Radiosurgical treatment for rolandic arteriovenous malformations

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Object. The authors reviewed the radiosurgical outcomes in patients with arteriovenous malformations (AVMs) located in the rolandic area, including the primary motor and sensory gyri.

Methods. The study population consisted of 38 patients with rolandic-area AVMs who underwent linear accelerator radiosurgery at the University of Toronto between 1989 and 2000. Obliteration rate, risk of hemorrhage during the latency period, radiation-induced complications, seizure control, and functional status were evaluated. Patients were also divided into two subgroups according to AVM volume (< 3 cm³ and ≥ 3 cm³).

Patients were followed up for a median of 42.4 months (range 30–103 months), and the median age of the patients was 40 years (range 12–67 years). The median AVM volume was 8.1 cm³ (range 0.32–21, mean 8.32 cm³), and the median dose at the tumor margin was 15 Gy (range 15–22, mean 16.8 Gy). The risk of hemorrhage after radiosurgery was 5.3% for the 1st year, 2.6% for the 2nd, and 0% for the 3rd. Two patients (5.3%) sustained adverse effects related to radiation for more than 6 months. Complete nidus obliteration after a single radiosurgical treatment was achieved in 23 patients (60.5%). The obliteration rate for AVMs smaller than 3 cm³ was 83.3% (10 of 12) and that for AVMs larger than or equal to 3 cm³ was 50% (13 of 26). Among the patients who had seizures as the initial presentation, 51.8% were free of seizures after radiosurgery and the seizure pattern improved in 40.7% during the 3rd and last year of follow up. Overall, excellent results (obliteration and no new or worsening neurological deficit) can be achieved in approximately 60% of patients. This percentage varies according to the AVM size and can reach 83% in patients with AVMs smaller than 3 cm³.

Conclusions. Radiosurgery is a safe and effective treatment for people with rolandic AVMs. The low rate of morbidity associated with radiosurgery, compared with other treatments, indicates that this method may be the first choice for patients with AVMs located in this area.

KEY WORDS • arteriovenous malformation • sensorimotor cortex • linear accelerator • radiosurgery • stereotactic radiosurgery

In general, the cure rate for patients treated using radiosurgery for AVMs located in diverse brain regions ranges from 53 to 86.6%, 1,3,5,6,13,14,25,40,49,50 and the incidence of radiation-related complications ranges from 2.4 to 9.4% when using either a Gamma Knife or a LINAC system. 5,6,10,13,40,48 Based on these data, radiosurgery has been accepted as an effective option for treating AVMs in eloquent locations. 7,33,37 However, the specific radiosurgical results for rolandic AVMs have been described in only one publication, 18 in which the authors reported the results for patients treated in a single center. The objective of the present study was to review the radiosurgical outcome obtained in patients with AVMs located in the rolandic area, including the primary motor and sensory gyri. Patients underwent LINAC radiosurgery at the University of Toronto.

Clinical Material and Methods

Patient Population

Between October 1989 and December 2000, 244 radiosurgical procedures for AVMs were performed at the Toronto Sunnybrook Regional Cancer Centre. Included in this study were 38 patients with an AVM located in the anatomical primary motor and sensory (pre- and postcentral) gyri or in the rolandic (central) fissure, which was confirmed using MR imaging. All cases were initially reviewed by the Brain Vascular Malformation Study Group, a multidisci-
A multidisciplinary team at the University of Toronto consisting of vascular neurosurgeons, endovascular radiologists, and radiation oncologists. It is a preference of the group to treat AVMs in eloquent areas by using radiosurgery, and AVMs with angiographic findings that increase the risk of hemorrhage during the latency period are always considered for preradiosurgical embolization. Patients with sensorimotor deficits or hemorrhages that facilitate surgical exposure, which decreases the risk associated with microsurgery, were considered possible candidates for microsurgery because there is less risk of causing a new deficit than when structures are intact. After radiosurgery, the patients underwent yearly follow-up MR imaging, and DS angiography was performed at the 3-year follow-up examination.

