complete absence of pathological vessels forming the AVM nidus, disappearance or normalization of veins draining the AVM, appearance of normal circulatory kinetics, and absence of visible arteriovenous shunt’ [36, 73]. Irradiation is thought to trigger endothelial proliferation of the pathological vessels which gradually leads to lumen occlusion [9, 74]. This process may take up to 3 years [2, 4, 16, 25, 30, 38, 52, 55, 62, 75, 77]. Although angiography is the gold standard method for determining obliteration, its associated risks prevent frequent use. Therefore, magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA) are used to track AVMs postoperatively. In many centers, if MRI or MRA shows obliteration, a patient is followed up with angiography for confirmation. Obliteration rates following radiosurgery range from 54 to 92%, but depend on the number of treatments, timing of follow-up, and follow-up imaging technique used [2, 4, 16, 25, 37, 38, 44, 47, 55, 60, 65, 68, 69, 81]. The true obliteration rate is difficult to determine because patients often refuse angiography or are lost to follow-up during the long latency period. In fact, 20–80%

<table>
<thead>
<tr>
<th>Table 1. Spetzler-Martin classification of AVM</th>
</tr>
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<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Eloquence</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Venous drainage</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

1 Sensorimotor, language, or visual cortex, hypothalamus or thalamus; internal capsule; brainstem; cerebellar peduncles, or cerebellar nuclei.
of patients may miss their follow-up angiography. Many of these reports consider only the angiographically followed up patients in their calculation, which leads to obliteration rate overestimation [2, 18, 38, 69]. Long-term angiographic follow-up is imperative to accurately assess the obliteration rate after radiosurgery. Obliteration detected by MRI or MRA and obliteration confirmed by angiography should be reported separately. In addition, obliteration rate may be reported using worst- to best-case scenarios [37, 69].

Despite a lack of standardization in the assessment of obliteration rate, many studies have successfully shown that certain factors are predictive of obliteration after AVM radiosurgery (table 2). Studies have found small AVM size (measured either by volume or largest diameter), single draining vein, low SM grade, high marginal or maximal dose, male gender, and history of previous hemorrhage to be predictive of obliteration [2, 4, 8, 13, 18, 19, 27, 37, 38, 69, 70, 72, 77].

The importance of a model that describes and quantifies the biological effects of radiation on tissues has been recognized since the conception of radiation-based treatments. A number of grading scales were developed to predict the rate of obliteration following radiosurgery using treatment parameters. The K-index was proposed after observing that the AVM obliteration rate increased with increasing minimum dose and that in the obliterated cases, there was a linear relationship between lesion size and peripheral dose (i.e. larger lesions receiving smaller doses) [30]. The K-index is calculated as the product of minimum dose (Gy) and AVM volume (cm$^3$). Obliteration rate was shown to increase linearly up to a K-index of 27 beyond which it reached a plateau at approximately 80%.

Similarly, the obliteration prediction index (OPI) was developed to estimate the probability of AVM obliteration on an individual basis [66]. Based on an independent cohort of patients treated with linear accelerator (LINAC) and a cohort of patients treated by Gamma Knife, the authors suggested a system using a patient’s OPI, calculated by dividing the marginal dose of radiation by the AVM diameter, to estimate the probability of obliteration for that patient. The system could also be used to ascertain the appropriate marginal dose to achieve obliteration. A similar model, called the complication probability model, assessed the probability of obliteration as a function of only the minimum peripheral dose to the AVM nidus [47]. This model has been criticized for assuming that only the feeding arteries and the draining veins of the nidus need to be eradicated for the AVM to obliterate, an assumption that may not hold true in clinical settings [43].

The K-index, OPI, and the complication probability model are based on the relationship between radiation dosimetry and AVM characteristics that correlates with AVM obliteration. However, such ‘mathematical dose-response models’ fail to take into account patient-specific factors and AVM characteristics [43, 52]. That partly explains why the K-index and the OPI have been reported to be poor predictors of excellent patient outcome [52]. Also, the models were developed before the advent of modern dose planning based on angiography with 3-dimensional imaging that has allowed better AVM localization. More importantly, these models fail to consider

