Subtotal obliteration of cerebral arteriovenous malformations after Gamma Knife surgery

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Object. Subtotal obliteration of cerebral arteriovenous malformations (AVMs) after Gamma Knife surgery (GKS) implies a complete angiographic disappearance of the AVM nidus but persistence of an early filling draining vein, indicating that residual shunting is still present; hence, per definition there is still a patent AVM and the risk of bleeding is not eliminated. The aim of this study was to determine the risk of hemorrhage for patients with subtotal obliteration of AVMs.

Methods. After GKS for cerebral AVMs, follow-up angiography demonstrated a subtotally obliterated lesion in 159 patients. Of these, in 16 patients a subtotally obliterated AVM developed after a second GKS was performed for the partially obliterated lesion. The mean age of these patients was 35.2 years at the time of the diagnosis of subtotally obliterated AVMs. The lesion volumes at the time of initial GKS treatment ranged from 0.1 to 11.5 cm³ (mean 2.5 cm³). The mean peripheral dose used in the 175 GKS treatments was 22.5 Gy (median 23 Gy, range 15–31 Gy). To achieve total obliteration of the AVM, 23 patients underwent a new GKS targeting the proximal end of the early filling vein.

The mean peripheral dose given in these cases was 23 Gy (median 24, range 18–25 Gy).

The incidence of subtotally obliterated AVMs was 7.6% from a total of 2093 AVMs treated and in which follow-up imaging was available. The diagnosis of subtotally obliterated AVMs was made a mean of 29.4 months (range 4–178 months) after GKS. The number of patient-years at risk (from the time of the diagnosis of subtotally obliterated AVMs until either the confirmation of a total obliteration of the lesion on angiography or the time of the latest follow-up angiographic study that still visualized the early filling vein) was a mean of 3.9 years, ranging from 0.5 to 13.5 years, and a total of 601 patient-years. There was no case of bleeding after the diagnosis of subtotally obliterated AVMs. Of 90 patients who did not undergo further treatment and in whom follow-up angiography studies were available, the same early filling veins still filled in 24 (26.7%), and the subtotally obliterated AVMs were subsequently obliterated in 66 patients (73.3%). In 19 patients who underwent repeated GKS for subtotally obliterated AVMs and in whom follow-up angiography studies were available, the AVMs were obliterated in 15 (78.9%) and remained patent in four (21.1%).

Conclusions. The fact that none of the patients with subtotally obliterated AVMs suffered a rupture is not compatible with the assumption of an unchanged risk of hemorrhage for these lesions, and implies that the protection from rebleeding in patients with subtotal obliteration is significant. Subtotal obliteration does not necessarily seem to be a stage of an ongoing obliteration. At least in some cases it represents an end point of this process, with no subsequent obliteration occurring. This observation requires further confirmation by open-ended follow-up imaging.

Key Words • arteriovenous malformation • subtotal obliteration • complication • Gamma Knife surgery • radiosurgery

The primary goal of GKS in treating cerebral AVMs is to achieve a complete obliteration of the nidus, thus eliminating the risk of cerebral hemorrhage. It is generally accepted that once the AVM is obliterated, the cure is permanent. Occasionally rebleeding has been reported despite the fact that the posttreatment angiogram was assessed as normal. However, usually either a small residual nidus was missed or, due to hemodynamic conditions at the time of the follow-up angiography, the nidus did not fill. Unsatisfactory quality of the neuroimaging studies or inadequate interpretation could lead to the misdiagnosis of angiographic cure.

Total obliteration of the AVM after radiosurgery was defined by Lindquist and Steiner as “complete absence of pathological vessels in the former nidus, disappearance or normalization of afferent and efferent pathological vessels, and a normal circulation time on high-quality rapid serial subtracted angiography” (Fig. 1). Any remaining nidus, regardless of its size, represents partial obliteration (Fig. 2). Already in 1988 and 1993, Steiner et al. defined as subtotal obliteration of an AVM the angiographic persistence of an early filling draining vein with no demonstrable nidus (Fig. 3). The early filling venous drainage suggests that the formation has not been completely obliterated, with an angiographically undefinable residual part of the malformation.