**Radiosurgical Procedures**

At the Toronto Sunnybrook Regional Cancer Centre, radiosurgery was delivered using a 6-MV LINAC and the dynamic rotation technique described by Podgorsak and colleagues. Specific modifications were made as described by O'Brien, et al., and Gillies, et al. During the procedure, an Ollivier-Bertrand-Tipal stereotactic frame (Tipal Instruments, Montreal, Quebec, Canada) was mounted to the patient's head after induction of local anesthesia. Patients subsequently underwent a contrast-enhanced CT study of the brain followed by a stereotactic angiography study. Images were transferred to the radiosurgery software, which was a modified version of CMI software (Montreal Stereotactic Planning System; CMI Services, Montreal, Quebec, Canada). Most patients were treated as outpatients, but early in the study, some patients were hospitalized overnight.

In general, the radiation dose we used was 15 Gy delivered to the 67% isodose line or 20 Gy delivered to the 90% isodose line. This decision was based on the degree of eloquence of the area in which the AVM was located (for example, 15 Gy was used for a more eloquent area, such as the hand motor cortex, whereas 20 Gy was used for a less eloquent area, such as the sensory cortex). The dose and marginal isodose line prescribed were chosen according to the radiosurgical and radiation oncology team’s experience with LINAC radiosurgery. The AVM volume was calculated using the best-fit isodose method.

**Patient Outcomes**

Any new or worsening neurological symptom that was associated with changes observed on MR images was considered to be related to radiation and not caused by hemorrhage. We designated the complications as either permanent deficits (duration of symptoms > 6 months) or transient deficits (≤ 6 months). These complications were assessed by our team or, for patients living outside of our city, by the neurologist or neurosurgeon involved in the patient’s treatment. Obliteration of an AVM was defined as the total disappearance of the nidus, including any early-filling veins visible on angiography at the end of 3 years. Because most patients did not undergo angiography during this interval, we cannot know precisely when obliteration occurred. The MR imaging diagnosis of AVM obliteration was defined as the disappearance of any flow voids in the area of the previously seen AVM in addition to the absence of the nidus on MR angiography. An attempt was made to ensure adequate follow up and confirmation of complete AVM obliteration based on angiography. The MR imaging diagnosis of AVM obliteration was used only in patients who refused a follow-up angiography study. To provide for a comparison with the previous report, the patients were also divided into two groups according to AVM volume (< 3 cm³ and ≥ 3 cm³).

Patient outcomes were classified as: 1) excellent (complete obliteration and no new or worsening deficit); 2) good/fair (complete obliteration but new or worsening deficit related to radiation or hemorrhage); 3) unchanged (residual AVM and no new or worsening deficit); 4) poor (persistent AVM and new or worsening deficit); and 5) death. The outcome was determined according to the patient’s last follow-up findings. The classification system was designed by Pollock and Flickinger to assist in the prediction of radiosurgical outcome in patients with brain AVMs. We also included one more subgroup: patients in whom an AVM was excised during the 3-year period after radiosurgery during which they were attending follow-up sessions.

The outcome in patients who had seizures prior to the treatment was classified according to their status during the last year in which they were followed up. It was assessed using the Engel Seizure Outcome Scale (Class I, free of disabling seizure; Class II, rare disabling seizure; Class III, worthwhile improvement; and Class IV, no worthwhile improvement). The seizures were also classified according to the following categories: 1) no seizures (with or without medication); 2) improved (decrease in frequency and duration of the seizures); and 3) unchanged (same pattern of seizures as before).

The OPI was tested in this cohort to confirm its capacity for predicting obliteration of sensorimotor cortex AVMs after a single radiosurgical treatment. A score on the index was calculated for each AVM by dividing the dose in Grays of radiation at the margin of the lesion by the lesion diameter in centimeters. Radiosurgery-based AVM scores also were calculated using the method described by Pollock and Flickinger, which was based on the AVM volume, location, and patient’s age.