<table>
<thead>
<tr>
<th>References</th>
<th>Patients</th>
<th>Median follow-up, months</th>
<th>Radiosurgery</th>
<th>Reported obliteration rate, %</th>
<th>Outcome</th>
<th>Predictors identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liscak et al. [37]</td>
<td>330</td>
<td>38 (1–118)</td>
<td>GK</td>
<td>92 (269/292) obliteration</td>
<td>volume, gender, marginal dose, maximal dose, previous hemorrhage, SM grade</td>
<td></td>
</tr>
<tr>
<td>Shin et al. [69]</td>
<td>400</td>
<td>65 (1–135)</td>
<td>GK</td>
<td>88.1b (274/311) obliteration</td>
<td>size, marginal dose, gender, previous hemorrhage volume</td>
<td></td>
</tr>
<tr>
<td>Bollet et al. [2]</td>
<td>188</td>
<td>44 (5–105)</td>
<td>LA</td>
<td>54 (60/112) obliteration</td>
<td>dose, SM grade</td>
<td></td>
</tr>
<tr>
<td>Friedman et al. [19]</td>
<td>269</td>
<td>–</td>
<td>LA</td>
<td>53 (115/218) obliteration</td>
<td>gender, marginal dose</td>
<td></td>
</tr>
<tr>
<td>Flickinger et al. [13]</td>
<td>351</td>
<td>51 (36–127)</td>
<td>GK</td>
<td>75 (268/351) obliteration</td>
<td>diameter, nidus shape, number of draining veins</td>
<td></td>
</tr>
<tr>
<td>Chang et al. [4]</td>
<td>23/254</td>
<td>24.7 (0.4–90.2)</td>
<td>GK</td>
<td>78.9 (101/128) obliteration</td>
<td>prior embolization, monoisocentric irradiation</td>
<td></td>
</tr>
<tr>
<td>Schlienger et al. [65]</td>
<td>169</td>
<td>(48–96)</td>
<td>LA</td>
<td>64 (108/169) obliteration</td>
<td>minimum dose, SM grade</td>
<td></td>
</tr>
<tr>
<td>Touboul et al. [77]</td>
<td>100</td>
<td>37.5 (1–117)</td>
<td>GK</td>
<td>51</td>
<td>obliteration volume</td>
<td></td>
</tr>
<tr>
<td>Lunsford et al. [38]</td>
<td>227</td>
<td>–</td>
<td>GK</td>
<td>80 (37/46) obliteration</td>
<td>volume</td>
<td></td>
</tr>
<tr>
<td>Starke et al. [72]</td>
<td>60</td>
<td>–</td>
<td>GK</td>
<td>76 (40/53) obliteration</td>
<td>volume, venous drainage</td>
<td></td>
</tr>
</tbody>
</table>

GK = Gamma Knife; LA = LINAC; mRS = modified Rankin score.

* Figures in parentheses indicate ranges.

b Obliteration percentage is best-case scenario.

Table 2. Predictive factors for nidus obliteration in AVM patients undergoing radiosurgery
that raising the dose is accompanied by an increasing chance of radiation-induced complications [14, 15, 19, 29, 34, 52, 58, 78]. Furthermore, Gamma Knife users often deliver higher doses to the AVM margins. Although studies using LINAC and Gamma Knife appear to have similar rates of obliteration and morbidity, these rates are often difficult to compare as AVM cases differ greatly according to study and institution treatment protocols. Although some scales such as the OPI were developed or confirmed in cohorts of both Gamma Knife and LINAC patients, predictive variables and grading scales should be assessed with caution when used universally across different treatment modalities.

Hemorrhage after Radiosurgery

The AVM natural history includes an annual hemorrhage risk of 2–4% with each incident carrying a 10% mortality and a 30–50% morbidity rate [3, 21, 22, 32, 42, 48]. The risk of neurological deficit in all patients due to hemorrhage ranges from 1.2 to 3.7%, while the risk of deficit per hemorrhage ranges from 26.1 to 71.4% [2, 37, 46, 51, 53, 56]. The risk of death in all patients due to hemorrhage ranges from 0.4 to 3.5%, while the risk of death per incidence of hemorrhage ranges from 5.9 to 39% [37, 38, 40, 46, 51, 53, 55, 56].

The degree of protection from bleeding after AVM radiosurgery remains controversial. Studies have reported widely different risks of hemorrhage during the latency period, ranging from 1.6 to 9% [5, 17, 28, 34, 39, 53, 60]. However, it is generally accepted that the risk of hemorrhage during the latency period is not significantly different from the risk prior to treatment [37, 53, 60] and that only complete AVM obliteration negates this risk [36, 38, 75]. AVM obliteration does not always mark the end of treatment and long-term follow-up may be necessary, as studies have noted a cumulative 5-year hemorrhage risk after radiosurgery ranging from 5.0 to 10.2% [53, 69]. Several studies have reported that AVMs can rupture even after angiographic obliteration [35, 68].

