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Role of radiosurgery In arteriovenous malformations

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REVIEW ARTICLE

ROLE OF RADIOSURGERY IN ARTERIOVENOUS MALFORMATIONS

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Background: Intracranial arteriovenous malformations (AVMs) consist of an abnormal nidus of blood vessels that shunt blood directly from an artery to a vein and thereby bypass an intervening capillary bed. AVMs may be found as an incidental finding. They may be associated with intracranial haemorrhage, seizures, headaches or neurological deficits. There are different treatment options for AVM. These include observation, microsurgery, Stereotactic radio surgery (SRS), endovascular embolization and intensity modulated radiotherapy (IMRT). **Method:** Data was collected using searching engines like Pubmed, Google scholar, Embase, Cinahl and Medline. MeSH and Non-MeSH terms were used like Arterio-venous malformations, microsurgery, endovascular embolization. **Results:** Multiple interventional radiosurgical techniques have been introduced in recent years. The most effective and least risk-associated methods are Stereotactic radiosurgery, Microsurgery, Embolization and Intensity modulated radiotherapy (IMRT). However, the outcome of such treatment modalities depends upon Site of malformation, grade of AVM, patient's age/gender, dose and volume of radiosurgery. Digital substraction angiography (DSA) and MR angiography (MRA) are most suitable methods for the follow-up of AVMs. **Conclusion:** Stereotactic radiosurgery is the most suitable technique for AVMs considering the good prognosis and the risks associated with this procedure. However, large AVMs require multi-disciplinary approach for better results.

Keywords: Arterio-venous malformations; Stereotactic radio-surgery, Microsurgery; Endovascular embolization

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INTRODUCTION

Intracranial arteriovenous malformations (AVMs) consist of an abnormal nidus of blood vessels that shunt blood directly from an artery to a vein and thereby bypass an intervening capillary bed.[1] They are intraparenchymal collection of dilated arteries and veins which lack normal vascular organization at the sub arteriolar level as well as a normal capillary bed.[2] The incidence of AVM is estimated to be 1.12–1.34 per 100,000 person/years.[3] AVMs may be found as an incidental finding. They may be associated with intracranial haemorrhage, seizures, headaches or neurological deficits.

There are different treatment options for AVM. These include observation, surgical removal of AVM, stereotactic radio-surgery (SRS), endovascular embolization[4] and intensity modulated radiotherapy (IMRT).

Gamma knife, x knife and charged particles are included in types of SRS. SRS has a clinical obliteration rate of 80%[5] with no long term cognitive effects[6]. The outcome of SRS was determined by a number of factors. The success rate was increased with smaller volume (up to 30 cm3)[7], lower grade, higher dose, and steeper dose gradient[8]. Complications after SRS include haemorrhage, seizures, delayed cysts and other adverse effects. Complication risk was increased due to incomplete obliteration of the lesion.[9] Complication risk was dependent on clinical history, previous AVM surgery and previous radiation exposure. It was not dependent on age or gender.[10] The purpose of the literature review was to compile all the previous research done on this topic. Although there have been previous reviews done, however, they are either specific to a particular tumour size or a particular type of radiosurgery. Since radiosurgery is a common modality used in many centres it was essential to compile all the different types of radio surgery and the effect of this treatment modality with regards to different tumour sizes and other factors that determine treatment outcome. On the basis of this literature review, stereotactic radio surgery was considered a good treatment modality due to it being a minimally invasive procedure with a high obliteration rate and low complication risk. It was considered as a good option for tumours that had lesser volume but higher grade. However, for tumours with greater volume and larger size a multimodal approach can be considered such as microsurgery combined with radiosurgery, combined embolization and radiosurgery and intensity modulated radiotherapy. The latter being the preferred choice in children with higher grade and larger size of AVM.[11]

Radio-surgery is surgery using ionizing radiation that precisely destroys targeted areas. In SRS, stereotactic refers to a three-dimensional coordinate system. This system relates the virtual target seen in diagnostic images with the actual target position. Among the many treatment options for AVM, SRS has become one treatment modality.[1,12–14]

The purpose of our study is to discuss radio surgery as a treatment modality for AVM and to evaluate its outcome.