Abbreviations used in this paper: AVM = arteriovenous malformation; GKS = Gamma Knife surgery; MR = magnetic resonance; SD = standard deviation.
tion shunting to the draining vein in an early phase, and the hemodynamics being largely but not optimally normalized.

It has been a widely accepted concept that patients remain at risk for hemorrhage as long as the AVM is patent, whether it is treated with microsurgery, endovascular techniques, or radiosurgery. Therefore, in cases of subtotal obliteration of AVMs, the risk of cerebral hemorrhage may exist as long as the shunting persists. On the other hand, our experience has shown that subtotally obliterated AVMs may represent an exception to the aforementioned rule because they seem to carry an extremely low risk for bleeding, and may thus represent a clinical if not angiographic cure.

The controversy surrounding both the clinical significance and management of subtotally obliterated AVMs is caused by the lack of understanding of the natural history of and treatment results in this condition. In this study, the long-term clinical and imaging outcomes, treatment options, and results of disease management in 159 patients with subtotally obliterated AVMs are presented and analyzed. The aim of the study was to determine the clinical risk of cerebral hemorrhage as well as the treatment options and results.

Clinical Material and Methods

Patient Population

Since the first AVM was treated with the Gamma Knife in 1970, more than 2500 patients with AVMs have been treated by the senior author (L.S.). This large patient population with a long-term follow up allowed us to attain a better understanding of subtotally obliterated AVMs. In this series of more than 2500 patients with AVMs who have undergone GKS during the past 36 years, 2093 with follow-up imaging are available for review.

A total of 159 patients with subtotally obliterated AVMs were identified based on follow-up angiography. Patient

Fig. 1. Vertebral arteriograms demonstrating obliteration of a midbrain AVM; frontal (A and C) and lateral (B and D) views were obtained before (A and B) and after (C and D) GKS. There was no neurological deficit.
characteristics and demographics are detailed in Table 1.

One hundred thirty-eight patients had received no other treatment prior to GKS. Sixteen patients in this series underwent two GKSs. Fourteen of them received the second Gamma Knife treatment for the residual nidi, and two patients underwent repeated treatment due to the formation of new nidi from recanalization of previously embolized AVMs.

Incidence of Subtotally Obliterated AVMs

From 1970 to 2004, more than 2500 patients with AVMs were treated with the Gamma Knife by the senior author. Follow-up angiographic studies were available for analysis in 2093. Subtotally obliterated AVMs were diagnosed in 159 patients (7.6% of the 2093 who underwent GKS and in whom appropriate follow-up angiographic studies were available). The diagnosis was made after a mean of 33.7 months (range 5–178 months) after the first GKS and 29.4 months (range 4–178 months) after the last GKS. The patients’ age at the diagnosis of subtotally obliterated AVMs ranged between 12 and 75 years, with a mean age of 35.2 years. In 68 patients, the subtotally obliterated lesions were detected on at least two follow-up angiograms.

Variables Analyzed in AVMs

A lobar location was encountered in 83 of the AVMs (frontal lobe in 18, parietal in 22, temporal in 28, occipital in 13, and insular in two), basal ganglion in 14, thalamus in 11, brainstem in 14, cerebellum in eight, corpus callosum in seven, and the subependymal region near a ventricle in 22 patients. The volume of the AVM nidi ranged from 0.1 to 11.5 cm$^3$, with a mean volume of 2.5 cm$^3$. The draining veins of the nidi were connected to the deep venous system in 83 patients, the superficial venous system in 70, and to both systems in six.

The GKS Technique

The technique of GKS has been detailed elsewhere. Stereotactic biplane angiography was performed to delineate the nidus. Since 1991, stereotactic MR imaging has been routinely used as a supplement to enhance the spatial accuracy of angiography for treatment planning.

