Review Article

Feasibility, Safety, and Outcomes of Stereotactic Radiosurgery in Intracranial Dural Arteriovenous Fistula: A Systematic Review

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ABSTRACT

The main objective of this study was to evaluate the feasibility, safety, and clinical outcomes of stereotactic radiosurgery (SRS) in treating intracranial dural arteriovenous fistulas (dAVFs). A thorough search across four databases identified 398 relevant publications. After removing duplicates using Rayyan QCRI and screening for relevance, the search yielded 232 publications, of which 30 full-text articles were reviewed, and 5 met the eligibility criteria for evidence synthesis. So, we included 5 studies with a total of 289 patients diagnosed with dAVFs, a total of 293 fistulas that underwent repair, and 168 (58.1%) were males. The median follow-up duration ranged from 17 months to 62 months. The obliteration rate ranged from 48% to 70.6%, with a total of 170 (58%). Nearly 71% of patients with pre-treatment symptoms experienced post-SRS symptom relief, particularly in cavernous sinus dAVFs. Radiation-induced changes (RIC) occurred in 14.5% of cases, with males and those with multiple arterial feeders being at higher risk. Post-SRS hemorrhage was rare, though prior hemorrhage increased susceptibility. Higher radiation doses were associated with improved obliteration rates, while new arterial feeders in adjacent sinuses led to retreatment in select cases. SRS is a safe and effective treatment for intracranial dAVFs, demonstrating high obliteration rates and symptom relief. However, long-term follow-up is essential due to the potential for new arterial feeders and delayed obliteration. Future research should focus on standardizing treatment protocols, refining patient selection, and developing predictive models to further optimize SRS outcomes for dAVFs.

Keyword: Stereotactic; Radiosurgery; Radiotherapy; Intracranial, Cerebral; Arteriovenous fistula; Systematic review.

Introduction

In the therapy of dural arteriovenous fistulas (dAVF). Stereotactic radiosurgery (SRS) is a crucial intervention. SRS is frequently saved for complicated lesions that cannot be effectively treated with endovascular or surgical techniques, as well as for patients with significant surgical risks, because of the instant obliteration that may be accomplished with these procedures [1].

Nevertheless, the literature reports that SRS offers good dAVF obliteration rates ranging from 41% to 90% [1]. There are still large differences across facilities and the best treatment approaches depending on patient and lesion characteristics are still unclear. There is potential for improvement in our capacity to forecast SRS outcomes in dAVF patients.

Access this article online	
Quick Response Code:	Website: www.smh-j.com
	DOI: 10.54293/smhj.v5i2.153

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Received: 10 Apr 2025 **Accepted:** 30 Apr 2025

Please cite this article as: Mohamed AMM, Alrahmani MAM, Ahmad Mohammed Jalal Alsayyad, Baqer Abdulwahab Mohammed Almohammedali, Saleh Hamed Alharbi, Afnan Hassan Mohammed Alsubi, Sultanah Nasser Omeir Alshahranie, Afit Dhaif Allah Alsharari, Mohammed Mustafa Alsumayen, Ebtesam Hamoud H. Albalawi. Feasibility, Safety, and Outcomes of Stereotactic Radiosurgery in Intracranial Dural Arteriovenous Fistula: A Systematic Review. SMHJ [Internet]. 2025;5(2):155-163. Available from: https://www.smh-j.com/smhj/article/view/153