Types of SRS

There are different types of stereotactic radio surgery. Among them are Gamma knife which uses photons, linear accelerator (LINAC) which uses X-rays and charged particles such as helium or protons.[15] All these types of radio surgery are in use and are equally effective. The physical accuracy was comparable between different radio surgical methods. Linear accelerators are preferred for intermediate sized lesions (5–25 cm^3).[16] However, Semwal *et al* in a more recent study in 2012 published a retrospective comparative study that suggested that gamma knife is better than x knife (LINAC). Gamma knife having a higher performance conformity index (PCI) 0.664±0.048 as compared to x knife 0.501±0.240 but as the distance from the target increases x-knife become a better option than gamma knife.[17] Beams of heavy charged particles, however, are preferred for intracranial lesions[15] as the complete obliteration rate was 94% for smaller lesions, the clinical outcome was excellent in 58% of patients and neurological complications occurred in 12% of patients.

After irradiation, there is endothelial cell proliferation, vessel wall thickening and closure of vessel lumen leading to successful obliteration.[18]

Treatment modalities

1) **SRS**-Stereotactic radiosurgery is a minimally invasive procedure and is considered as an effective treatment. In 1992, Steiner *et al*. published an interventional clinical study that was done to assess the clinical outcome of radio surgery; it suggested that the complete obliteration rate of AVM was 79–95%.[12] This was in line with findings of 2 more articles which determined the factors associated with AVM radio surgery outcome. In 1998 Pollock *et al* published a multivariate analysis that found that the AVM obliteration rate was 80%.[1] Chang *et al* published an interventional study in the year 2000 and stated that the AVM obliteration rate was 78.9%.[14] Besides the obliteration rate a cohort study was done by Raghunath *et al* in 2016 to determine the cognitive outcomes of radio surgery.[2] This study stated that there were no long-term cognitive effects of this method as the outcome rate involving nidus obliteration with no new neurological deficits was found to be 66.6% and in fact several years later there was also improvement of memory after treatment. The perseverative responses that is the ability to repeat a particular phrase was seen to decrease from a value of 26.5–18.2. Set shifting that is the ability to unconsciously shift from one task to another was seen to improve in 11 out of 34 patients. This study however mentioned that more research is required to assess AVM obliteration and its effect on neuropsychological outcome because all AVMs showed some response at 2 years follow up and so effect of obliteration could not be analysed.[2] B. Shäuble *et al* in the year 2004 did a comparative cross-sectional study on seizure outcome after radiosurgery and it was found to improve with 78% patients having an excellent outcome.[19]

2) Microsurgery- This treatment modality can be used alone or in combination with each other. Pikus *et al* published a prospective analysis of 72 patients in 1998 and it suggested that microsurgery is better than radio surgery for AVM of grade 1–3 according to the Spetzler Martin Grading.[20] This was also confirmed by Lunsford *et al.* who in 1991 published an interventional study that stated that microsurgery is the most effective method for AVM.[21] Steiner *et al* in 1993 performed a comparative study that discouraged the overuse of radiosurgery.[22] However, Firlik *et al*. in 1998, in a technical case report suggested that radiosurgery and microsurgical resection should be combined for grade 5 AVM.[23] This had been contraindicated previously by Steinberg *et al.* in 1996 who in a clinical study stated that resection becomes more difficult after radio surgery but it went on to suggest that if radio surgery is done several years before surgery then it can be useful for large AVMs because they might be untreatable if a single treatment modality is used.[24] A more recent retrospective cohort study done by Marciscano *et a.* which was published in the year 2017 was done to assess the long-term outcomes of repeat radio surgery. They concluded that high grade AVM can be treated with multistage radio surgery with complete obliteration rate being 38%.[25] Robin M. Starke *et al* in the year 2013 created the Virginia Radiosurgery Scale (VRS). Although, the Spetzler-Martin Grading is the most frequently used and quoted grading system, however, its elements which include size, venous drainage pattern and location are not accurate predictors of outcome in those who receive treatment with SRS. The VRS with three elements which included history of haemorrhage, AVM volume and AVM location was found to be mathematically more complex but in terms of accuracy it was more superior to the Setzler Martin grading.[26]