We have previously found that when untreated, increasing age, deep brain location, and exclusive deep venous drainage are predictive of future hemorrhage [71]. A prior history of hemorrhage has also been shown to correlate with a higher risk of future rebleeding [5, 42, 49, 50, 71]. Similar factors are implicated in postradiosurgical hemorrhage: older age, large volume, brainstem location, subependymal nidus, low minimum dose, incomplete coverage, and proximal, para- or intranidal aneurysms (table 3). In addition, continued enhancement on CT or MRI has been shown to be predictive of postobliteration hemorrhage [67]. However, there is no grading scale that assesses or accounts for the risk of hemorrhage after radiosurgery. Postoperative bleeding is undoubtedly one of the most discussed shortcomings of AVM radiosurgery and should be addressed by a predictive model. Efforts are needed to develop radiosurgery-based AVM grading systems that incorporate associated aneurysms, venous stasis, or venous aneurysms that have been associated with hemorrhagic risk [48]. Furthermore, it is important to consider factors that are associated with AVM recanalization or redevelopment [35, 80].

### Table 3. Predictive factors for postoperative and postobliteration hemorrhage in AVM patients undergoing radiosurgery

<table>
<thead>
<tr>
<th>References</th>
<th>Patients</th>
<th>Median follow-up* months</th>
<th>Radio- surgery</th>
<th>Annual hemorrhage rate, %</th>
<th>Morbidity due to hemorrhage, %</th>
<th>Mortality due to hemorrhage, %</th>
<th>Outcome</th>
<th>Predictors identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shin et al. [67]</td>
<td>4</td>
<td>77 (1–133)</td>
<td>GK</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>hemorrhage continued enhancement on last CT or MRI</td>
</tr>
<tr>
<td>Shin et al. [69]</td>
<td>400</td>
<td>65 (1–135)</td>
<td>GK</td>
<td>1.9</td>
<td>–</td>
<td>1.5 (6/400)</td>
<td>hemorrhage</td>
<td>last CT or MRI</td>
</tr>
<tr>
<td>Nataf et al. [46]</td>
<td>756</td>
<td>24 (0–178)</td>
<td>LA</td>
<td>6.5 (51/756)</td>
<td>3 (23/756)</td>
<td>0.4 (3/756)</td>
<td>hemorrhage</td>
<td>age &gt;60 years, brainstem location, subependymal nidus</td>
</tr>
<tr>
<td>Karlsson et al. [28]</td>
<td>1,593</td>
<td>–</td>
<td>GK</td>
<td>3.5 (56/1593)</td>
<td>–</td>
<td>–</td>
<td>hemorrhage</td>
<td>dosimetric coverage, nidal aneurysm, prescribed dose age, average dose, AVM volume, minimum dose</td>
</tr>
<tr>
<td>Pollock et al. [53]</td>
<td>315</td>
<td>47 ± 20</td>
<td>GK</td>
<td>7.4 (23/315)</td>
<td>1.9 (6/315)</td>
<td>2.9 (9/315)</td>
<td>hemorrhage</td>
<td>age, brainstem location, nidus, minimum dose</td>
</tr>
<tr>
<td>Starke et al. [72]</td>
<td>60</td>
<td>54 (23–97)</td>
<td>GK</td>
<td>2.0 (5/53)</td>
<td>–</td>
<td>1.9 (1/53)</td>
<td>hemorrhage</td>
<td>aVM volume, minimum dose, proximal aneurysm, marginal dose</td>
</tr>
</tbody>
</table>

GK = Gamma Knife; LA = LINAC.

* Figures in parentheses indicate ranges.

b Indicates mean ± SD.

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Complications and Permanent Morbidity

Complications associated with radiosurgery include seizures, headache, neurological deficits, and radiation-induced cerebral injuries such as edema, necrosis and cyst formation (table 4). Postoperative morbidity leading to permanent deficits is observed in 0.4-20.6% of patients in the current literature [2, 4, 11, 12, 18-20, 37, 38, 40, 51, 54-56, 69, 79]. While many factors have been shown to be predictive of neurological deficit, seizure, or other morbidities, functional status has not been evaluated extensively. Independence and quality of life would allow accurate complication assessment and better elucidate the overall outcomes of treatment.

Two factors have been shown to be predictive of permanent injury: AVM location and the volume of tissue receiving radiation in excess of 12 Gy [11, 12, 16]. Postoperative morbidity risk is predicted by a large nidus volume, specific arterial involvement (striate arteries and the artery of Heubner), number of arterial feeders, presurgical sensory disturbance, the sole use of biplanar angiography in treatment planning, and a prior history of seizure [20, 37, 67, 72]. Mixed results have been reported regarding the effect of endovascular procedure on radiosurgical morbidity; one study found a lack of prior embolization to be predictive of neurological deficit [37], while others have refuted these results [52, 54]. This could reflect treatment variability among institutions.