SMHJ
Saudi Medical Horizons Journal

While it is uncertain which patients would be most suited for SRS. Because SRS therapy involves unique adverse effects such radiation-induced changes (RIC) and bleeding during the latency period, it might be difficult to develop clinically meaningful prediction models that accurately capture these occurrences, despite their great clinical significance [2]. SRS results in dAVFs are influenced by anatomical location in addition to angiographic and clinical features. Previous angiographic-based grading schemes have emphasized the risk stratification of untreated dAVF hemorrhage and offered therapeutic recommendations [3, 4]. Abnormal connections between dural arteries and venous sinuses or cortical veins are known as intracranial dAVFs, and they carry serious concerns, including the potential for bleeding and neurological impairments. While endovascular embolization and microsurgical resection are the primary treatment modalities. SRS has emerged as a non-invasive alternative, particularly for complex or high-risk cases. SRS offers the potential for gradual obliteration of dAVFs while minimizing procedural morbidity. However, its safety, efficacy, and long-term outcomes remain variable across studies [6]. Although, given the limited consensus on optimal patient selection and the variability in treatment response, a systematic review is warranted to assess the feasibility, safety, and effectiveness of SRS in managing intracranial dAVFs. The purpose of this systematic review is to assess the clinical results, safety, and viability of using SRS to treat intracranial dAVFs. Specifically, it seeks to (1) assess the overall obliteration rates and time to obliteration following SRS, (2) report the incidence of adverse events, including RIC and hemorrhagic complications, and (3) identify factors influencing treatment success.

Methods

To maintain openness and scientific rigor, this systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. This review's main goal was to assess the clinical results, safety, and viability of using SRS to treat intracranial dAVFs. To find pertinent English-language papers, a thorough search technique was used across many electronic databases, including PubMed, Web of Science, SCOPUS, and ScienceDirect. Keywords such as "stereotactic radiosurgery," "dural arteriovenous fistula," "intracranial dAVF," "Gamma Knife radiosurgery," "CyberKnife radiosurgery," "LINAC radiosurgery," "endovascular embolization," "microsurgical resection," "dAVF obliteration," "radiation-induced changes," "intracranial hemorrhage," "neurological outcomes," "angiographic outcomes," and "arteriovenous shunts" were used to refine the search. After screening the search results, two independent reviewers chose studies that fit the qualifying requirements, retrieved the data, and evaluated the included studies' quality.

Eligibility Criteria: Inclusion criteria:

- SRS for intracranial dAVFs has been the subject of case series, observational studies, retrospective or prospective cohort studies, clinical research, and systematic reviews/meta-analyses.
- Studies including patients diagnosed with intracranial dAVFs treated with Gamma Knife, CyberKnife, or LINAC-based SRS.
- Studies assessing the efficacy, safety, and clinical outcomes of SRS as a treatment modality for dAVFs.
- Studies reporting obliteration rates, RIC, and post-SRS hemorrhage rates.
- Articles published in English.
- studies that have been released in the recent five years to guarantee their applicability to modern SRS methods.

Exclusion criteria:

- Case reports with fewer than 5 patients, expert opinions, editorials, letters to the editor, and conference abstracts lacking full data.
- Studies involving extracranial dAVFs or those focusing solely on arteriovenous malformations (AVMs) instead of dAVFs.
- Studies where SRS was not a primary treatment modality, or where results are confounded by other major interventions such as surgical resection or embolization without separate SRS outcomes.
- Studies lacking data on clinical or radiologic outcomes or failing to provide measurable indicators of treatment success or complications.
- Studies published in languages other than English without available translations.

Data Extraction: Consistency and dependability were ensured by managing and screening the search results using the Rayyan (QCRI) tool. The inclusion and exclusion criteria were used to assess abstracts and titles for relevancy. Two reviewers separately examined full-text papers of possibly qualifying research. Discussion and agreement were used to settle any differences in the choice of studies. Key information was gathered using a standardized data

extraction form, which included: Study title, authors, and publication year.

- Examine the layout and setting.
- Demographics of participants (e.g., age and sex).
- Follow-up duration (in months).
- Any reported adverse effects.
- Main outcomes.

Data Synthesis Strategy: The extracted data were synthesized qualitatively and presented in summary tables to facilitate comparison across studies. Key findings related to the safety and clinical outcomes of SRS in treating intracranial dAVFs were summarized. Subgroup analyses were performed based on factors such as cabergoline dosage, patient characteristics, and study design.