3) Embolization- Mathis *et al* performed a retrospective study that was published in the year 1995. They found that geometry of the equipment and dose limitation led to a fall in the obliteration rate from 80% to 28% for AVM with a volume greater than 10 cm^3 and a size greater than 2.7 cm treated with radio surgery alone. AVM which were treated with embolization and radiosurgery with size greater than 3 cm were found to have an obliteration rate of 50% with no permanent neurological deficits. And hence they concluded embolization before radiosurgery was a better option for large AVMs.[27]

However, in the year 2007, Watanabe *et a.* published a clinical trial that suggested that radiosurgery alone is a better treatment modality as embolization decreases the obliteration rate. In the group that was treated with radiosurgery and embolization the obliteration rate was found to be 47% while in those treated with radiosurgery alone the obliteration rate was found to be 70%.[28] This was found due to recanalization of embolized AVM, difficult targeting and dose reduction due to high density material that is used.[29]

In a more recent retrospective study done in 2011 by Blackburn *et al*. it was found that that the obliteration rate was higher in large AVMs (greater than 3 cm) that were treated with a combination of embolization and radiosurgery being 81%.[30]

Xu *et al* in the year 2014 performed a meta-analysis that also confirmed that embolization decreases the obliteration rate. The group that received SRS and embolization (group 1) had an obliteration rate of 41% (group 2). While those who only underwent SRS the obliteration rate was 59%. The haemorrhage rate in group 1 was found to be 7.3% while that in group 2 was found to be 5.6%. Neurological deficits in group 1 were found to be 3.3% while those in group 2 were found to be 3.4%. However, statistically there was no difference in the haemorrhage rate and in occurrence of neurological deficits.[31] However, one of the limitations of the study that was mentioned was that most of the cases were retrospective and none of the studies had a randomized design.

The material used for embolization also plays a role in the obliteration rate as particulate embolization may be found to have a risk of recanalization of the nidus.[27] Onyx embolization has been found to be an alternative. Xu *et al* performed a clinical trial where instead of using the high-density material, Onyx embolization was used to reduce the size of AVM without significant complication. Complete obliteration was found in 18.6% of patients with large AVMs (greater than 3 cm) and a volume reduction of 80.5%. This study, however, had the limitation of not having a large sample size and patients were lost to follow-up.[32]

Hence with regards to embolization there is some controversy, however, there is general consensus that using embolization before radiosurgery for large AVMs has a beneficial outcome.

4) Intensity modulated radiotherapy (IMRT) Another treatment modality could be the use of IMRT. Optically guided technology provides improved patient localization and online monitoring of patient position during treatment delivery, it allows for safe and efficient delivery of intensity modulated radiotherapy.[33] A clinical study was done to compare SRS with IMRT. It revealed that for a single small target both SRS and IMRT have comparable results. However, for AVM that are larger (greater than 4 cm) and more irregular IMRT seems to be more superior.[34] With radiosurgery, the entire target was covered by the 90.7% isodose line. The maximum dose within the target was 1.02 G. The coverage was 0.99. The homogeneity index (HI) was 1.13 and the conformity index was 4.1. With IMRT, the maximum dose within the target was 1.25 Gy. The coverage was 0.99. The HI was 1.25 and the CI was 2.57.[34]

