In the 32 years since Dr. Ladislau Steiner, et al., from the Karolinska Institute recognized that single-fraction, high-dose irradiation causes the progressive obliteration of arteriovenous malformations (AVMs) and subsequent release from the risk of later hemorrhage, stereotactic radiosurgery has become an accepted option for patients with intracranial AVMs. Radiosurgery has been used extensively to treat patients with AVMs and numerous improvements in this method have been documented during the past decades. In fact, if one compares the number of patients undergoing resection or radiosurgery for their intracranial AVMs during the past 30 years, it appears that radiosurgery is actually the preferred management strategy (Table 1). Despite its acknowledged role in the treatment of patients with intracranial AVMs, the indications for this method continue to be debated and refined.

For some time, discussions about AVM radiosurgery have focused on three factors: obliteration rate, the risk of radiation-related complications, and the chance of a postradiosurgical hemorrhage. Each of these variables has been thoroughly analyzed, resulting in the following conclusions. First, AVM obliteration correlates with the radiation dose delivered to the margin of the malformation. Assuming that the radiation is well targeted, the chance of an AVM cure is approximately 70, 80, and 90% for radiation doses of 16, 18, and 20 Gy, respectively. Second, the likelihood of radiation-related complications occurring after AVM radiosurgery relates in some measure to the radiation dose directed to surrounding tissue (most commonly used is the 12-Gy volume) and the location of the AVM. Patients harboring AVMs in the thalamus, basal ganglia, and brainstem are more likely to experience neurological deficits secondary to imaging changes noted on magnetic resonance (MR) imaging. Third, radiosurgery does not increase the bleeding rate of AVMs. Nonetheless, it is accepted that the absence of arteriovenous shunting through the nidus, as demonstrated by angiography, is the gold standard of an AVM cure after radiosurgery. A more holistic approach can also be used in the evaluation of AVM radiosurgery. In this manner, it has been demonstrated that almost 80% of patients with AVMs are released from the future risk of bleeding and are able to continue their normal activities of daily living after one or more radiosurgical procedures.

Zipfel and colleagues from the University of Florida have reviewed their experience with AVM radiosurgery performed using a modified linear accelerator for patients treated between 1989 and 1999. This paper, in conjunction with its sister publication on the same patient group, provides an analysis of the clinical, dosimetric, and morphological factors associated with pre- and postradiosurgical bleeding, radiation-related complications, and AVM obliteration. Briefly, at their institution radiosurgical dose planning was based primarily on computerized tomography scanning. The mean AVM volume was 9.4 cm³ and the mean dose directed to the AVM margin was 15 Gy. In 118 (58%) of 204 patients in whom a minimum of 3 years of follow-up data were available, obliteration was confirmed by angiography (81 patients) or MR imaging (37 patients). In three patients (1%) new permanent deficits developed and were considered radiation related, and in 26 patients (10%) a hemorrhage occurred after radiosurgery. A multivariate logistic regression analysis was performed for each of these outcomes; absolute rates were not specified. Patients in whom the AVM was located in a periventricular region and those in whom the AVM volume was greater than 4 cm³ were

### Table 1

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Management Strategy</th>
<th>~No. of Patients Treated*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steiner</td>
<td>radiosurgery</td>
<td>2000</td>
</tr>
<tr>
<td>Forster</td>
<td>radiosurgery</td>
<td>1800</td>
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<td>1329</td>
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<td>Lansford</td>
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<td>750</td>
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<tr>
<td>De Oliveira</td>
<td>microsurgery</td>
<td>500</td>
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<td>Yasargil</td>
<td>microsurgery</td>
<td>500</td>
</tr>
<tr>
<td>Stein</td>
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<td>450</td>
</tr>
<tr>
<td>Spetzler</td>
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</tr>
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<td>Heros</td>
<td>microsurgery</td>
<td>300</td>
</tr>
<tr>
<td>Drake</td>
<td>microsurgery</td>
<td>166</td>
</tr>
</tbody>
</table>

* Estimated number of treated patients based on extrapolation from published reports, lectures, and information obtained from the Internet.
more likely to present with an AVM hemorrhage. No clinical or morphological variable could be used to predict post-radiosurgical bleeding. Obliteration of the AVM was more prevalent among patients who received margin doses greater than 15 Gy, and patients in whom the AVM had a diffuse nidus or was associated with neovascularity were less likely to attain a cure. The patient’s Spetzler–Martin grade did not predict neuroimaging-defined outcomes. Last, permanent radiation-related complications correlated with the 12-Gy volumes. Taken together, these papers support previous studies on AVM radiosurgery, and add a new hypothesis that nidus structure should be considered when counseling patients about radiosurgery.

When interpreting the results of this and other studies of AVM radiosurgery, one can argue that they are not very good. For example, if the rate of cure is based on angiographic data alone, and one does not take into account that not every patient received adequate imaging follow up, the obliteration rate can be calculated as 30% (81 of 268 patients). Moreover, one of every 10 patients suffered an AVM hemorrhage after radiosurgery. When one also considers the chance of late radiation-related complications, such as cyst formation or radiation-induced neoplasms, radiosurgery looks even less appealing as an option for patients with AVMs. These considerations are frequently cited by cerebrovascular neurosurgeons in making their argument for resection of cerebral AVMs.

Conversely, proponents of radiosurgery state that it is impossible to make direct comparisons of the two methods because patient characteristics are dissimilar. In fact, many patients only undergo radiosurgery after they have been refused surgery. Although angiographic follow up on patients with AVMs is desirable, this is simply not possible for a large number of patients. Moreover, one of every 10 patients suffered an AVM hemorrhage after radiosurgery. When one also considers the chance of late radiation-related complications, such as cyst formation or radiation-induced neoplasms, radiosurgery looks even less appealing as an option for patients with AVMs. These considerations are frequently cited by cerebrovascular neurosurgeons in making their argument for resection of cerebral AVMs.

Evaluating the results of AVM radiosurgery is significantly influenced by one’s perspective. Much like two people can look at the same glass and state that it is half full (radiosurgeons) or half empty (cerebrovascular neurosurgeons), the published results of AVM radiosurgery can also be used to support whichever argument one prefers. To assert that one knows the correct manner of AVM management, however, shuts out the consideration of alternative ways to accomplish the same goal. Advances in microsurgical resection, stereotactic radiosurgery, and endovascular techniques have all contributed to improving outcomes for patients with AVMs treated during the past several decades. To provide the best care for patients with AVMs, we should use every tool available to individualize their treatment, taking into account the patient’s age, presentation, nidus size and structure, AVM location, and patient preference. If this multimodal approach is effectively used, one can say that the glass is not only full, but is overflowing for the majority of patients with AVMs.

References