ARTIGO DE REVISÃO

MICROSURGERY AND STEREOTACTIC RADIOSURGERY FOR TREATMENT OF PATIENTS WITH BRAIN ARTERIOVENOUS MALFORMATION

Microcirurgia e radiocirurgia estereotáxica para o tratamento de pacientes com malformação arteriovenosa cerebral

ISSN: 2178-7514

Vol. 16| Nº. 2| Ano 2024

Guilherme Nobre Nogueira[1]; Wilson da Silva Rocha Vidal Neto[2];
Luiza Heitmann Paglioli[3]; Ana Letícia Gurgel Sampaio de Sousa[4]

ABSTRACT

Cerebral arteriovenous malformations (AVMs) pose a significant challenge in clinical management due to their complex nature and potential for severe complications. This review provides a comprehensive analysis of therapeutic options for AVMs, including microsurgery, stereotactic radiosurgery (SRS), and embolization, based on a thorough examination of existing literature. Eight studies involving 817 patients underscored microsurgery's superiority in achieving complete obliteration of AVMs and reducing the risk of bleeding during follow-up, despite a higher incidence of post-operative neurological deficits. Notably, the success of microsurgery correlated with the severity of AVMs, with higher grades exhibiting lower success rates. Meanwhile, SRS offers a less invasive alternative but presents challenges such as a latency period until complete obliteration and risks associated with radiation. Embolization serves as a valuable adjunctive therapy, often utilized preoperatively to reduce bleeding risk. Combined approaches, such as embolization followed by radiosurgery, show promise in certain cases. However, treatment selection necessitates a personalized, multidisciplinary approach, considering AVM severity, location, and patient-specific factors. Post-operative care plays a crucial role in patient recovery and favorable outcomes, emphasizing the importance of monitoring and intervention to prevent complications. Despite advancements, further research is warranted to fully assess therapeutic options and ensure patient safety and efficacy. Collaboration among specialists is essential to optimize treatment strategies and enhance patient outcomes in AVM management.

Keywords: Cerebral Arteriovenous Malformation (AVM); Microsurgery; Stereotactic Radiosurgery; Neurosurgery; Review

RESUMO

As malformações arteriovenosas cerebrais (MAVs) representam um desafio significativo no manejo clínico devido à sua natureza complexa e ao potencial de complicações graves. Esta revisão fornece uma análise abrangente das opções terapêuticas para MAVs, incluindo microcirurgia, radiocirurgia estereotáxica (SRS) e embolização, com base em um exame minucioso da literatura existente. Oito estudos envolvendo 817 pacientes destacaram a superioridade da microcirurgia em alcançar a obliteração completa das MAVs e em reduzir o risco de sangramento durante o acompanhamento, apesar da maior incidência de déficits neurológicos pós-operatórios. Notavelmente, o sucesso da microcirurgia correlacionou-se com a gravidade das MAVs, com graus mais elevados exibindo taxas de sucesso menores. Enquanto isso, a SRS oferece uma alternativa menos invasiva, mas apresenta desafios como um período de latência até a obliteração completa e riscos associados à radiação. A embolização serve como uma terapia adjunta valiosa, frequentemente utilizada no pré-operatório para reduzir o risco de sangramento. Abordagens combinadas, como embolização seguida de radiocirurgia, mostram-se promissoras em certos casos. No entanto, a seleção do tratamento requer uma abordagem personalizada e multidisciplinar, considerando a gravidade da MAV, localização e fatores específicos do paciente. O cuidado pós-operatório desempenha um papel crucial na recuperação do paciente e nos resultados favoráveis, enfatizando a importância do monitoramento e intervenção para prevenir complicações. Apesar dos avanços, mais pesquisas são necessárias para avaliar plenamente as opções terapêuticas e garantir a segurança e eficácia dos pacientes. A colaboração entre especialistas é essencial para otimizar as estratégias de tratamento e melhorar os resultados dos pacientes no manejo das MAVs.

Palavras-chave: Malformação Arteriovenosa Cerebral (MAV); Microcirurgia; Radiocirurgia Estereotáxica; Neurocirurgia; Revisão

1 Universidade Federal do Ceará, Fortaleza, CE
2 Universidade Nove de Julho (UNINOVE)São Bernardo do Campo, SP
3 Universidade Nove de Julho (UNINOVE)São Bernardo do Campo, SP
4 Centro Universitário Christus (UNICHRISTUS) - Fortaleza, CE

Autor de correspondência

Guilherme Nobre Nogueira

guiermenobre@gmail.com

INTRODUCTION

Management of cerebral AVMs encompasses medical follow-up through consultations and imaging tests, along with interventional options such as endovascular embolization, microsurgery resection, and stereotactic radiosurgery. The combination of these therapies may be employed to achieve complete nidal obliteration, thereby eliminating the risk of intracranial hemorrhage. Microsurgery and stereotactic radiosurgery are primary interventions, while endovascular embolization serves as a complementary therapy [(1)].