**Results**

**Patients, AVM Characteristics, and Treatment**

Thirty-eight patients were treated and followed up for a median of 42.4 months (range 30–103 months, mean 51.4 months). There were 24 male patients (63.2%) and 14 female patients (36.8%). The median age was 40 years (range 12–67 years, mean 40.3 years). Clinical presentation, neurological deficits before the radiosurgery, previous treatment, Spetzler–Martin grade, and AVM volume are summarized in Table 1. The median maximum AVM diameter during the radiosurgery was 2.61 cm (range 1.2–4.2 cm, mean 2.60 cm), and the median AVM volume was 8.1 cm³ (range 0.32–21 cm³, mean 8.32 cm³). Fourteen patients underwent embolization prior to radiosurgery. The median maximum AVM diameter before embolization in these patients was 3.45 cm (range 2.5–4 cm, mean 3.35 cm). After embolization, the median maximum diameter was 2.75 cm (range 2.20–3.70 cm, mean 2.82 cm). Nineteen patients (50%) had an AVM on the right side, and 19 (50%) had one on the left side.

The AVM had a single feeding vessel in 13 patients (34.2%) and multiple feeding vessels in 25 (65.8%). In 26
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patients (68.4%) the feeding vessels arose from the anterior cerebral artery, in 35 (92.1%) from the middle cerebral artery, and in six (15.8%) from the posterior cerebral artery. The venous drainage was strictly superficial in 29 patients (76.3%), and it was deep or deep and superficial in nine patients (23.7%). With relation to the cortical surface, 29 patients (76.3%) harbored a cortical AVM, and nine patients (23.7%) had a completely subcortical AVM. The AVM was located predominantly in the precentral gyrus in 22 patients (57.9%) and predominantly in the postcentral gyrus in 16 patients (42.1%).

The median radiation dose delivered to the tumor margin was 15 Gy (range 15–22 Gy, mean 16.8 Gy) and was directed to the 67% isodose line in 18 patients (47.4%), to the 90% isodose line in 13 patients (34.2%), and to a different isodose line in seven patients (18.4%). The median maximum dose was 22.3 Gy (range 20–33.3 Gy). One isocenter was used in 28 patients (73.7%), two isocenters in nine patients (23.7%), and three isocenters in one patient (2.6%).

Hemorrhage and Death After Radiosurgery

Three patients experienced hemorrhage during the latency period: two during the 1st year and one during the 2nd year. The risk of hemorrhage after radiosurgery in this cohort was 5.26% for the 1st year, 2.63% for the 2nd year, and 0% for the 3rd year. For all three patients in whom the AVM ruptured during the latency period, the lesion was microsurgically removed. During the 3rd year of follow up, one patient experienced status epilepticus and died of aspiration. That patient had seizures as the initial presentation. At autopsy, there was no sign of AVM hemorrhage. An example of a patient who experienced hemorrhage and required surgical evacuation and excision of the AVM is shown in Fig. 1.

Radiation-Induced Deficits

During the follow-up period, seven patients (18.4%) suffered radiation-induced deficits. These deficits were transient (≤ 6-month duration) in five patients (13.2%). A transient motor deficit developed in one patient; a transient sensory deficit developed in two patients; a transient sensory and motor deficit developed in one patient; and a transient speech deficit developed in one patient. Two patients (5.3%) sustained adverse effects related to radiation for more than 6 months. Both patients had a motor deficit before radiosurgery that worsened after radiosurgical treatment. One of these patients is not able to walk but is still working. The other patient’s hand weakness worsened, and he was unable to return to work. The AVM volumes in these two patients were 11.1 and 9.8 cm³, respectively.