Treatment Parameters

Dose rates at the Lars Leksell Center for Gamma Surgery were as follows: 1) 3.73 Gy/minute in March 1989 until lowered to 1.57 Gy/minute in October 1995; 2) 3.60 Gy/minute in November 1995 following a reload of a model U to 1.73 Gy/minute in May 2001; and 3) 3.56 Gy/minute in June 2001 following an upgrade to a model C until lowered to 2.06 Gy/minute in November 2005.

Of the 175 treatments in 159 patients, the mean peripheral dose was 22.5 Gy (median 23 Gy, range 15–31 Gy). The mean maximum dose was 41.3 Gy (median 40 Gy,
The isodose configuration ranged between 30 and 91%, with a median of 50%. The mean number of isocenters was 1.8, ranging from 1 to 11.

**Use of GKS for Subtotally Obliterated AVMs**

Of 159 patients with subtotally obliterated AVMs, 23 underwent a repeated treatment with the Gamma Knife. There were nine men and 14 women in this subgroup, who were between 20 and 61 years of age (mean 35.8 years) at the time of treatment. The treatments were performed 14 to 86 months (mean 48.5 months) after the first GKS and 0 to 51 months (mean 10.5 months) after the diagnosis of subtotally obliterated AVMs.

The mean peripheral dose used in this group of patients was 23 Gy (median 24 Gy, range 18–25 Gy) prescribed to an isodose configuration ranging from 50 to 90%. The mean maximum dose was 42.3 Gy (median 44 Gy, range 22–50 Gy). The mean number of isocenters used per patient was 1.7, ranging from one to six. The target area covered the proximal part of the early filling vein. The mean treatment volume was 1.1 cm³, ranging from 0.3 to 3 cm³.

**Follow-Up Imaging**

Before the era of MR imaging, angiography was performed on a yearly basis. After its introduction, follow-up MR imaging was performed at 6-month intervals, and the absence of flow-void areas prompted follow-up angiography. When for some reason MR imaging was contraindicated, computed tomography scanning was performed. The diagnosis of subtotally obliterated AVM required a careful assessment of angiography by an interested and experienced neuroradiologist and neurosurgeon. Because MR angiography is not accurate enough for depicting minor pathological phenomena like subtotally obliterated AVMs, clinical follow-up data were obtained by examination of the patient or by written and verbal communication with both the patient and the referring physician.

**Statistical Analysis**

All statistical analyses were performed using the statistical software package SPSS Version 10.1. The Fisher exact test or chi-square test was used as appropriate for comparison of group parameters. The Mann–Whitney U-test or independent t-test was used as appropriate for comparison of continuous variables. Statistical significance was set at a probability of less than 0.05.

**Results**

**Risk of Hemorrhage and Radiation-Induced Side Effects in the Period Between GKS and Diagnosis of Subtotally Obliterated AVMs**

In the 159 patients, rebleeding occurred in the latency period, 30 days after GKS, when the AVM was still patent.
The subtotally obliterated AVM was diagnosed subsequent to this event, 2 years after GKS.

Eighty-two patients in this series had follow-up MR imaging, which revealed increased white matter signal intensity on T2-weighted MR imaging in 37 cases (45.1%). Concomitantly, in three patients transient and in one permanent neurological deficits developed. In addition, an asymptomatic cyst developed in one patient.

Risk of Hemorrhage After the Diagnosis of Subtotally Obliterated AVMs

Four patients were lost to follow up after receiving the diagnosis of subtotally obliterated AVMs. Of the remaining 155 patients, the clinical follow-up duration ranged from 5 to 185 months (mean 59.4 months). During the cumulative period of 767 patient-years, a mean of 4.9 years per patient, no subtotally obliterated AVM had ruptured. If we exclude the follow-up period of subtotally obliterated AVMs after obliteration occurred, either spontaneously or following repeated GKS, there was no hemorrhage from subtotally obliterated AVMs during the cumulative period of 601 patient-years at risk, a mean of 3.9 years, ranging from 0.5 to 13.5 years. In 36 patients in this series the follow-up duration was longer than 5 years and in 15 it was longer than 10 years.