Factors determining the outcome of SRS

The outcome of radio surgery was determined by a number of factors. Small volume (less than 2 cm in diameter), hemispheric AVM and single session predict success after radio surgery with an AVM obliteration rate of 80%.[1] This is in conjunction with a meta-analysis and systemic review published in 2014 by Xu *et al.* and that suggested that treatment failure occurred more frequently when AVM volume was greater than 10mL, lower dose 50cGy was used, there were multiple isocentres and previous haemorrhage history.[31] Ellis *et al* in 1996 in a multivariate analysis looked at reasons for treatment failure after radio surgery and found that 72 patients attained angiographically confirmed cures after radiosurgery and 36 were retreated after the initial radio surgical treatment failed.[35] L Dade Lunsford *et al*. performed a clinical trial that was published in the year 1991 and found that success and complication risks are related to the AVM location and the volume that needs to be treated. These complications included 6.7% of patients developing neurological deficits which were due to radiation induced injury, intracranial haemorrhage occurred in 4.7% of patients, however, post radio surgery seizure and headache frequency was seen to improve, with reduction of seizures in 51% of patients and headache improvement in 75% of patients.[21]

A multivariate analysis published in 1999 that was performed by Miyawaki *et al*. to assess the relationship of dose and volume to obliteration as well as to complications found that obliteration rate for volumes <4 mL was 67% and as volume increased the obliteration rate decreased and complication rate increased. There was also a greater incidence of radiation necrosis.[36] This is however in contradiction to a previous study published in 1996 by Flickinger et al. which stated that obliteration rate was related to minimum dose but it had no relation with volume or maximum dose.[37]

A retrospective analysis published in 1995 by Yamamoto *et al*. was done to find out the relationship between dose and volume. It revealed that malformations up to 30 cm^3 in volume could be treated effectively with an acceptably low complication rate using a dose of 16 Gy.[3]

In a multivariate analysis published in 1992 by Flickinger *et al* it was found that volume was the only significant factor associated with the development of imaging changes on MRI which included new regions of increased T2 signal on MRI.[38]

Pasquale Gallena *et al* performed a retrospective study that was published in the year 1998, they found that that partial volume irradiation shouldn't be done and aim of treatment should be to completely obliterate the nidus as this lead to an increased risk of haemorrhage which was because of the rise in the pressure gradient through the malformations.[39]

An inferential analysis done by Karlsson *et al* that was published in 1997 stated that the probability of obliteration of AVMs after gamma knife surgery is related both to the lowest dose given to the AVMs and the AVM volume which can be predicted by K index.[40] The obliteration rate was seen to increase as the K value increased up to a value of 27.

Large AVMs are usually considered those that are larger than 30 cm^3.[41] Treatment becomes more difficult as size increase. There are many treatment options for such a situation e.g. repeated gamma radiation, stereotactic radio-surgery, staged volume radio-surgery, hypo fractionated stereotactic radiation (HSRT) and surgical excision. Yu *et al* did a clinical review in 2010 where they found out that repeated Gamma radiation should be considered as a treatment option for large AVMs. Even though this method had the disadvantage of taking longer but the complication and obliteration rate were quite acceptable. The overall obliteration rate was found to be 34.1%, the approximate obliteration rate in 120 months was calculated to be 41.8%. Of 44 patients, 3 (6.8%) experienced haemorrhages after GKS, cysts developed in 2 patients (4.5%), One patient (2.3%) experienced a newly developed seizure and another patient (2.3%) developed radiation necrosis.[41] This is in concurrence with a retrospective study done in 2009 that suggested that stereotactic radio-surgery is a safe and effective option for large sized AVM.[42] Prospective staged volume radio-surgery is also a treatment option that can be utilized for cases where no other therapy can be used.[43]