Obliteration Rate and Excellent Outcome

Complete nidus obliteration after a single radiosurgical treatment was achieved in 23 patients (60.5%) and angiographically confirmed in 20 (86.9%) of those patients. Eleven patients (29%) had residual AVMs, in three the AVM was removed, and one died, as described earlier. The obliteration rate for AVMs smaller than 3 cm³ was 83.3% (10 of 12) and for AVMs larger than or equal to 3 cm³ it was 50% (13 of 26). All AVMs smaller than 3 cm³ had a maximum diameter less than 2 cm and all AVMs larger than or equal to 3 cm³ had a maximum diameter larger than 2 cm. Thus, the same obliteration rates, 83.3 and 50%, apply for AVMs smaller than and larger than or equal to 2 cm in diameter, respectively, in this cohort. Figure 2 displays the outcome after a single radiosurgical treatment for the entire cohort; Fig. 3 shows this same outcome according to AVM volume.

In this cohort, the obliteration rate in patients with AVMs 2 cm or larger who underwent embolization prior to radiosurgery was 46.2% (six of 13) and the obliteration rate was 60% (nine of 15) in patients with AVMs larger than 2 cm who did not undergo embolization before radiosurgery. There was no difference in the mean volume during treatment between these two subgroups (10 ± 4.3 and 10.9 ± 5.1 cm³, respectively; the preceding values are given as the mean ± the standard deviation).

The mean OPI score in this cohort was 7.8 (95% CI 6.6–8.8). The expected obliteration rate for this group was 57.5%, and the observed rate was 60.5%. The mean OPI score in the subgroup of patients who had AVMs smaller than 3 cm³ was 11.8 (95% CI 10.2–13.3), and in the subgroup of patients with AVMs 3 cm³ or larger, it was 5.9 (95% CI 5.2–6.5). The expected obliteration rates in these two subgroups were 75 and 47.5%, and the observed obliteration rates were 83 and 50%, respectively.

The mean radiosurgery-based AVM score for the entire group was 1.51 (range 0.41–2.48). The expected excellent outcome was 67.5%, and the observed outcome was 57.8%. The group was divided into two subgroups that consisted of patients who had radiosurgery-based AVM scores that were less than 1.5 and greater than or equal to 1.5. The mean radiosurgery-based AVM score in the first subgroup was 1.10, and in the second subgroup it was 2.01. The expected excellent outcome rates were 82.5 and 47.5%, respectively, and the observed rates were 66.7 and 47.1%, respectively. Figure 4 shows the excellent outcome rates in the two sub-
groups. An example of a patient with a radiosurgery-based AVM score with an excellent outcome is shown in Fig. 5.

Seizures After Radiosurgery

Twenty-seven patients (71.1%) had seizures before radiosurgery. Among these patients, 14 (51.8%) were free of seizures during the last year of follow up, 11 (40.7%) had an improvement in their seizure pattern after the procedure, one (3.7%) had the same seizure frequency as before the procedure, and one (3.7%) died during status epilepticus, as described earlier. Among the 14 patients who were free from seizures after the treatment, eight (57.1%) were not taking any anticonvulsant medication. The obliteration rates in patients who became free of seizures and in patients who still had seizures were 64.3% (nine of 14) and 46.2% (six of 13), respectively. Using the Engel Seizure Outcome Scale, seizure status in 92.6% of the patients was categorized as Engel Class I and in 3.7% as Engel Class II; 3.7% (one) of the patients died. In one patient (2.6%), in whom hemorrhage was the initial presenting sign and who had no seizures before the treatment, seizures developed during the follow-up period after radiosurgery. This patient was receiving seizure medication to achieve partial control of the seizures, and the AVM was obliterated.

Functional Status

Thirty-three patients (86.8%) had no decline in their functioning abilities at the time of the last follow-up review, and they were either working or retired (not related to the AVM). Five patients were not working: three because of related neurological deficits prior to radiosurgery, one because of a radiation-induced deficit, and one for emotional reasons.