Quality Review: Since bias resulting from missing factors is frequent in research in this field, we used the ROBINS-I approach to assess the likelihood of bias since it enables a thorough examination of confounding. The ROBINS-I tool may be used for cohort designs where individuals exposed to different staffing levels are tracked over time and is designed to assess non-randomized studies. Each paper's risk of bias was evaluated independently by two reviewers, and any differences were settled by group discussion [5].

Results

The targeted search approach produced 398 papers (Figure 1). Following the elimination of duplicates (n = 166), 232 articles were assessed using the abstract and title. After 199 of these were found to be ineligible, just 30 full-text publications remained for further evaluation. 5 individuals met the criteria for eligibility with synthesized evidence for analysis. Sociodemographic and clinical outcomes: A total of 289 individuals with dAVF diagnoses, 293 fistulas that were repaired, and 168 (58.1%) male patients were included in 5 trials. Every study that was included was a retrospective cohort [7-11]. Two studies were implemented in Japan [7, 10], one in the USA [8], one was multi-centered [9], and one in South Korea [11] as illustrated in table (1). In (Table 1), the median follow-up duration, in the included 5 studies, ranged from 17 months [11] to 62 months [7]. The obliteration rate ranged from 48% [9] to 70.6% [10], with a total of 170 (58%). Symptomatic improvement was frequently observed post-SRS, with some studies reporting up to 71% of patients experiencing relief from dAVF-related symptoms [7,8]. However, the degree of symptomatic improvement varied depending on lesion location, with cavernous sinus dAVFs showing symptom relief irrespective of obliteration status, while non-cavernous sinus dAVFs required obliteration for symptom resolution [9]. Additionally, SRS was particularly effective in treating transverse sigmoid sinus dAVFs, demonstrating minimal complications, good obliteration rates, and improved symptoms [10]. Some cases required retreatment due to angiographic worsening, mainly due to the recruitment of arterial feeders in adjacent sinuses not initially targeted by SRS [11]. Adverse events following SRS were generally minimal, but some studies reported significant considerations. Hemorrhagic events were observed in 16% of patients before undergoing SRS, though post-SRS hemorrhages were rare [7]. One case involved post-SRS hemorrhage in a patient with a Borden type II dAVF who had previously experienced bleeding [10]. The most commonly reported SRS-related complication was RIC, affecting 14.5% of patients, with males and those with multiple arterial feeders being at higher risk [9]. Additionally, a lower maximum radiation dose was associated with an increased likelihood of complications. In cases where retreatment was necessary, new arterial feeders developed in previously untreated sinus regions, suggesting that lesion progression outside the targeted area may occur in some patients post-SRS [11]. Despite these considerations, overall SRS appears to have a favorable safety profile, with most complications being manageable and not leading to severe neurological deficits [7- 11]. (Table 2) demonstrates that the majority of research reveal low to moderate degrees of bias in several categories.

Discussion

The findings from this systematic review demonstrate that SRS is a viable treatment option for intracranial dAVFs, particularly for cases where endovascular embolization or microsurgical resection is not feasible. Obliteration rates ranged from 57% to 70.6%, with cumulative obliteration increasing over time, suggesting that SRS is an effective long-term strategy for selected patients. Additionally, symptomatic improvement was frequently observed, especially in cavernous sinus dAVFs, where symptoms resolved regardless of obliteration status. However, non-cavernous sinus dAVFs demonstrated a stronger correlation between obliteration and symptom relief, emphasizing the importance of lesion location in treatment planning. Similarly, Garg *et al*. [12] reported that SRS is a dAVF treatment that works well and has little side effects. But bleeding could continue until the fistula is completely gone. High-grade fistulas can also