Xiao *et al* in 2009 published a retrospective study that suggested that before single dose radio surgery, HSRT can be given and it had the advantage of not increasing the bleeding risk with the median AVM volume decreasing to a value of 13.51 cm3. But they also stated that future studies needed to be done to confirm their results.[44] This was in line with a literature review published in 2012 by Wang *et al*. that stated that rate of AVM obliteration utilizing HSRT as a primary treatment was comparable with that of radio-surgery.[45] Reinard *et al* in 2015 published a clinical review on 'Surgical management of giant AVM' and suggested that surgery could be one of the treatment options since it caused complete obliteration in 90% of patients. But since giant AVMs have a high mortality rate a multimodal treatment approach should be used.[46]

Friedman *et al*. in 2012 in a multi variate analysis suggested that lower Spetzler- Martin grade, higher dose and steeper dose gradient increased the success rate.[4] This was in accordance with a multivariate analysis that treatment failure was because of increasing AVM size, decreasing treatment dose, and higher Spetzler Martin grade.

There was also an important factor that needed to be considered which was treating high grade AVM with planned multi stage dose or single dose. An interventional study done by Pollock *et al* published in the year 2000 suggested that staged volume radio surgery had the advantage of less radiation exposure to the adjacent brain. However, it also mentioned that further follow up will be required to find out if this technique provides high obliteration rate.[47] A more recent article done to find long-term outcomes of mutli-stage dosage in 2017 by Marciscano *et al* found that this method achieves successful AVM obliteration with acceptable adverse effect rates.[25] This was in agreement with a retrospective study done by Iyas *et al* and was published in 2017. It suggested that volume staged stereo-static radio-surgery was a good treatment option for large AVMs. There were no cases of post treatment haemorrhage and this approach was found to decrease the nidus size.[48] The median AVM volume reduction was found to be 87%.

A retrospective analysis was done by Pollock et al. published in 1996 to find out the reasons for incomplete obliteration. The most frequent factor turned out to be incomplete angiographic definition.[49] This was also stated in a previously mentioned article that observed some errors in finding out AVM target shape and size. These errors were attributed to inaccurate definition of the nidus and because of incomplete stereo-angiography.[39] Rate of AVM obliteration depended on marginal dose and problems in dose response plateau were attributed to problems in target definition.[50]

Outcome of radio-surgery was also dependant on the location of the AVM. Brain AVMs are classified into superficial and deep types. Superficial AVMs are further divided into sulcal, gyral, or mixed, while deep types that are relatively rare are subdivided into subarachnoid, deep parenchymal, plexal, and mixed types.[51] In a retrospective review done by Kurita *et al*. published in the year 2000, it was stated that radio surgery is a good treatment option for small deep parenchymal brain stem AVMs.[52] Ellis *et al* in 1996 in a multivariate analysis showed that radiosurgery is also a good treatment option for intracranial dural AV fistulas.[35] However if the AVM is located at a deeper location it decreases the chance of radio-surgical success. Pollock *et al* in 2004 published a clinical study that was done for deeply located AVM revealed that there is difficulty in treating patients with deeply located AVMs and that most of them are also poor candidates for surgical resection or embolization.[13] There was general consensus that radiosurgery is a good treatment modality for deep AVM however there was still some risk of latent haemorrhage in incompletely obliterated nidus.[52]

Grade is also an important factor. A number of articles suggest that microsurgery is preferred for lower grade.[20,21,26] Radio surgery with stereotactic MR targeting and multiplanar dose planning can be used for treatment of larger AVMs (30 cm^3).[53]