Natural Course of Subtotally Obliterated AVMs

One hundred thirty-six patients in whom subtotally obliterated AVMs were diagnosed had no further treatment. Subsequent follow-up angiography was performed in 90 patients after a mean period of 22.4 months (range 5–124 months). These studies showed a total obliteration of the AVM as well as disappearance of the early filling vein in 66 patients (73.3%) after a mean period of 18.9 months (range 5–106.4 months). Twenty-four patients (26.7%), however, had persistent subtotally obliterated AVMs after a mean follow-up duration of 32 months (range 5.4–124 months, Fig. 3).

There is no difference in the initial treatment parameters in these two groups of patients (Table 2) in terms of peripheral dose (totally obliterated compared with subtotally obliterated lesions [expressed as mean ± SD]; 22.4 ± 3.1 Gy compared with 21.8 ± 3.2 Gy, p = 0.393), maximum dose (41.8 ± 9.8 Gy compared with 38.8 ± 7.6 Gy, p = 0.183), number of isocenters (1.5 ± 0.7 compared with 2.3 ± 2.2, p = 0.134), and AVM volume (2.8 ± 2.5 cm3 compared with 3.3 ± 2.2 cm3, p = 0.387). Neither patients’ age nor sex differed between these two groups. However, in the group of patients with deep draining veins, the incidence of subsequent obliteration of subtotally obliterated AVMs is higher (71.2% compared with 28.8% for patients with mainly superficial venous drainage, p < 0.001). The incidence of persistent subtotally obliterated AVMs was also higher (p < 0.001) in the group of patients in whom the AVMs were located in the lobar area (cerebral or cerebellar hemispheres) compared with those harboring deep AVMs (basal ganglia, thalami, corpus callosum and brainstem, and subependymal region near ventricle). The interval between GKS and diagnosis of subtotally obliterated AVMs is shorter in patients who subsequently attained total obliteration (p = 0.018). The angiography follow-up duration is longer in patients with persistent subtotally obliterated AVMs, but this finding is probably a result of the fact that this subgroup of patients received longer angiographic follow up because their AVMs failed to disappear (p = 0.039).

Subtotally Obliterated AVMs Treated With GKS

Twenty-three patients were treated with GKS targeting the proximal end of the early filling veins. In this group, follow-up angiography was performed in 19 patients after a mean period of 25.3 months (range 8–62 months) after GKS, confirming disappearance of the early filling vein after a mean period of 22.9 months (range 8–62 months) in 15 patients (78.9%) and persistent subtotally obliterated AVMs in four patients (21.1%) after a mean period of 34 months (range 13.5–52 months). In four patients only follow-up MR imaging was available. On those studies we could no longer visualize the draining veins; nevertheless, MR imaging is not sensitive enough to detect small-caliber draining veins. Of all 23 patients, none had suffered a cerebral hemi-
On angiograms, the larger arteriovenous fistulous malformations (AVMs) were also reported to have an early phase, and that the hemodynamics has been largely but not optimally normalized. 11,22,27

Previous reports have shown that radiosurgery can at times thrombose only the small-vessel component of the AVM. 22,23 On angiograms, the larger arteriovenous fistulous portions may be the only part apparent. Historically, angiographic persistence of an early draining vein either after extirpation or radiosurgery implied some residual but angiographically occult nidus. Aggressive treatment is deemed appropriate. 22

Obliteration of AVMs After GKS

The most important objective in treating AVMs is to eliminate the risk of intracranial hemorrhage, which represents the most devastating and potentially fatal complication of cerebral AVMs. The incidence of hemorrhage has been related to the lesion size, previous hemorrhage, aneurysm, pregnancy, and location. Karlsson et al. 10 also reported increased annual risk of hemorrhage with increased age; in particular, they reported a rate of 2% at 10 years of age, 5% at 25, and 7% at 50 years of age. Given the fact that there were not enough patients in the 70 and older subgroup, only an extrapolation was possible and that suggested a 10% hemorrhage rate at this age. Generally, natural history studies reveal that untreated cerebral AVMs have an annual incidence of hemorrhage of 2 to 4%. 1,4,5,7,18,19 Forster et al. 6 analyzed patients with AVMs that were managed non-operatively by Olivecrona. They found that approximately one third of patients died, one third were disabled, and one third remained neurologically intact. The morbidity rate after a rupture of an AVM has been as high as 53 to 81%, and the mortality rate after initial rupture is 10 to 17.6% . 2,5,7,28