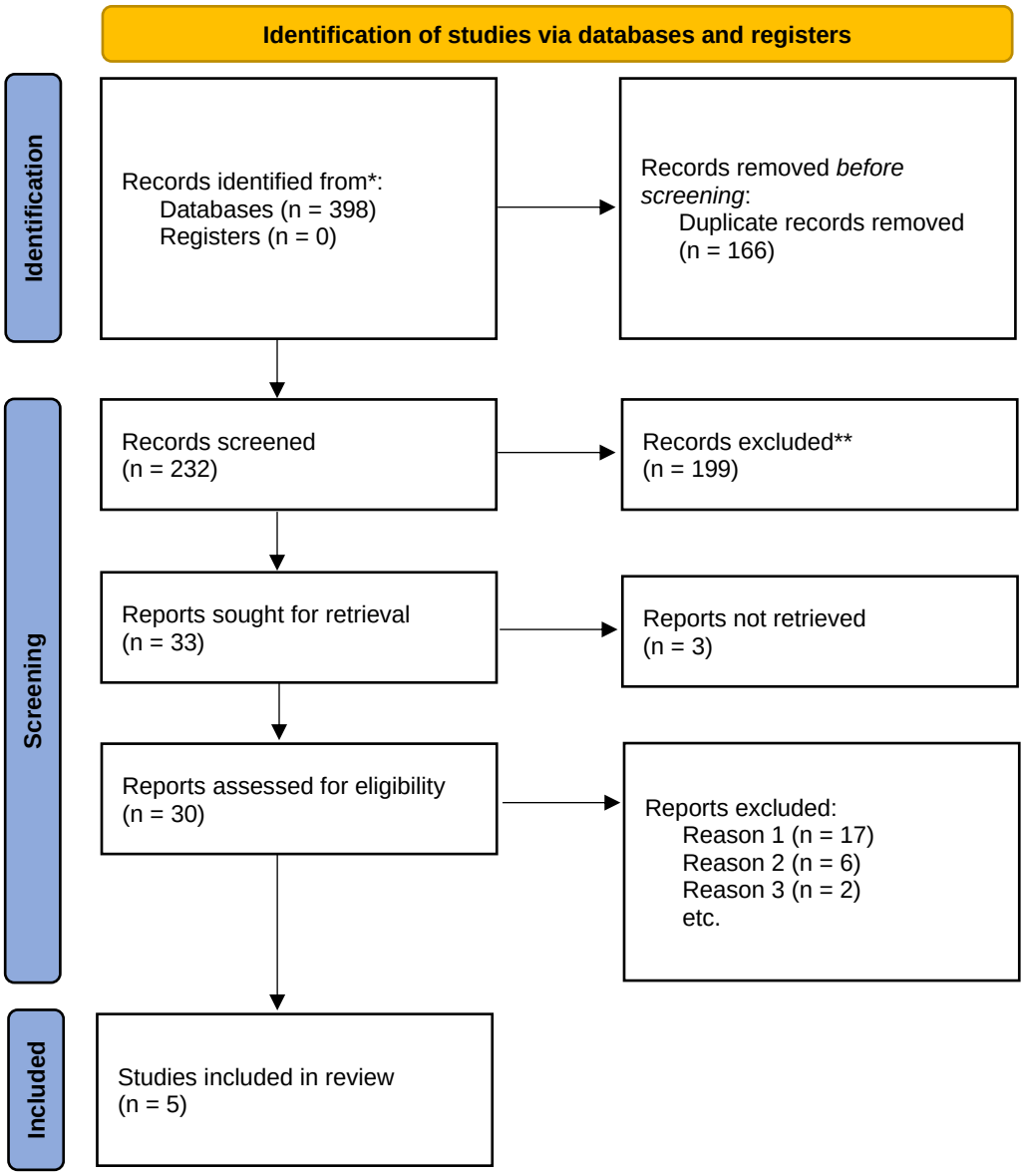

Figure 1: PRISMA flowchart [6].

Table 1: Outcome measures of the included studies.