In children, different treatment options are considered. Capitanio *et al* in 2016, in a retrospective review suggested that stereotactic radiosurgery (SRS) at an optimum radiation dose of 18–25 Gy can be used as a safe and effective method for AVM.[54] This is in agreement with a clinical study done by Yen *et al*. in 2010 that states that gamma knife radiosurgery at an optimum radiation dose of 21.9 Gy causes reasonable obliteration of AVM with decreased radiation induced adverse effects.[55] Another clinical article by Blamek *et al* in 2013 states that stereotactic linac radiosurgery is an effective method for AVM in children. However, follow up is required because of the high incidence of radiation induced side effects.[56] This is in concurrence with Rajshekhar *et al*. who in 2016 in a retrospective cohort study stated that a marginal dose of 15 Gy resulted in an obliteration rate of 66.7%.[57] A univariate and multivariate analysis was done by Reyns *et al*. in 2007 in which they reviewed data from 100 children and suggested that radiosurgery is a safe method.[58]

However, for high grade AVM in children the success rate of single dose SRS is limited and other treatment options should be explored. One option could be intensity-modulated radiosurgery (IMRS) for treatment of complex AVM which has favourable outcomes.[7] A clinical trial done by Woo *et al*. in 1996 compared SRS with IMRS and stated that IMRS is superior to SRS for irregular shaped AVMs.[34] This is in accordance with a literature review done by Sterzing *et al* in 2007. They stated that conventional radiotherapy has been associated with limited dose to the target and there is high risk of damage to normal tissues.[59]

Complications

Complications after radio surgery include haemorrhage, seizures, delayed cysts and other adverse effects. Factors that determine complications include clinical history, previous AVM surgery and previous radiation exposure.[6]

During a mean post Gamma knife radio surgery (GKRS) follow up over a period of 10.2 years, 15 (8.3%) of the 181 patients who underwent surgery experienced stereotactic radiosurgery related symptomatic complications. Among the 15 patients, 12 manifested complications in 5 years or more after GKRS and in 5 of these 12 patients, complications were seen in 10 years or more after GKRS.[6]

Flickinger *et al* in 1998 in a multivariate analysis study suggested that the risk of complication can be predicted according to the PIE (post radiosurgery injury expression) score but other factors that may eventually lead to radiation necrosis still need to be researched.[60] Results showed that symptomatic post radiosurgery sequelae developed in 30 (9%) of 332 patients.

Karlsson *et al* in 1998 suggested that risk of complication is not dependent on age or gender.[6] In a study, published in 2005, from 201 patients who underwent radio surgery only 12 developed post treatment haemorrhage. Patient age was not related to post treatment bleeding.[61] This was in concordance with the clinical study done by Karlsson *et al*. in 1997 that stated complication risk is not dependent on age.[6] However, Lv *et al* in a retrospective analysis of a case series of 496 patients in 2016 suggested that occurrence of subsequent haemorrhage from AVM was associated with younger age and female gender.[62]

Pollock *et al* in 1996 did a multi variate analysis in which angiographic characteristics of 315 patients after radio surgery were observed. It was found that patients who had complete obliteration did not experience hemorrhage.[63] This was also confirmed by a univariate and multivariate analysis done by Nataf *et al* in 2004 that suggested that haemorrhage risk is increased in patients with poor obliteration levels.[5]

Such was shown in a study where median clinical follow-up was 53.8 months. 47.6% of patients had an AVM with a Spetzler-Martin grade ≥ III. The median administered margin and maximum doses were 22 and 40 Gy, respectively. The overall obliteration rate was 70.5%. Of patients who showed complete obliteration, 74.4% developed adverse radiation effects within 4–6 months after GKRS.[64]

Besides haemorrhage late adverse radiation effects (ARE) can occur after radio surgery.[64] These include lesional oedema and cyst formation. Treatment usually involves resection of the thrombosed AVM.[51] One article suggests that these adverse effects peak at 7–12 months.[64] Late-onset ARE (i.e., >12 months) correlated to a failure to obliterate the nidus. 58.1% of patients who developed appreciable AREs (defined as ARE index >8) proceeded to have complete nidus obliteration. Appreciable AREs were found to be influenced by AVM nidus volume >3 ml, lobar location, number of draining veins and feeding arteries, prior embolization, and higher margin dose. On the other hand, a minimum ARE index >8 predicted obliteration (p=0.043) the study hence proved that ARE development after radiosurgery follows a temporal pattern peaking at 7–12 months after stereotactic radiosurgery and that ARE index serves as an important tool in patient follow-up and outcome prediction.