Karlsson et al. 11 studied the factors that influenced the obliteration rate after GKS and demonstrated that neither sex, age, collimator size, nor maximum dose correlated with the outcome; the only parameter that was decisive for obliteration of AVMs was the peripheral dose. The higher the peripheral dose given, the higher the incidence of obliteration and the shorter the time until total obliteration. The obliteration rates increased progressively with the radiosurgical dose, up to the peripheral dose of 25 Gy, which was found to result in the best obliteration rates with the relatively lowest risk of complications. In this series, a mean

### TABLE 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Still Subtotally Obliterated (24 patients)</th>
<th>Subsequent Total Obliteration (66 patients)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (yrs) at Dx of subtotal oblit</td>
<td>33.0 ± 15.0</td>
<td>32.7 ± 14.9</td>
<td>0.931</td>
</tr>
<tr>
<td>sex (M/F)</td>
<td>9/15</td>
<td>31/35</td>
<td>0.424</td>
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<td>location of AVMs (lobar/deep)</td>
<td>21/3</td>
<td>29/37</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>deep draining vein (yes/no)</td>
<td>5/19</td>
<td>47/19</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>interval btwn GKS &amp; Dx of subtotal oblit (mos)</td>
<td>33.8 ± 26.6</td>
<td>19.7 ± 8.9</td>
<td>0.018</td>
</tr>
<tr>
<td>peripheral dose (Gy)</td>
<td>21.8 ± 3.2</td>
<td>22.4 ± 3.1</td>
<td>0.393</td>
</tr>
<tr>
<td>maximum dose (Gy)</td>
<td>38.8 ± 7.6</td>
<td>41.8 ± 9.8</td>
<td>0.183</td>
</tr>
<tr>
<td>isodose configuration (%)</td>
<td>57.7 ± 12.5</td>
<td>56.0 ± 13.2</td>
<td>0.601</td>
</tr>
<tr>
<td>no. of isocenters</td>
<td>2.3 ± 2.2</td>
<td>1.5 ± 0.7</td>
<td>0.134</td>
</tr>
<tr>
<td>AVM vol (cm³)</td>
<td>3.3 ± 2.2</td>
<td>2.8 ± 2.5</td>
<td>0.387</td>
</tr>
<tr>
<td>angiography follow up (mos)</td>
<td>32.0 ± 28.0</td>
<td>18.9 ± 16.1</td>
<td>0.039</td>
</tr>
<tr>
<td>radiation-induced changes (yes/no)</td>
<td>9/15</td>
<td>11/55</td>
<td>0.036</td>
</tr>
</tbody>
</table>

**Discussion**

**Definition of the Stages of AVM Obliteration After GKS**

After the GKS, the first change is in the hemodynamics, with a decrease of the blood flow through the malformation, and the start of normalization of the afferent and efferent vessels to and from the nidus. It can be seen on the angiogram occasionally 3 weeks posttreatment, although usually the phenomenon is more delayed. We defined partial obliteration as a reduction in size of the nidus that could be slight or significant. Total obliteration of the AVM after radiosurgery was defined as complete absence of pathological vessels in the former nidus, disappearance or normalization of afferent and efferent pathological vessels, and a normal circulation time on high-quality rapid-series digitally subtracted angiography. Subtotal obliteration of an AVM was defined as the angiographic persistence of an early filling draining vein with no demonstrable nidus. The early filling vein suggests that the malformation has not been completely obliterated, that an angiographically undefined residual part of the malformation is shunting to the draining vein in
In a recent retrospective study by Maruyama et al., the risk of hemorrhage was reported to decrease by 54% during the latency period. In a previous study using Kaplan–Meier life-table estimates, we found that the shape of the curve could be interpreted as an indication of a sustained decrease in the risk of hemorrhage late in the follow-up period. Nevertheless, we qualified this statement that the end plateau is not long enough. Based on our experience with the management of a large number of AVMs, we believe that patients, whether treated by microsurgery, endovascular techniques, or radiosurgery, remain at risk for a hemorrhage as long as the malformation is still patent.