Study ID	Study design	Country	Socio-demographic	Follow-up (months)	Obliteration rate (%)	Adverse events	Main outcomes
Shinya et al., 2023 [7]	Retrospect-ive cohort	Japan	Cases: 51 Fistulas: 51 Median age: 62 Males: 33 (65%)	62	34 (67%)	Hemorrhagic events occurred in 8 patients (16%) before undergoing SRS.	Post-SRS, 24 of the 34 patients (71%) who had DAVF-related symptoms at the time of treatment experienced symptomatic improvement.
Maglinger et al., 2021 [8]	Retrospect-ive cohort	USA	Cases: 10 Fistulas: 14 Median age: 63 Males: 5 (50%)	19.5	8 (57%)	No specific adverse events were explicitly mentioned.	Nearly all dAVF demonstrated a reduction in arterial feeders following treatment. Notably, factors such as arterial feeders, drainage site, sex, Borden type, lesion volume, and treatment volume did not predict obliteration outcomes.
Hung et al., 2020 [9]	Retrospect-ive cohort	Multi-centered	Cases: 131 Fistulas: 131 Median age: 56 Males: 74 (56.5%)	>6	63 (48%)	The most common adverse event was RIC 19 (14.5%). Males were more likely to experience complications, along with those who had multiple arterial feeding fistulas and who received a lower maximum radiation dose.	A higher maximum dose was a predictor of favorable clinical outcomes in cavernous sinus dAVFs (P = .014). For non-cavernous sinus dAVFs, symptomatic improvement was closely linked to obliteration (P = .005), whereas in cavernous sinus dAVFs, symptoms improved regardless of whether obliteration was confirmed.
Umekawa et al., 2024 [10]	Retrospect-ive cohort	Japan	Cases: 34 Fistulas: 34 Median age: 64 Males: 22 (64.7%)	31	24 (70.6%)	One patient (2.9%) with Borden type II dAVF who had previously suffered bleeding had post-SRS hemorrhage.	For transverse sigmoid sinus dAVF, SRS is safe and effective, and it produces minimal complication rates, good shunt obliteration, and improved symptoms.
Kim et al., 2023 [11]	Retrospect-ive cohort	**South Korea**	Cases: 63 Fistulas: 63 Median age: 57 Males: 34 (54%)	17	41 (63.1%)	Six patients required retreatment due to angiographic worsening, with five of these cases showing newly recruited arterial feeders in an adjacent sinus that was not initially targeted by SRS.	Although SRS is safe for non-cavernous sinus dAVFs, its effectiveness varies greatly depending on the site. Greater radioresistance may be indicated by high-flow shunts.

Dural arteriovenous fistulas (dAVF)

Table 2: Risk of bias assessment using ROBINS-I.

Study ID	Bias due to confound-ing	Bias in the selection of participants into	Bias in the classifica-tion of interventions	Bias due to deviations from the intende d interval	Bias due to missing data	Bias in the meas-urement of outcomes	Bias in the selecti on of reported result	Overall bias
Shinya et al., 2023 [7]	Low	Low	Mod	Low	Low	Low	Mod	Low
Maglinger et al., 2021 [8]	Mod	Low	Low	Low	Low	Mod	Low	Low
Hung et al., 2020 [9]	Mod	Low	Mod	Low	Mod	Mod	Low	Moderate
Umekawa et al., 2024 [10]	Mod	Low	Mod	Low	Low	Mod	Low	Moderate
Kim et al., 2023 [11]	Mod	Mod	Low	Low	Low	Mod	Low	Moderate