To guide therapeutic decisions, classifications have been developed based on the severity of cerebral AVMs, with the Spetzler-Martin classification being widely utilized. This classification categorizes AVMs from grade I to V, incorporating factors such as size, location, and venous drainage to assess risks and prognosis, aiding in the selection of surgical approaches. According to Spetzler-Martin, microsurgery is the preferred technique for grade I or II AVMs due to its immediate resolution and superior efficacy. Grade III AVMs are preferably treated with microsurgery or stereotactic radiosurgery, with or without adjuvant endovascular embolization. Stereotactic radiosurgery is particularly indicated for patients refusing microsurgery or those with severe comorbidities, offering a non-invasive alternative. However, its drawback lies in the delayed response time of up to 3 years, maintaining the risk of intracranial hemorrhage [(2)].

Observation is recommended for grade IV and V lesions, necessitating an individualized therapeutic approach, especially for high-risk hemorrhage patients. Despite established classifications, determining the optimal therapeutic approach for cerebral AVM patients remains challenging due to postoperative divergence in patient outcomes across AVM grades. Understanding the indications for each procedure is crucial for determining the most appropriate approach, with a focus on achieving a favorable prognosis while mitigating potential irreversible sequelae [(3)].

Thus, this literature review aims to investigate microsurgery versus stereotactic radiosurgery for the treatment of patients with cerebral arteriovenous malformations, as well as their indications, while also evaluating morbidity and mortality rates, the risk of sequelae and other prognostic aspects associated with these treatments.

METHODS

This article is a systematic literature review, a method of analysis with methodological rigor which gathers evidence for clinical practice by searching, evaluating and synthesizing the information available on the specific topic to be analyzed. To carry out this study, the following methodological steps were followed: identification of the theme and guiding question of the research; definition of the inclusion and exclusion criteria; identification of the information to be extracted from the selected articles; analysis and interpretation of the results and presentation of the review.

First, the topic “Types of AVM treatment, their indications and the importance of each” was established. Next, the guiding question was: “What is the difference in prognosis and indication between microsurgery and stereotactic radiosurgery for the treatment of patients with AVMs?”.

The search strategy used the English descriptors registered in the Medical Subject Headings (MeSH): “Microsurgery Arteriovenous Malformation Stereotactic Radiosurgery”. For scientific support, searches were carried out in the PubMed, Medline (BVS) and ScienceDirect databases, using the Boolean operator “OR” to associate the descriptors in the search.

The search results were selected using the exclusion and deletion criteria applied to the articles available in full. Only original studies related to the topic were included, which answered the guiding question and were in English or Spanish. At the same time, duplicate articles, reviews and those that did not fit the theme of this review were excluded.

RESULTS

Microsurgery:

One of the analyses included eight studies with a total of 817 patients, of whom 432 underwent microsurgery and 385 underwent stereotactic radiosurgery (SRS). The results show that microsurgery is superior to SRS, as it has a greater chance of obliterating AVMs and a lower risk of bleeding during follow-up. Although surgery has a higher risk of post-operative neurological deficits [4]. The grade of the lesion is one of the main factors in obtaining better results after surgery, with grade I AVMs having a success rate of between 92% and 100% and grade II AVMs having a success rate of between 94% and 95% 5. When investigating 977 patients with AVMs, only 155 of them were eligible for microsurgical resection, of which patients with lower grades (grade 1 and grade 2) were more likely to undergo microsurgery alone, accounting for 71.6%, while those with higher grades (grade 4) often received preoperative embolization in order to block blood flow to the AVM, accounting for 25.2%. Follow-up with these patients lasted an average of 36.1 months and complete obliteration of the AVM was achieved in 94.2% after the initial surgery and 98.1% at the final angiography. In cases of low-grade AVMs, complete obliteration was 99.2%, with 9.3% presenting early disabling deficits and 3.4% permanent deficits. Among the surgical complications, severe bleeding was the main predictor of early disabling deficits [5,6]. In another study of 104 patients with AVMs who underwent microsurgical resection as the sole treatment, over an average of 5.3 years of follow-up, 7.7% of patients suffered significant permanent deficits, and none of them had treatment-related mortality. The risk of permanent deficits was lower in low-grade AVMs (grade I or II) compared to high-grade AVMs. In the same article, another reference pointed out that 155 of the patients with predominantly low-grade AVMs treated mainly by microsurgery, the rate of disabling permanent deficits was 4.5% over a mean follow-up of 3 years. Intraoperative bleeding was again identified as a major risk factor for permanent deficits, highlighting the importance of preoperative embolization to reduce bleeding during the surgical procedure [7,8]. A study of 95 patients with AVMs established their approach by dividing these patients into two large groups, defined as group I, made up of 54 patients, who underwent total AVM removal by microsurgical surgery where all but one of the patients in this group survived the surgery, resulting in a mortality rate of 1.8%. Some of these patients with grade 4 and grade 5 AVMs had temporary new neurological symptoms after surgery, but most of them recovered completely or had persistent mild symptoms. The surgery was also directly related to the cure of 10 of the 13 epileptic patients, and none of them suffered recurrent hemorrhages after the procedure. In contrast, in group II, made up of 41 patients, where open surgery was refused and other approaches were applied, 10 patients (24%) suffered intracerebral hemorrhages and 6 of them had progressive seizures. The mortality rate in this sample was 17% over 6 years and 16 patients underwent endovascular embolization of the AVM, only one patient (6.2%) achieved complete obliteration of the AVM, while the other 15 patients achieved only partial occlusion, indicating that the AVM still presented a risk of bleeding. In group II, 4 patients died due to recurrent intracerebral hemorrhage (ICH), and another patient had a non-fatal ICH after radiosurgery. Overall, 10 patients in group II experienced ICH, a serious complication of AVMs, resulting in a mortality rate of 17% for this group. With regard to epileptic patients, surgery resulted in a cure in 77% of cases. There were no cases of rebleeding after surgery, and the mortality rate was 1.8% for the angiographically revealed AVM group overall and 5.9% for the grade 4 and grade 5 AVM subgroup [8, 9,10]. Regarding preoperative embolization, 32 studies were analyzed with a total of 1,828 patients undergoing microsurgery alone and 1,088 patients undergoing microsurgery with preoperative embolization, with results in which AVM treated exclusively by microsurgery show acceptable results, it may be reasonable to avoid preoperative embolization due to the higher risk of postoperative complications associated with this procedure [11]. The indication of a combined protocol of SRS followed by microsurgical resection can be effective in some cases of AVMs, as presented by a study involving 59 patients with AVMs in which complete resection was achieved in 90% of these cases [12].

Stereotactic radiosurgery:

Radiosurgery has proven effective in treating cerebral arteriovenous malformations (AVMs) of less than 3 cm in diameter, but it faces concerns due to the long latency period for complete obliteration, with success rates of 60% in 2 years and 80% in 5 years, as well as not preventing hemorrhages in the first 12-14 months after treatment. These hemorrhages can be serious, with associated mortality, and radiosurgery also presents risks of late morbidity, such as radiation necrosis and cyst formation [8]. The average time between radiosurgery and complete obliteration of cerebral arteriovenous malformations (AVMs) is usually between 3 and 5 years. A study with an average follow-up of 2.8 years did not allow a full assessment of the potential protective benefits of radiotherapy in cases of AVMs. However, a subsequent study involving 1351 patients eligible for the ARUBA study, with an average follow-up of 6.5 years, showed a similar incidence of stroke in the first 5 years between the group undergoing medical treatment and the group that opted for Gamma Knife radiosurgery. After 5 years, the cumulative incidence of stroke was higher in the medical treatment group, indicating that radiosurgery may provide long-term benefits. In addition, this study showed that for sizable AVMs (greater than 5 cm^3), extended follow-up of more than 11 years may be necessary to demonstrate lower morbidity and mortality compared to the observation strategy. Radiosurgery has also proven effective in reducing adverse neurological complications in treated patients, with an occurrence rate of 13% over an average follow-up of 7.2 years. Recent studies have indicated that the rate of complete eradication of AVMs has varied between 70% and 80% in patients eligible for ARUBA. This suggests that in longer follow-up periods beyond the latency period, radiosurgery can result in superior outcomes to natural history in the treatment of unruptured AVMs [10]. There is also literature on the use of focused stereotactic radiosurgery (SRS) to eliminate high-risk areas in AVMs, followed by microsurgical resection, as a potentially effective treatment approach. 59 patients with arteriovenous malformations (AVMs) were involved, with a mean age of 30.1 years. Bleeding was the most common symptom, present in 46% of cases, followed by seizures, headaches and neurological deficits. Around 61% of patients had AVMs with deep venous drainage, increasing the risk of bleeding. The majority of AVMs were grade III or IV, considered high-grade. Radiation treatment resulted in an improvement in AVM grade in 73% of patients, although 22% experienced post-radiation bleeding. The combined protocols of radiotherapy and resection for AVMs, suggesting the efficacy of the combination of SRS and resection [12]. As for the treatment of AVMs classified as Spetzler-Martin Grade I and II, an extensive series of 217 patients revealed a complete obliteration rate of 90% at 5 years and 93% at 10 years. Although the average time to complete obliteration is approximately 30 months, only 58% of patients with lesions treated with SRS achieved healing within 3 years. Notably, there was a 6% bleeding rate during the latency period, resulting in death for 6 patients. According to previous reports in the literature, obliteration is more likely in smaller lesions and with higher doses of radiation. For Grade I and II AVMs located in critical brain areas, SRS represents a reasonable alternative to the surgical approach, especially in older patients or those with delicate health conditions. The authors did not present a separate data set to highlight their experience in treating Grade III AVMs, as these lesions are notoriously difficult to predict in terms of morbidity after resection due to their heterogeneous nature. Total obliteration rates for this type of AVM vary between 70% and 72% over a period of 5 years after the application of SRS, which makes SRS a reasonable choice as primary treatment for lesions that were previously asymptomatic. However, it is important to note that the treatment of lesions located in the brainstem resulted in a relatively high rate of radionuclear adverse events, translating into permanent neurological morbidity in 10% of cases. However, this rate decreased to 2.7% after excluding patients with recurrent bleeding episodes over a period of less than 6 months. The use of SRS in stages in a group of 47 patients with large AVMs is documented.During the study, 17% of these patients experienced AVM-related bleeding, and 5 patients did not survive these occurrences.The overall cumulative rate of AVM bleeding during a 3-year follow-up was 28.2%, with an annual bleeding rate of 6.5% during the latency period.In addition, radiation-related adverse events were recorded in 6 patients. During the study, 13 patients suffered AVM-related hemorrhages, and 8 patients died due to these complications.Following Kaplan-Meier analysis, excluding a second hemorrhage in a patient who experienced two occurrences, the overall rate of AVM bleeding after 3 years of SRS was 28.2%, and the annual rate of hemorrhage during the latency period was 5.3%.Adverse effects of radiation were reported in 6 patients. According to the criteria adopted in this study and in previous research, the maximum obliteration rate achieved was 55% after 10 years of follow-up. However, it is important to note that these patients underwent at least 3 sessions of SRS. In contrast, in patients treated with the original protocol of 2 SRS sessions in stages, obliteration rates were 36% after 10 years and only 7% after 3 years. These results indicate that substantial additional efforts are needed not only to identify which patients should be treated more intensively, but also to determine the most appropriate treatment to be employed 13.In a study of 170 patients who underwent a second stereotactic radiosurgery (SRS) procedure to treat AVMs, AVM eradication rates at 3, 5 and 10 years were 37.6%, 57.3% and 80.9%, respectively, with marginal doses $\geq$ 19 Gy associated with higher eradication rates ($p = 0.001$).In the second SRS procedure, 8.2% of patients experienced bleeding, including one fatal case.The risk factors for intracranial hemorrhage were age <18 years ($p = 0.03$) and residual AVM diameter > 20 mm ($p = 0.004$).Lower eradication rates were associated with patients with residual AVM diameter > 20 mm ($p = 0.04$) and those aged < 18 years ($p = 0.04$).Radiation-induced changes (RICs) after the second SRS procedure occurred in 25.9%, 8.8% and 5.3% of patients, including asymptomatic, symptomatic and permanent RICs, respectively.These GERs were related to the GERs after the first SRS procedure ($p = 0.006$). Lower eradication rates were associated with patients with a residual AVM diameter > 20 mm ($p = 0.04$) and those aged < 18 years ($p = 0.04$). Radiation-induced changes (RICs) after the second SRS procedure occurred in 25.9%, 8.8% and 5.3% of patients, including asymptomatic, symptomatic and permanent RICs, respectively. These GERs were related to the GERs after the first SRS procedure ($p = 0.006$). In addition, there was one case of radiation-induced meningioma diagnosed 12 years after SRS [13, 14]. In an effort to clarify the causes of radiosurgery failures, we examined a total of 36 patients who underwent repeat radiosurgery after an initial failure to eradicate their AVMs and compared them with 72 patients who were cured during the same period.The retreatment group had a statistically significantly higher Spetzler-Martin grade, larger AVM size and lower treatment dose compared to the group of patients who were cured.Statistical analysis also showed that patients treated with a peripheral dose of less than 15 Gy had a higher failure rate.In addition, patients with AVM volumes greater than 10 cm^3 had a higher failure rate 15. The causes of failed radiosurgery were identified as follows: in 5 patients (11%), the complete AVM was not visualized due to incomplete angiography (2 vessels instead of 4 vessels) or inadequate angiographic technique (failure to perform superselective angiography). In 3 patients (7%), the AVM recanalized after previous embolization. In 4 patients (9%), the AVM nidus expanded again after resorption of a previous hematoma that had compressed the vessels within the nidus. In 21 patients (46%), the three-dimensional shape of the AVM nidus was not assessed due to reliance on biplane angiography alone.In the remaining patients, it was not possible to determine a definitive cause for the failure.The researchers considered that the AVMs in these patients had some kind of radiobiological resistance, i.e. they were not eradicated despite proper planning and the delivery of adequate doses.In a previous analysis by the same group, the dose to the periphery (Dmin) of the target was identified as the most significant predictor of success. In this analysis, neither volume nor maximum dose were predictive. Problems in defining the complete AVM nidus have been cited as significant limitations to successful AVM eradication [15,16]. By analyzing a subset of 945 patients out of the 1319 patients with AVMs treated with the gamma knife from 1970 to 1990, they again identified the peripheral dose as the most significant predictive factor. The higher the minimum dose, the higher the eradication rate, up to 25 Gy. The eradication rate in the 268 cases that received this minimum dose (25 Gy) was 81%. A high average dose and a low AVM volume also predicted success. A high average dose reduced the latency time for AVM eradication.They proposed that the product of the cube root of AVM volume and peripheral dose (the K-index) would serve as a good combined predictor of success and found that a K-index of 27 was optimal.Eradication rates increased with increasing K values, up to 27, beyond which there was no further improvement observed [17,18,19].The studies highlight the importance of factors such as AVM size, radiation doses and peripheral doses in treatment success. A multidisciplinary approach, considering the risks and benefits, is crucial for clinical decision-making in the treatment of AVMs with radiosurgery [20,21].