Successful Treatment

Excellent outcome is defined as ‘obliteration of the AVM with no new or worsed symptoms’ [10]. Various factors have been shown to be predictive of excellent outcome: small AVM diameter or volume, noneloquent location, hemispheric location, low number of draining veins, and young age [52]. Good symptom resolution can be predicted by low symptom severity and prior hemorrhage [73]. Another study tested the Engel seizure frequency score, which grades seizures in terms of intensity and timing, and found a low Engel score (<4), small AVM diameter and size to also be predictive of excellent outcome [64]. Cognitive improvement following radiosurgery has been studied as well. Interestingly, one study found that patients whose AVMs remained patent exhibited preserved memory [76]. This again may be due to the rela-

Table 4. Predictive factors for clinical outcome in AVM patients undergoing radiosurgery

<table>
<thead>
<tr>
<th>References</th>
<th>Patients</th>
<th>Median follow-up*, months</th>
<th>Radiosurgery</th>
<th>Permanent morbidity*, %</th>
<th>Outcome</th>
<th>Predictors identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liscak et al. [37]</td>
<td>3,530</td>
<td>38 (1–118)</td>
<td>GK</td>
<td>2.7</td>
<td>morbidity</td>
<td>volume, prior embolization</td>
</tr>
<tr>
<td>Pollock et al. [51]</td>
<td>243</td>
<td>65 (3–170)</td>
<td>GK</td>
<td>10</td>
<td>mRS decline</td>
<td>RBGS</td>
</tr>
<tr>
<td>Andrade-Souza et al. [1]</td>
<td>136</td>
<td>40 (21–122)</td>
<td>LA</td>
<td>7.4</td>
<td>excellent outcome</td>
<td>volume, diameter, gender, modified SM grade, eloquence, RBGS</td>
</tr>
<tr>
<td>Shin et al. [69]</td>
<td>400</td>
<td>65 (1–135)</td>
<td>GK</td>
<td>1.5</td>
<td>morbidity</td>
<td>dose planning using biplanar angiography alone, medial striate artery or artery of Heubner, perioperative sensory disturbance</td>
</tr>
<tr>
<td>Schauble et al. [64]</td>
<td>65</td>
<td>48 (12–144)</td>
<td>GK</td>
<td>26.1</td>
<td>excellent outcome$^d$</td>
<td>diameter, size, Engel score (&lt;4)</td>
</tr>
<tr>
<td>Steinworth et al. [76]</td>
<td>95</td>
<td>-</td>
<td>LA</td>
<td>-</td>
<td>permanent injury</td>
<td>attention score, full-scale IQ (at 2 years), memory score occlusion</td>
</tr>
<tr>
<td>Flickinger et al. [12]</td>
<td>14/88 of 1,255</td>
<td>34 (9–140)</td>
<td>LA/GK</td>
<td>20.6</td>
<td>symptom resolution</td>
<td>symptom severity, prior hemorrhage</td>
</tr>
<tr>
<td>Pollock et al. [54]</td>
<td>220</td>
<td>47 ± 20$^b$</td>
<td>GK</td>
<td>4</td>
<td>excellent outcome$^e$</td>
<td>volume, location, venous drainage, no prior embolization, age</td>
</tr>
<tr>
<td>Gobin et al. [20]</td>
<td>125</td>
<td>40 (3–116)</td>
<td>GK</td>
<td>0</td>
<td>morbidity rate</td>
<td>SM grade</td>
</tr>
<tr>
<td>Starke et al. [72]</td>
<td>60</td>
<td>54 (22.8–97)</td>
<td>GK</td>
<td>9</td>
<td>mRS decline</td>
<td>seizure history, number of arterial feeders</td>
</tr>
</tbody>
</table>

GK = Gamma Knife; LA = LINAC; mRS = modified Rankin score; RBGS = radiosurgery-based grading system.
$^a$ Figures in parentheses indicate ranges.
$^b$ Indicates mean ± SD.
$^c$ Morbidity refers to any complication due to radiosurgery and can include radionecrosis, edema, seizure, neurological deficit, or hemorrhage when not explicitly defined.
$^d$ Engel score.
$^e$ Obliteration and no new deficit.
tionship between obliteration and radiation-induced complication.