benefit with SRS use. Despite these favorable outcomes, some patients required retreatment due to the recruitment of new arterial feeders in adjacent sinuses, highlighting the potential for progressive vascular changes in untreated areas. Additionally, while SRS-related adverse events were minimal, RIC were observed in up to 14.5% of cases, with male patients and those with multiple arterial feeders being at higher risk. Hemorrhage post-SRS was rare, though some patients who previously experienced bleeding remained vulnerable [10]. These findings suggest that while SRS is a safe and effective option, careful patient selection, dose optimization, and long-term monitoring are essential to mitigate complications and optimize treatment success. The elements that predict obliteration can be grouped in the same way as those that predict bad occurrences [13]. Söderman *et al*. [14] also found that hemorrhage is the most researched post-SRS consequence. Numerous investigations have found that while post-SRS hemorrhage risk is similar to the natural risk of bleeding, rupture risk does not alter considerably until obliteration is completed. Raper *et al*. [15] reported that most patients who receive SRS for dAVFs experience total obliteration, with good symptom recovery rates and little toxicity. The cure rates for symptoms are lower in patients with higher-grade dAVFs and/or non-cavernous sinuses. To increase the chance of symptom cure, combined therapy with embolization and SRS is advised when practical for clinically aggressive dAVFs or those that are embolization-refractory. Additionally, Chen *et al*. [16] stated that SRS treatment provides good dAVF obliteration rates with little complications. Patients with dAVFs who are resistant to endovascular or surgical treatment can be safely and effectively treated with SRS. SRS therapy targets both the dural feeder arteries and the fistulas, leading to radiation-induced vessel thickening that ultimately results in fistula occlusion [17]. Recently, SRS has been recommended as a non-invasive and low-risk alternative for treating dAVFs, particularly in cases where conventional treatment poses significant risks or previous interventions have been unsuccessful. However, planning SRS for dAVFs can be challenging due to their complex angioarchitecture, especially when the fistulas are embedded within the venous sinus wall [18]. To ensure accurate targeting, selective angiography is essential in treatment planning, as multiple fistulas may be supplied by different arterial feeders. Without selective imaging, critical arterial feeders may be overlooked [19]. The radiosurgical target should focus on the arteriovenous shunt itself, but unintentional irradiation of the surrounding venous sinus is likely. Nevertheless, unlike in AVMs, venous sinus irradiation does not appear to be a significant concern, and similar therapeutic effects are observed in dAVFs treated with transvenous embolization [20]. Several clinical implications for the use of SRS in treating intracranial dAVFs are highlighted by the review's findings. Given the variability in treatment outcomes, patient selection should be guided by the location of the lesion, angioarchitecture, and individual risk factors for complications. Patients with high-flow shunts or complex angioarchitecture may require additional considerations, including the possibility of retreatment [17]. Although SRS has demonstrated a favorable safety profile, risk mitigation strategies should be implemented for high-risk patients, particularly those with multiple arterial feeders or a history of hemorrhage. While RIC and post-SRS hemorrhage are infrequent, they require close observation to prevent complications. Ensuring an appropriate radiation dose and limiting unnecessary exposure to adjacent venous structures may help reduce adverse effects while maintaining treatment efficacy [20].

Study Strengths: This review provides a comprehensive analysis of SRS for intracranial dAVFs across multiple studies, enhancing the generalizability of its findings. By synthesizing data on long-term obliteration rates, symptomatic improvement, and risk factors, this study offers clinically relevant insights that aid in treatment planning and patient counseling. Additionally, the inclusion of adverse event data allows for a balanced evaluation of the safety profile of SRS, highlighting both efficacy and potential risks.

Study Limitations: This review has a number of shortcomings in spite of its advantages. Retrospective cohort analyses, which are always prone to selection bias and inconsistent data reporting, comprised the included research. Additionally, the lack of standardized SRS protocols across different studies makes direct comparisons of outcomes challenging. Variations in follow-up durations further limit the ability to assess long-term complications comprehensively, particularly in detecting delayed radiation-induced effects. Future studies should aim to address these limitations by conducting prospective, multicenter trials with standardized treatment protocols.

Conclusion

SRS is a feasible, safe, and effective treatment for intracranial dAVFs, particularly in cases where surgical or endovascular interventions are unsuitable.

It demonstrates high obliteration rates over time, with significant symptomatic improvement, although outcomes vary based on lesion location and angioarchitecture. While adverse events are relatively rare, complications such as RIC and post-SRS hemorrhage may occur in select patients, necessitating long-term follow-up and risk mitigation strategies. Additionally, new arterial feeders may develop in untreated regions, leading to the need for retreatment in some cases. Moving forward, standardizing treatment protocols, refining patient selection criteria, and developing predictive models will be crucial to optimizing SRS outcomes for intracranial dAVFs.

Conflict of Interest

None

Funding

None

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