Discussion

Obliteration Rate for Rolandic AVMs

There has been only one previous report about the radiosurgical outcome for patients who harbored AVMs primarily in the precentral gyrus. In that study, 33 patients were treated using a Gamma Knife. The overall obliteration rate, after one or two radiosurgical treatments, was 70%. Dividing these patients into two subgroups, those with AVMs smaller than 3 cm$^3$ and those with AVMs larger than or equal to 3 cm$^3$, the obliteration rates were 63.6% (7 of 11) and 50% (7 of 14), respectively, after a single treatment. After one or two procedures, the incidence increased to 87% (13 of 15) and 56% (10 of 18) for AVMs smaller than 3 cm$^3$ and larger than or equal to 3 cm$^3$, respectively. In the present

Fig. 1. Neuroimages obtained in a 35-year-old man with one seizure episode. He was treated using 15 Gy prescribed at the 67% isodose contour. After 19 months, he had an intracranial hemorrhage and the AVM was removed. A: Anteroposterior DS angiogram showing the nidus prior to radiosurgery. B: Sagittal T$_1$-weighted MR image demonstrating the nidus preradiosurgery. C: Axial T$_1$-weighted MR image showing the nidus prior to radiosurgery. D: Axial CT scan revealing intraventricular hemorrhage 19 months postradiosurgery. E: Axial CT scan showing intraparenchymal hemorrhage 19 months after radiosurgery. F: Postoperative DS angiography image showing complete excision of the AVM.
study, the obliteration rates were 83.3 and 50% for the same subgroups of patients (AVMs < 3 cm³ and ≥ 3 cm³) after a single treatment. The results achieved using the LINAC system at our center after a single treatment for AVMs smaller than 3 cm³ in the rolandic region were better than those reported in the previous study. This outcome probably is related to chance because the cohorts were small. Scores on the OPI also can be used to predict obliteration for AVMs in this location; thus, the same results should be expected independent of the radiation source because the OPI was developed to predict AVM obliteration after a single treatment from either LINAC or Gamma Knife data.45

In the present study, the diagnosis of obliteration was based on either angiographic evidence of complete obliteration (the gold standard) or on the disappearance of all flow voids in the area of an AVM as demonstrated on MR imaging, in addition to the nonvisualization of the nidus on MR angiography. This analysis assumes that every AVM that appears to be obliterated on MR imaging in fact would prove to be completely obliterated if the patients had undergone angiography. This is probably not the case. Nevertheless, assuming that the predictive value of a negative MR imaging study after radiosurgery is 91%, the obliteration rate would be reduced from 60.5 to 59.8%, because three patients had the AVM obliteration confirmed by MR imaging without angiography. This decrease of 0.7% in the obliteration rate does not change any conclusion in this study. On the other hand, if we had included just patients who had undergone angiography, this would have inaccurately increased the obliteration rate to 76.9%, as also suggested by other authors.19

The radiosurgery-based AVM score was also useful in dividing these patients into two subgroups based on their scores. High scores have a very tight correlation with the results published in the original study.38 However, for patients with low scores, the results observed were worse than the results expected. This overestimation of excellent results is probably related to the fact that the radiosurgery-based AVM score does not differentiate between frontal and parietal AVMs in eloquent and noneloquent locations.

Of note, patients in whom the AVM has not been obliterated after the first treatment, in general, can undergo a second procedure with an expectation of obtaining the same obliteration rate (59–86%) and having an acceptable risk of radiation-induced deficits (3.8–12.5%).12,24,44 However, to date, there has been no report published concerning retreatment specifically for patients with rolandic AVMs or AVMs in eloquent areas.