Simple dose-response models were deemed inadequate as clinical outcome became increasingly recognized. The symptomatic postradiosurgery injury expression (SPIE) scale was developed in an attempt to utilize both the AVM variables and treatment parameters to predict radiosurgical outcomes and permanent symptomatic sequelae [13]. This scale was developed through analysis of the effects of AVM location and the 12-Gy volume. Using the SPIE score, 11 AVM locations were ordered according to increasing risk of permanent symptomatic injury. Despite its unprecedented effort to consolidate radiation-related complications into a grading system, the SPIE/12-Gy volume model has been criticized for the small sample size (85 patients for 11 categories) and multiple categories that may lead to an oversplitting error.

In order to address the short-comings of the SPIE scale, the radiosurgery-based AVM grading system (RBGS) was proposed [52]. The RBGS, composed of patient and AVM variables, is based on factors that are shown to be specifically predictive of AVM radiosurgery outcome: patient age, volume, and location (table 5). The system originally included two additional variables (previous embolization and number of draining veins), which were eliminated because they added only a slight predictive value. The system was verified in Gamma Knife surgery and LINAC patients treated at different centers [1, 52] and correlated with excellent 5- to 14-year outcome [55]. In addition, increasing RBGS scores were significantly associated with adverse radiation-related injury in a small group of brainstem AVM patients [41].

Though the RBGS has been shown to be predictive of radiosurgical outcomes, it should be employed with discretion due to inherent limitations. First, the system is developed to predict outcome after a single radiosurgical treatment. Previous studies report that obliteration is achieved after repeated radiosurgery in 60–70% of patients [26, 39]. It would be important to consider outcomes after multiple treatments, especially as staging becomes accepted as a valuable management option, particularly for large AVMs [10, 37, 57]. Second, long-term follow-up information was not factored into the development of the RBGS. For instance, complications after radiosurgery, such as cyst development, edema formation, and radiation necrosis injury may take many years to manifest [31, 79]. Such long-term results must be incorporated to accurately determine outcome in radiosurgically treated AVM patients. The RBGS was predictive of long-term outcome up to 14 years, but studies with a similar follow-up duration are lacking [11]. The RBGS has been tested in only a few centers thus far and will require validation in other radiosurgical patient populations to attain greater acceptance.

**Conclusion**

It has been nearly five decades since Leksell introduced radiosurgery as a treatment modality for AVM. Many studies have demonstrated that radiosurgery is an effective treatment option for AVMs with few complications. The optimal indications for AVM radiosurgery, however, continue to evolve. Radiosurgery is currently recommended for smaller lesions in eloquent locations. Embolization is used in conjunction with radiosurgery to reduce larger lesions, as well as obliterate feeding vessels and associated aneurysms.

Although the SM grading system and RBGS offer the best models for AVM radiosurgical planning, there continues to be difficulty in incorporating the numerous factors that are predictive of radiosurgical complications and outcome into a single model. Furthermore, some variables are easy to record and assess such as radiation dose and AVM volume and are commonly tested for predictive value. Other variables such as flow rate through the AVM are difficult to ascertain and some factors such as operator experience cannot be factored into any model. Complicated yet accurate models have not been successfully adopted in the clinical setting secondary to the need for simple and practical grading scales. The challenge lies in developing an AVM grading system that:

**Table 5. Radiosurgery-based AVM grading system**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>0.1</td>
</tr>
<tr>
<td>Patient age</td>
<td>0.02</td>
</tr>
<tr>
<td>Locationa</td>
<td></td>
</tr>
<tr>
<td>frontal, temporal = 0</td>
<td>0.3</td>
</tr>
<tr>
<td>parietal, occipital, intraventricular, corpus callosum, cerebellar = 1</td>
<td></td>
</tr>
<tr>
<td>basal ganglia, thalamic, brainstem = 2</td>
<td></td>
</tr>
</tbody>
</table>

a RBGS = (0.1) (volume) + (0.02) (patient age) + (0.3) (location).

b When an AVM involves multiple sites, fractional values are used according to the number of sites (0.5 for two sites, 0.33 for three sites).
Radiosurgery for Cerebral Arteriovenous Malformations

(1) is easy and simple to use in the clinical arena; (2) accounts for hemorrhage risk; (3) predicts long-term outcome; (4) incorporates postoperative functional status and quality of life; (5) is useful for both single and repeated radiosurgery; (7) is applicable to different types of radiosurgery such as LINAC, Gamma Knife surgery, and Cyberknife, and (8) enables clinicians to adequately compare the expected results of microsurgery, endovascular treatment, and radiosurgery on an individual basis. Moving forward, expanding databases of radiosurgical patients and their outcome information will eventually aid in the development of a comprehensive grading system.

References


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Radiosurgery for Cerebral Arteriovenous Malformations