DISCUSSION

The treatment of cerebral arteriovenous malformations (AVMs) presents significant challenges, and therapeutic options vary according to the severity of the AVM and the patient's condition. When analyzing the data, the researchers identified four key variables that played a crucial role in the success of curative embolization of AVMs without the occurrence of significant clinical complications. These variables included the number of arterial pedicles and draining veins, the size of the AVM nidus and vascular eloquence. In addition, certain risk factors, such as advanced age, male gender, deep location of the AVM, large size and specific genetic factors, are associated with a higher risk of bleeding after treatment. Therefore, these aspects should be carefully considered when planning and performing the treatment of cerebral AVMs [17]. Delving into the literature on microsurgical intervention and SRS for AVMs revealed that microsurgery remains the gold standard option for treating AVMs, with SRS being reserved for hard-to-reach sites, eloquent areas and for patients with significant medical risks or who do not wish to undergo surgery 8 . In addition to promising results, microsurgery is considered more economical, while radiosurgery is less accessible and has a high incidence of complications. One that stands out during surgery is the increase in perfusion pressure, which is a potential complication involving an abnormal increase in blood flow, increasing the risk of possible brain damage to the patient. Therefore, pre-treatment with propranolol, partial occlusion of the cervical carotid artery and embolization are recommended as strategies to minimize these risks. Pre-treatment with propranolol for 2 weeks improved cerebrovascular reactivity in patients with impaired cerebral autoregulation. On the other hand, intraoperative embolization and the use of a coloured sulphatrylate compound allowed for minimal blood loss during surgery, as well as good functional recovery.

Therefore, before surgery, a thorough investigation of cerebral blood flow should be carried out to correct any impairment of cerebrovascular reserve capacity. During planning, neuronavigation plays a vital role, ensuring a precise craniotomy and effective intraoperative guidance. During surgery, the strategy is even more precise. Intraoperative embolization aims to eliminate the AVM nidus, minimizing damage to nearby healthy vascular and brain structures. In this world of cerebral microsurgery, every step is calculated to ensure the best possible outcome [18]. SRS is a less invasive strategy that uses targeted radiation to induce vascular damage and gradually occlude the AVM. This process involves degeneration of the vascular endothelium and proliferation of smooth muscle, resulting in compression or occlusion of the vascular lumen. Radiation also reduces the levels of circulating pro-angiogenic factors by up to three months. However, the therapeutic effects of radiation can take several years to manifest, during which time the risk of bleeding persists. In addition, radiation can affect adjacent brain tissue, resulting in non-specific radiation-related changes or, in rare cases, triggering malignancies or other vascular malformations that can cause neurological symptoms.