Seizure Control After Radiosurgery

In an international multicenter study of 1289 patients with brain AVMs,42 40% of the patients initially presented with seizures, compared with 71.1% of the patients in the present study. This high percentage is expected because only patients with AVMs in the eloquent cortex (sensorimotor...
were included in the present study. However, it becomes clear that seizure control also is an important result for patients with AVMs located in this region. In the present study, 51.8% of the patients who had seizures before the radiosurgical treatment were seizure-free after the treatment and 40.7% experienced improvement in the seizure pattern. In a previous report about radiosurgery for motor cortex AVMs, 18 63% of the patients were free of seizures at the time of the last follow-up examination. In the present study, 92.6% of the patients were classified as having Engel Class I outcomes and none of the patients had to leave their jobs because of disabling seizures after the treatment. This high proportion of patients with Engel Class I outcomes is explained by the fact that this scale was developed as an aid in evaluating outcomes after epilepsy surgery in patients with disabling seizures. Although this scale has been used in evaluating radiosurgical results, 23 it is certainly not very sensitive for AVM radiosurgery in general. Although 11 patients were still experiencing seizures during the last year of follow up, their outcomes were classified as Engel Class I because none of the seizures was disabling or because they had disabling seizures only during or after the withdrawal of antiepileptic medication. The rate of seizure control after radiosurgery for patients with AVMs in different locations was between 55 and 85%. 15,20,26,28 Interestingly, this result was not related to AVM obliteration, as demonstrated in this study and confirmed by other authors. This improvement could be related to a decrease in focal cerebral ischemia attributable to a “steal” phenomenon even before the total obliteration of the AVM, 15,20,28 or radiosurgery could lead to inhibition of epileptogenic areas around the AVM by ionizing radiation. 2,15,20

Seizures developed in 0 to 4.5% of patients after they underwent radiosurgery. 15,27,28 In a multicenter analysis of complications related to AVM radiosurgery in diverse locations, new or worsened seizures developed in 22 (1.8%) of 1255 patients. 10 We believe that most cases are not related to radiation by itself, but are also related to scarring after hemorrhage, ischemia related to the “steal” phenomenon, or previous epileptogenic areas that become active later. In the present study, one (2.6%) of the 38 patients had hemorrhage as the initial presentation and seizures developed after the treatment. No patients in this group had seizures that became worse after radiosurgery. However, two of 244 patients with AVMs who underwent radiosurgical procedures that were performed in our center during the study period had seizures that were worse after the treatment. In both patients remarkable edema (radiation footprint) developed in the area treated. One patient had an AVM in the mesial temporal lobe and the other had one in the occipital lobe. In the latter patient, who underwent treatment early in our series, some normal brain tissue was included in the radiosurgical treatment.

Heros and colleagues 21 studied 153 patients treated with

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**Fig. 5.** Neuroimages obtained in a 39-year-old woman with a history of seizures. She underwent one session of embolization followed by radiosurgical treatment with a 15-Gy dose at the tumor margin at the 90% isodose contour. After 3 years, the AVM had disappeared and no new deficit had developed; this was considered an excellent outcome. A: Sagittal T1-weighted MR image showing the nidus preradiosurgery. B: Lateral DS angiogram demonstrating the nidus prior to radiosurgery. C: Axial T1-weighted MR image showing the nidus prior to radiosurgery. D: Stereotactic planning CT angiogram showing the AVM site 3 years postradiosurgery. E: Digital subtraction angiogram showing the AVM site 3 years postradiosurgery. F: Axial T2-weighted MR image of the AVM site 3 years after radiosurgery.
microsurgery for AVMs in different locations of the brain. Of the patients who did not have seizures before surgery, 8.2% had one or two seizures during the immediate postoperative period and 7.1% had late seizures, all of which were well controlled with medication. Of the patients who had seizures before surgery, more than half were either cured or had great improvement with respect to the seizures. Thorpe, et al., studied seizures in patients who underwent excision of supratentorial AVMs and found that 21% of the patients had an incidence of seizures after radiosurgery (less than half that were found preoperatively). The incidence of postoperative seizures first manifesting after 1 year postradiosurgery was 6.3%. Although radiosurgical series have more consistently demonstrated low rates of new seizures after treatment, in our opinion, it is inconclusive whether microsurgery or radiosurgery can offer better seizure control and lower rates of new seizures after treatment.