### Risk of Hemorrhage From the GKS to the Obliteration of the AVM

The issue of possible protection against hemorrhage for patients with patent AVMs after GKS is highly controversial. In a recent retrospective study by Maruyama et al., the risk of hemorrhage was reported to decrease by 54% during the latency period. In a previous study using Kaplan–Meier life-table estimates, we found that the shape of the curve could be interpreted as an indication of a sustained decrease in the risk of hemorrhage late in the follow-up period. Nevertheless, we qualified this statement that the end plateau is not long enough. Based on our experience with the management of a large number of AVMs, we believe that patients, whether treated by microsurgery, endovascular techniques, or radiosurgery, remain at risk for a hemorrhage as long as the malformation is still patent.

### Risk of Hemorrhage in Subtotally Obliterated AVMs

The traditional concept that as long as the arteriovenous shunting persists the risk of hemorrhage cannot be eliminated should be applied to subtotally obliterated AVMs. Considering a 2 or 4% annual risk, the probable number of hemorrhages in our series of subtotally obliterated AVMs should have been 12 to 24 during the cumulative period of 601 patient-years at risk. Even if we only consider the 68 patients who repeatedly demonstrated subtotally obliterated AVMs on follow-up angiography and assume a 2 to 4% annual risk of hemorrhage, the numbers of hemorrhages for a total of 226 patient-years at risk should still be five to nine. If one were to use the annual hemorrhage rates of 5 to 7% noted by Karlsson et al. for patients between 25 to 50 years of age, the number of hemorrhages for a total of 226 patient-years at risk would be even greater, and would range from 11 to 16. Thus, the zero incidence of hemorrhage in our series seems remarkable indeed compared with the incidence of hemorrhage in the natural history of AVMs. In 19 patients with subtotally obliterated AVMs reported by Pollock et al., no patient suffered a hemorrhage after a median follow-up duration of 25 months. These new observations require critical, open-minded consideration and an open-ended imaging follow-up period. If they hold, it will be necessary to revise the present views on possible protection against hemorrhage in irradiated but still patent AVMs.

### Pathophysiological Features of Subtotally Obliterated AVMs

Compared with the information gathered for the partially obliterated AVMs, little is reported regarding subtotally obliterated lesions. The mechanism of this phenomenon is not clear and no histological studies are available either from our series or the literature. The early draining veins probably derive blood flow from feeding arteries through an angiographically invisible shunting channel. Shin et al. reported four occurrences of hemorrhage from AVMs that had been angiographically confirmed as obliterated in patients treated with the Gamma Knife. In two patients surgical specimens were available for histological examinations, which revealed, in addition to closure of the greater part of the vascular lumen by intimal thickening, a patent nidus in one and small capillaries entering the nidus in the other. This observation provides evidence that sometimes the feeding vessels, nidi, or draining veins might be angiographically occult. Guo et al. reported a case of subtotally obliterated AVM in which follow-up angiography performed after a rehemorrhage detected a new portion of the nidus that was not visible during the diagnosis of subtotally obliterated AVM and was located beyond the previous treatment isocenters. Their conclusion is that the nidus might be obscured by poor-quality angiography. Indeed, angiography may occasionally be misleading due to certain hemodynamic conditions that result in failure to visualize the nidus or a portion of it.