Embolization is an alternative, and in many cases complementary, method that is often used as a pre-surgical adjuvant to reduce microsurgical risk, although its efficacy as a primary or adjuvant treatment is controversial [19]. Regarding SRS for AVMs located in regions that present a surgical challenge, it has been noted that AVMs in these regions require multimodal therapy. Resection and embolization is a reasonable treatment option in younger patients with lesions located superficially in the brainstem or thalamus. The neurological sequelae of AVM hemorrhages in these eloquent locations result in a poor natural history for untreated lesions, and the treatment of asymptomatic lesions is less controversial than the treatment of AVMs in other locations. Data indicate that total obliteration rates are reported to be 70% to 72% at 6 years after SRS, making primary treatment with SRS in previously asymptomatic lesions a reasonable recommendation. However, the rate of radionuclear adverse events following treatment of brainstem lesions has been as high as 10% in terms of permanent neurological morbidity. Furthermore, in AVMs in the basal ganglion and thalamus, the annual rate of hemorrhage after SRS was close to 4%, which is almost equivalent to natural history estimates of annual bleeding rates in untreated lesions. This rate was reduced to 2.7% only after excluding patients with episodes of early bleeding recurrence (less than 6 months). For these reasons, multimodal treatment with resection of AVMs in the brainstem or thalamus/basal ganglia in experienced hands remains a prime consideration for intervention, especially in patients with symptomatic lesions. The authors explore the approach in the treatment of large-volume AVMs, including Grade IV and V, as well as some Grade III. These lesions are known to have high surgical risk and complication rates, and are generally reserved for cases with progressive bleeding or high-risk features such as associated aneurysms. Grade III AVMs adjacent to high-functioning cerebral cortex also carry a similar risk of complications and are treated conservatively. In situations where surgery is considered, a multimodal approach with embolization performed in stages is often necessary. Partial resection can be followed by SRS for the remaining parts of the AVM, as long as their size is adequate. However, it is important to note that, despite ongoing advances in radiosurgery and endovascular therapy, microsurgical techniques are still constantly evolving and continue to play an essential role in the primary treatment of these lesions [13]. The advantages of radiosurgery, compared to microsurgical and endovascular treatments, are that it is non-invasive, has minimal risk of acute complications and is performed as an outpatient procedure that requires no recovery time for the patient. The main disadvantage of radiosurgery is that healing is not immediate. Although thrombosis of the lesion is achieved in most cases, it usually doesn't occur until 2 or 3 years after treatment. During the interval between radiosurgical treatment and AVM thrombosis, the risk of bleeding persists. Another possible disadvantage of radiosurgery is the potential long-term adverse effects of radiation. In addition, radiosurgery has been shown to be less effective for lesions larger than 10 cm^3 in volume. For these reasons, choosing the ideal treatment for an AVM is a complex decision that requires input from specialists in endovascular treatment, open surgery and radiosurgery. Factors such as peripheral dose, mean dose and AVM volume affect the success of radiosurgery, and a high mean dose reduces the latency for AVM obliteration. The risk of bleeding decreases with AVM thrombosis, and permanent side effects from radiation are rare. Radiosurgery failure can be attributed to several causes, including inadequate radiation doses due to inaccurate targeting or sub-optimal administration, complexity and size of AVMs that may require multiple treatment sessions, the natural history of AVMs, smoking, hypertension and age that can impact success, and the rare but existing risk of radiation-induced permanent side effects, which can limit the use of radiosurgery in some cases. For large AVMs not suitable for radiosurgery, pre-surgical or pre-radiosurgical embolization can be considered, reducing the size of the lesion and treating associated aneurysms. Combined treatment of embolization followed by radiosurgery has shown promising results, but the role of embolization in radiosurgery is less clear, as it can create challenges in identifying targets and pose risks of neurological complications [20]. Conventional radiation therapy does not cause consistent structural changes in AVMs, but it does inflame blood vessels and capillaries, leading to swelling and necrosis. This can result in changes to the vessel wall, narrowing of the lumen and thickening of the wall. However, this approach is less effective than high-dose radiosurgery. The success of radiation depends on the dose rate and the ability of the tissue to recover. High-dose single-fraction radiation techniques perform better than conventional low-dose radiation. Although some AVMs can regress spontaneously, the efficacy of conventional radiation therapy in cerebral AVMs is limited, and understanding of the mechanisms underlying this spontaneous regression is still limited [21]. Radiosurgery is also an alternative to traditional surgery for patients with grade I or II AVMs who do not want surgery or have medical contraindications. However, its effectiveness is controversial due to the latency period between the procedure and total obliteration, highlighting the importance of assessing eradication in short-term follow-ups. After surgery to treat brain AVMs, patients require critical post-operative care for better recovery and reduction of unwanted post-operative responses, including blood pressure control and fluid balance with arterial and urinary catheters. Antibiotics, steroids and anticonvulsants are administered to prevent infections, reduce inflammation and control epileptic seizures when necessary [5]. The approach combining focused stereotactic radiosurgery (SRS) for high-risk areas in AVMs and microsurgical resection is advocated. This can reduce the degree of risk of AVMs, making surgery safer and more feasible. However, more comprehensive studies are needed to fully evaluate the safety and efficacy of this approach [12].