Cyst formation, although rare but a study mentioned a case where 3 years after radio surgery a 24-year-old woman developed a cyst in the parietal lobe of her brain.[44] Another older article also mentioned 2 case reports of delayed cyst formation.[65]

In a Retrospective review of 233 AVM patients having SRS from 1990 to 2009. Patients had sporadic AVM, no prior radiation, and a minimum of 5 years of magnetic resonance imaging (MRI) follow-up. The study showed that late ARE were observed in 16 patients (6.9%) at a median of 8.7 years after SRS (range, 2.0–16.1). The 5, 10, and 15-year incidence of late ARE was 0.4%, 7.7%, and 12.5%, respectively. Eight patients (3.4%) were symptomatic at the time of ARE detection. Three of 8 patients who were initially asymptomatic had documented cyst progression (at 11, 40, and 42 months), for an overall symptomatic rate of 4.7%. Five patients with asymptomatic ARE have been observed for a median of 9.3 years (range, 2.0–14.1) without progression. Patients having early radiation induced changes RIC (hazard ratio [HR] = 2.11, p< .001), patients having obliteration (HR = 1.24, p= .02), and patients having SRS before April 1997 (HR = 1.12, p= .02) were more likely to develop late ARE.[51] Therefore it was proved that late ARE are common in AVM patients who develop early RIC after SRS. Resection of the thrombosed AVM and the adjacent damaged tissue is effective at eliminating the mass effect and improving patients' neurological condition.

A clinical study was done by Malikova *et al* in 2016 to determine late morphological changes after radio surgery. The study stated that Gamma knife radiosurgery for AVM is a safe treatment method but delayed complications cannot be avoided and were found. Also, post-gadolinium enhancement could be a sign of an active, delayed post-irradiative process.[66]

Murray *et al.* in a cohort study published in the year 2014 discussed the Neuropsychological outcomes of hypo-fractionated stereotactic radiotherapy (HSRT) for AVM. It demonstrated that patients had memory improvement several years later and this form of treatment was not associated with long-term, harmful cognitive side effects.[67]

Prior to HSRT treatment AVM showed deviations from the mean of the normal population in a number of cognitive domains measured. Five out of nine cognitive domains were impaired especially processing speed, learning, naming, verbal fluency, and executive functioning were mildly impaired. However, domains of semantic processing, memory, attention and visuospatial function were in normal limits although the mean score of major cognitive domains we're reaching impaired levels. Mild CNS toxicity is expected in HSRT treatment but in contrast to above cognitive domains remained stable during follow up assessments.[67]

Follow up:

The current standard for assessing obliteration after SRS is digital subtraction angiography (DSA). As of late MRI and MR angiography (MRA) have gained considerable popularity. A study was done to compare MRI with conventional angiography. The results of the study revealed that there was no difference in diagnosing the patency of AVM on MRI and with conventional angiography.[68]

This is in contradiction to a more recent study that was done to find out the specificity and sensitivity of MRI/MRA. This study revealed that the sensitivity and specificity were in the range of 70–95% and were not that low but still DSA should be used to confirm the obliteration rate.[69]

CONCLUSION

Considering the above literature, stereotactic radio surgery seems to be a good treatment modality due to its high obliteration rate and low complication risk. It was considered as a good option for tumours that had lesser volume but higher grade. Haemorrhage, seizures, headaches and neurological deficits occur less frequently and the complications of radio surgery are usually because of incomplete obliteration. However, for tumours with greater volume and larger size a multimodal approach can be considered such as microsurgery combined with radiosurgery, combined embolization and radiosurgery and intensity modulated radiotherapy. The latter being the preferred choice in children with higher grade and larger size of AVM.

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