### Natural Course of Subtotally Obliterated AVMs

Subtotally obliterated AVMs might represent a temporary stage of the obliteration process that finally results in total cure without additional treatment intervention. In the series reported by Pollock et al., seventeen of 19 patients underwent follow-up angiography after a median of 12 months following initial diagnosis of subtotally obliterated AVMs, and all had complete obliteration of these malformations. Kondziolka et al. stated that “we suspect that those patients with only an early draining vein remaining will progress to total obliteration over an additional 1 to 2 years.” In the present series, in 26.7% of patients the lesions persisted on angiograms obtained 5 to 124 months after the diagnosis of subtotally obliterated AVMs. This suggests that occasionally subtotally obliterated AVMs may represent an end point of the change in the lesion after GKS.

### Repeated GKS for Subtotally Obliterated AVMs

We recommend repeated GKS for patients with incomplete obliteration of their AVMs after their initial treatment, assuming that a residual nidus could bleed. The obliteration rate after a second GKS for a partially obliterated AVM has...
been reported to be similar to that for initial GKS. The risk of adverse effects when the treatment is repeated depends on the size of the residual nidi being treated. The complication rate reported by one group was 5% when treating a mean residual nidus volume of 2.6 cm\(^3\).\(^{16}\) Another group noted a complication rate of 10.9% in AVMs with a mean nidus volume of 3.2 cm\(^3\).\(^{18}\) In our as yet unpublished series of 90 patients who were treated for a residual AVM, the complication rate was 1.2%, with a mean nidus volume of 0.9 cm\(^3\).

Whether to treat the subtotally obliterated AVMs with GKS is still controversial considering its complications and the poorly defined target. In his comment on the article by Pollock et al.,\(^{20}\) Steinberg mentioned a case of an intracerebral hemorrhage after radiosurgery with only an early draining vein visible on the follow-up angiograms, and he stated that patients may require further treatment. In another comment, he stated that it may be prudent to continue follow-up evaluations of these patients rather than repeating the treatment.\(^{19}\)

Earlier in our series, we repeated GKS for subtotally obliterated AVMs, targeting the outflow of the initial nidus and the proximal part of the early filling vein with a prescription dose similar to the first one (23 GY compared with 22.5 GY). After repeated GKS, 15 of 19 subtotally obliterated AVMs were obliterated. However, given the fact that in the whole group no hemorrhage occurred over the observation period and that 73% of subtotally obliterated AVMs obliterated spontaneously, the necessity of retreatment remains still to be determined.

**Postoperative Complications**

No patient in our series experienced new neurological deficits related to the presence of subtotally obliterated AVMs, and this is in line with other reported series.\(^{16}\) Radiation-induced changes seen on MR imaging were present in 45% of patients, higher than the incidence previously reported by the senior author.\(^{26}\) However, only four patients presented with new clinical symptoms and in only one was this permanent. The reversible nature of these changes on MR imaging studies supports the suggestion, as previously stated by the senior author, that these neuroimaging findings all too frequently are labeled as radiation-induced necrosis, whereas actually they may represent a whole gamut of pathological, physiological, and clinical entities.

**Conclusions**

In this study, we analyzed the incidence, natural history, and outcome of repeated GKS in patients with subtotally obliterated AVMs. After a mean follow-up duration of 3.9 years with a total of 601 patient-years at risk, no case of hemorrhage related to a subtotally obliterated AVM was observed. The fact that none of the 159 patients suffered a rupture of the lesion speaks against the assumption of an unchanged risk of hemorrhage for subtotally obliterated AVMs after GKS and implies that the protection from rebleeding at the stage of subtotal obliteration is significant. Also, in this study subtotal obliteration did not prove always to be a premature stage of an ongoing obliteration, and might be the end point of the obliteration process. However, open-ended angiographic follow-up review still has to be continued to test this assumption. Repeated GKS treatment for subtotally obliterated AVMs seems to achieve a favorable obliteration rate with limited complications, but it might not be necessary considering the good chance of spontaneous obliteration and the 0% hemorrhage rate in this series.

**References**


C. P. Yen et al.