CONCLUSION

The treatment of AVMs is a challenging and complex field of medicine, with several therapeutic options available. The analysis of the studies led to the conclusion that the decision on the most appropriate approach to treating an AVM should be carefully considered and personalized based on clinical and technical factors and the patient's preferences. Furthermore, microsurgery remains the gold standard in the treatment of AVMs, demonstrating efficacy especially in symptomatic cases that are difficult to access. SRS offers a less invasive alternative, but with a latency period until complete obliteration and risks associated with radiation. Embolization plays an important role as a complementary treatment, often as a pre-surgical adjuvant. Combined approaches, such as embolization followed by radiosurgery, have shown promising results. However, the choice of the ideal treatment must be made by a multidisciplinary team of specialists and take into account the severity of the AVM, the location and the patient's individual conditions. While radiosurgery offers advantages in terms of invasiveness, it presents a persistent risk of hemorrhage during the latency period until complete obliteration, as well as potential long-term adverse effects of radiation. After treatment, post-operative care is essential for the patient's recovery and favorable prognosis, involving blood pressure control, fluid balance and the administration of medication to prevent infections and control epileptic seizures, when necessary. Ultimately, research and clinical practice continue to evolve in the field of AVMs, with the ideal approach varying for each patient. Therefore, more comprehensive studies are needed to fully evaluate the therapeutic options and guarantee the safety and efficacy of the treatment. Collaboration between specialists from different fields is essential to provide patients with the best treatment options and maximize their chances of recovery.