Microsurgery and Embolization for Rolandoic AVMs

In a consecutive series of 62 patients treated with microsurgery for AVMs less than 3 cm in diameter (Spetzler–Martin Grades I–III), Schaller and Schramm reported that after the microsurgical removal of 33 small AVMs in eloquent regions, permanent significant deficits occurred in 6.1% of cases. In a recent publication about microsurgical results for patients with Spetzler–Martin Grade III AVMs, Lawton, et al., evaluated a consecutive series of 174 patients, among whom were six with rolandic AVMs. Two of the six patients died and one had a worse outcome when Rankin Scale scores before and after radiosurgery were compared. One-half of the poor outcomes of the entire series were associated with rolandic cortex AVMs. Patients with rolandic AVMs were considered to have poorer outcomes compared with patients who had other types of eloquent Grade III AVMs. In a series of 344 patients who underwent microsurgery for small AVMs in eloquent areas, de Oliveira and coworkers found that 27.8% of the patients had a poor outcome and 2.1% died after surgery. The same authors concluded that small AVMs in eloquent areas should be managed by radiosurgery.

Burchiel and associates described the excision of eight AVMs located within the sensorimotor and speech-related neocortex. Electrocorticography was used to identify epileptogenic brain in the region of the AVM and to establish after-discharge thresholds to electrical stimulation. Stimulation-mapping techniques were then used to delineate critical motor, sensory, and language areas. At a later time, a second procedure was performed, after induction of general anesthesia, to excise the lesion and any epileptogenic foci with the aid of cortical maps that were derived earlier. The use of these techniques made it possible to complete the excision of the lesions in seven of the eight patients without causing additional neurological deficits. In one patient aphasia developed after a series of temporary clips had been applied. No resection was performed in that case. The seizure control rate is not described. The extent to which preoperative functional imaging and cortical mapping can assist in the excision of AVMs in eloquent areas has not been evaluated in a large series.

Paulsen and colleagues studied 17 patients in whom embolization of rolandic cortex AVMs was attempted under clinical control using superselective amytol injection and somatosensory evoked potentials. Two patients were unable to undergo embolization because of positive results of an amobarbital test, despite repeated attempts to reposition a microcatheter in the AVM circulation. All patients who underwent embolization experienced a reduction in the size of the AVM. Transient neurological deficits developed in 23% of the patients but there were no permanent deficits. In none of the patients was complete obliteration of an AVM achieved after embolization alone. That study demonstrated that embolization of the sensorimotor cortex is a safe procedure when performed by an experienced team with the aid of clinical and electrophysiological monitoring.

In the current study, the obliteration rate for patients with AVMs measuring 2 cm or larger in diameter who had undergone previous embolization was 46.2%, compared with 60% for patients with AVMs measuring 2 cm or larger who had not undergone embolization. There was no difference in the mean AVM volume during the radiosurgical treatment between the two subgroups, confirming that this effect is not related to the AVM volume. Although preradiosurgical embolization has allowed the development of radiosurgical plans with a smaller treated volume, this has been associated with a decrease in the obliteration rate.

In the difficulty of locating the target after embolization and recanalization of the AVM have been offered as explanations for the decrease in the obliteration rate. In our opinion, some degree of radiation attenuation should be expected from the radiopaque contrast added to the glue mixture during the embolization. We have conducted an experiment and confirmed this last hypothesis (our unpublished data).

Conclusions

The treatment of rolandic AVMs is a formidable neurosurgical challenge. Radiosurgery as a definitive treatment for this condition is a safe and effective procedure compared with microsurgery and embolization alone. Overall, excellent results (obliteration and no new or worsening neurological deficit) can be achieved in 60% of the patients. This percentage varies according to the size of the AVM and can reach 83.3% in patients with AVMs smaller than 2 cm in diameter. Considering the low morbidity rate associated with this procedure and the possibility of radiosurgical retreatment in cases of failed treatment, stereotactic radiosurgery may be considered the first choice for patients with AVMs located in the sensorimotor area.

References


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