REFERENCES

1. Ren Q, Wang S, Peng W, Wang R, Zhang L, Zhu W, et al. Microsurgery for intracranial arteriovenous malformation: Long-term outcomes in 445 patients. PLOS ONE. 2017 Mar 21;12(3):e0174325. Disponível em: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5360342/
2. Rutledge C, Kan P, Siddiqui F, Chen YF, Yassari R, Auluck T. Brain arteriovenous malformations. In: Krishnan K, editor. Brain AVMs: Present and Future. Elsevier; 2019. Capítulo 10. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/B9780444640345000201?via%3Dihub
3. Ferrara AR. Brain arteriovenous malformations. Radiol Technol. 2011;82(6):543MR-56MR. Disponível em: https://pubmed.ncbi.nlm.nih.gov/21771938/
4. Shaligram SS, Rajiv SD, Sebastian P, Sai-Kiran S, Biswas S, Suresh S, et al. Risk factors for hemorrhage of brain arteriovenous malformation. CNS Neurosci Ther. 2019 Jul 29;25(10):1085–95. Disponível em: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6776739/
5. Starke RM, Komotar RJ, Hwang BY, Fischer LE, Garrett MC, Otten ML, et al. Treatment guidelines for cerebral arteriovenous malformation microsurgery. Br J Neurosurg. 2009 Aug 1;23(4):376–86. Disponível em: https://pubmed.ncbi.nlm.nih.gov/19637008/
6. Lopes DK, Satti SR, Fraser JF, Mocco J, Siddiqui AH, Fitzsimmons BFM, et al. Arteriovenous malformation embocure score: AVMES. J Neurointerv Surg. 2015 Jun 15;8(7):685–91. Disponível em: https://jnis.bmj.com/content/8/7/685.long
7. Fanous AA, Xu DS, Garcia RM, Catapano JS, Shah H, Attenello F, et al. Intracranial stereotactic radiosurgery. J Neurosurg Sci. 2018 Dec;63(1). Disponível em: https://pubmed.ncbi.nlm.nih.gov/28945054/
8. Sattari SA, Moosa S, Mehta A, Rao SD, Sinclair AG, Barrow DL, et al. Microsurgery Versus Stereotactic Radiosurgery for Treatment of Patients With Brain Arteriovenous Malformation: A Systematic Review and Meta-Analysis. Neurosurgery. 2023 Mar 31. Disponível em: https://pubmed.ncbi.nlm.nih.gov/36999929/
9. Wong J, Slomovic AM, Ibrahim GM, Kulkarni AV, Drake JM. Microsurgery for ARUBA Trial (A Randomized Trial of Unruptured Brain Arteriovenous Malformation)–Eligible Unruptured Brain Arteriovenous Malformations. Stroke. 2017 Jan;48(1):136–44. Disponível em: https://pubmed.ncbi.nlm.nih.gov/27856955/
10. Feghali J, Huang J. Updates in arteriovenous malformation management: the post-ARUBA era. Stroke Vasc Neurol. 2019 Sep 21;svn-2019-000248. Disponível em: https://pubmed.ncbi.nlm.nih.gov/32411406/
11. Sattari SA, Moosa S, Mehta A, Rao SD, Sinclair AG, Barrow DL, et al. Microsurgery versus Microsurgery With Preoperative Embolization for Brain Arteriovenous Malformation Treatment: A Systematic Review and Meta-analysis. Neurosurgery. 2022 Oct 26;92(1):27–41. Disponível em: https://pubmed.ncbi.nlm.nih.gov/36519858/
12. Wild E, Barry J, Sun H. Targeted Stereotactic Radiosurgery for Arteriovenous Malformation Downgrading Followed by Microsurgical Resection: A Case Report and Review of the Literature. World Neurosurg. 2019 Nov;131:82–6. Disponível em: https://pubmed.ncbi.nlm.nih.gov/31369878/
13. Bambakidis NC, Selman WR. Stereotactic radiosurgery for arteriovenous malformations. J Neurosurg. 2012 Jan 1;116(1):3–6; discussion 9–10. Disponível em: https://pubmed.ncbi.nlm.nih.gov/22077455/
14. Pikis S, Yeung R, Silva M, Sheehan JP. Repeat stereotactic radiosurgery for cerebral arteriovenous malformations. Neurosurg Focus. 2022 Jul;53(1):E11. Disponível em: https://pubmed.ncbi.nlm.nih.gov/35901714/
15. Ellis TL, Friedman WA, Bova FJ, Kubilis PS, Buatti JM, Mendenhall WM. Analysis of treatment failure after radiosurgery for arteriovenous malformations. J Neurosurg. 1998 Jul 1;89(1):104–10. Disponível em: https://pubmed.ncbi.nlm.nih.gov/9647180/
16. Karlsson B, Lax I, Söderman M. Factors influencing the risk for complications following Gamma Knife radiosurgery of cerebral arteriovenous malformations. Radiother Oncol. 1997 Jun;43(3):275–80. Disponível em: https://pubmed.ncbi.nlm.nih.gov/9215787/
17. Lopes DK, Satti SR, Fraser JF, Mocco J, Siddiqui AH, Fitzsimmons BFM, et al. Arteriovenous malformation embocure score: AVMES. J Neurointerv Surg. 2015 Jun 15;8(7):685–91. Disponível em: https://pubmed.ncbi.nlm.nih.gov/26078359/
18. Krivoshapkin AL, Melidy EG. Microsurgery for cerebral arteriovenous malformation management: a Siberian experience. Neurosurg Rev. 2005 Apr 1;28(2):124–30. Disponível em: https://pubmed.ncbi.nlm.nih.gov/15690217/
19. Shaligram SS, Rajiv SD, Sebastian P, Sai-Kiran S, Biswas S, Suresh S, et al. Risk factors for hemorrhage of brain arteriovenous malformation. CNS Neurosci Ther. 2019 Jul 29;25(10):1085–95. Disponível em: https://pubmed.ncbi.nlm.nih.gov/31359618/
20. Friedman WA. Stereotactic radiosurgery of intracranial arteriovenous malformations. Neurosurg Clin N Am. 2013 Oct 1;24(4):561–74. Disponível em: https://pubmed.ncbi.nlm.nih.gov/24093574/
21. Elisevich K, Assaad S, Kaufman HH. Neuropathology of intracranial arteriovenous malformations following conventional radiation therapy. Stereotact Funct Neurosurg. 1994;63(1-4):250–4. Disponível em: https://pubmed.ncbi.nlm.nih.gov/7624642/

Observação: os/(as) autores/(as) declaram não existir conflitos de interesses de qualquer natureza.