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Clinical Study

# Stereotactic radiosurgery for intramedullary spinal arteriovenous malformations

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ABSTRACT

Spinal cord arteriovenous malformations (AVM) are rare lesions associated with recurrent hemorrhage and progressive ischemia. Occasionally a favorable location, size or vascular anatomy may allow management with endovascular embolization and/or microsurgical resection. For most, however, there is no good treatment option. Between 1997 and 2014, we treated 37 patients (19 females, 18 males, median age 30 years) at our institution diagnosed with intramedullary spinal cord AVM (19 cervical, 12 thoracic, and six conus medullaris) with CyberKnife (Accuray, Sunnyvale, CA, USA) stereotactic radiosurgery. A history of hemorrhage was present in 50% of patients. The mean AVM volume of 2.3 cc was treated with a mean marginal dose of 20.5 Gy in a median of two sessions. Clinical and MRI follow-up were carried out annually, and spinal angiography was repeated at 3 years. We report an overall obliteration rate of 19% without any post-treatment hemorrhagic events. In those AVM that did not undergo obliteration, significant volume reduction was noted at 3 years. Although the treatment paradigm for spinal cord AVM continues to evolve, radiosurgical treatment is capable of safely obliterating or significantly shrinking most intramedullary spinal cord AVM.



## 1. Introduction

Spinal cord arteriovenous malformations (AVM) are a complex and somewhat heterogeneous disease spectrum, possibly involving dural vasculature at the nerve root, extra-dural vessels or the spinal cord vascular supply. They range from arteriovenous fistulae to more complex nidal malformations of the extra-dural and spinal vasculature.

Stereotactic radiosurgery has emerged over the last few decades as an option for treating cerebral AVM, along with traditional microsurgical and endovascular embolization techniques. Over 5000 patients have been treated with this technique since its introduction in 1972 [1]. Focal radiation is delivered by tuning the confocal geometry of the beams to a predefined lesion, causing progressive hyperplasia of the endothelial tissue of the AVM nidus. Over time, this results in progressive blood vessel occlusion and thrombosis [2]. In cerebral AVM measuring less than 2.5 cm, radiosurgery affords an obliteration rate of 80–85% [3–9].

Given its favorable obliteration outcomes for cerebral AVM, attention has been given to treating spinal cord AVM using stereotactic radiosurgery. Unlike cerebral AVM, multiple spinal cord AVM subtypes exist (Table 1), with typical classification into four distinct pathologic groups based on the location of the arteriovenous connections. Type I and Type IV are dural and perimedullary arteriovenous fistulae; these are often optimally treated with endovascular embolization and/or microsurgical resection. Among the variety of subtypes, those with a more compact nidus represent the optimal targets for radiosurgical treatment. Type III, also called juvenile-type or metameric AVM, are characterized by a large and diffuse intramedullary nidus, which can also extend into the extramedullary space. Juvenile-type AVM are less well-defined lesions, and thus are not optimal radiosurgical targets. Type II, also called glomus-type AVM, represent a compact vascular nidus and are often suitable radiosurgical targets. Embolization, with or without subsequent microsurgical resection, has previously been utilized as the cornerstone of glomus AVM treatment with good success [10].

Treating spinal cord AVM with radiosurgery was not feasible prior to the development of frameless, image-guided stereotaxy [11]. Spinal radiosurgery is dependent on the delivery of a large number of cross-fired radiation beams in order to effectively dose

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**Table 1**
Classification scheme of the four types of arteriovenous malformations with reference to demographics, location, feeding/draining vessels, and presenting symptoms

| Type | Age, years | Etiology | Location | Feeding vessel | Draining vessel | Pressure | Flow |
|---|---|---|---|---|---|---|---|
| I. Dural arteriovenous fistula | 40–70 | Acquired | Thoracic, conus | Single transdural radicular artery | Perimedullary | ↑ | ↓ |
| II. Glomus AVM | <20 | Congenital | Cervico-medullary junction | Multiple radiculomedullary arteries | Epidural venous plexus | ↑ | ↑ |
| III. Juvenile/metameric AVM | <15 | Congenital | Entire cord (extra- and intra-medullary) | Multiple radiculomedullary arteries | Bidirectional, epidural venous plexus | ↑ | ↑ |
| IV. Perimedullary arteriovenous fistula | 20–50 | Congenital | Conus (anterosuperior to cord) | Anterior spinal artery | | ↑ | ↓ |

From http://www.learnneurosurgery.com/avm-arteriovenous-malformation.html.
AVM = arteriovenous malformation.

the delivery to specific targets in and around the spine. Radiosurgical treatment of AVM builds on prior work related to radiosurgical treatment paradigms for spinal tumors [11–13]. Although treatment of spinal tumors has proven to be successful, radiation toxicity to the spinal cord remains a concern. The ability to deliver multiple sessions of radiosurgery to an intramedullary vascular malformation has played a role in reducing this risk of neurotoxicity related to radiation delivery.

At Stanford, we employ the CyberKnife system (Accuray, Sunnyvale, CA, USA) for radiation delivery to patients with radiosurgically treatable lesions. We have since reported our spinal cord AVM radiosurgical experience, including an update [14,15]. Here, we include more recent results.

## 2. Materials and methods

### 2.1. Patient identification and selection

The Stanford University Medical Center, USA, offers CyberKnife radiosurgery to patients with Type II spinal cord AVM who are otherwise not candidates for microsurgical or endovascular embolization. Additionally, patients with Type III spinal cord AVM are considered candidates for radiosurgery if the vascular nidus is compact. In contrast, Type I and IV AVM are better treated with microsurgery or endovascular embolization. Low-flow vascular malformations, such as cavernous malformations and hemangioblastomas, are not considered candidates.

### 2.2. Treatment planning and preparation

Every patient with a previously identified spinal cord AVM undergoes formal review by a multidisciplinary team comprised of cerebrovascular, endovascular and radiosurgery specialists. Team members include neurosurgeons, interventional radiologists and radiation oncologists with expertise in the management of spinal cord AVM. Candidate patients for radiosurgery undergo formal radiographic evaluation consisting of spinal MRI and conventional spinal angiography to identify the three-dimensional (3D) parameters and location of the vascular malformation [16]. Feeding arteries and draining veins are identified in order to exclude

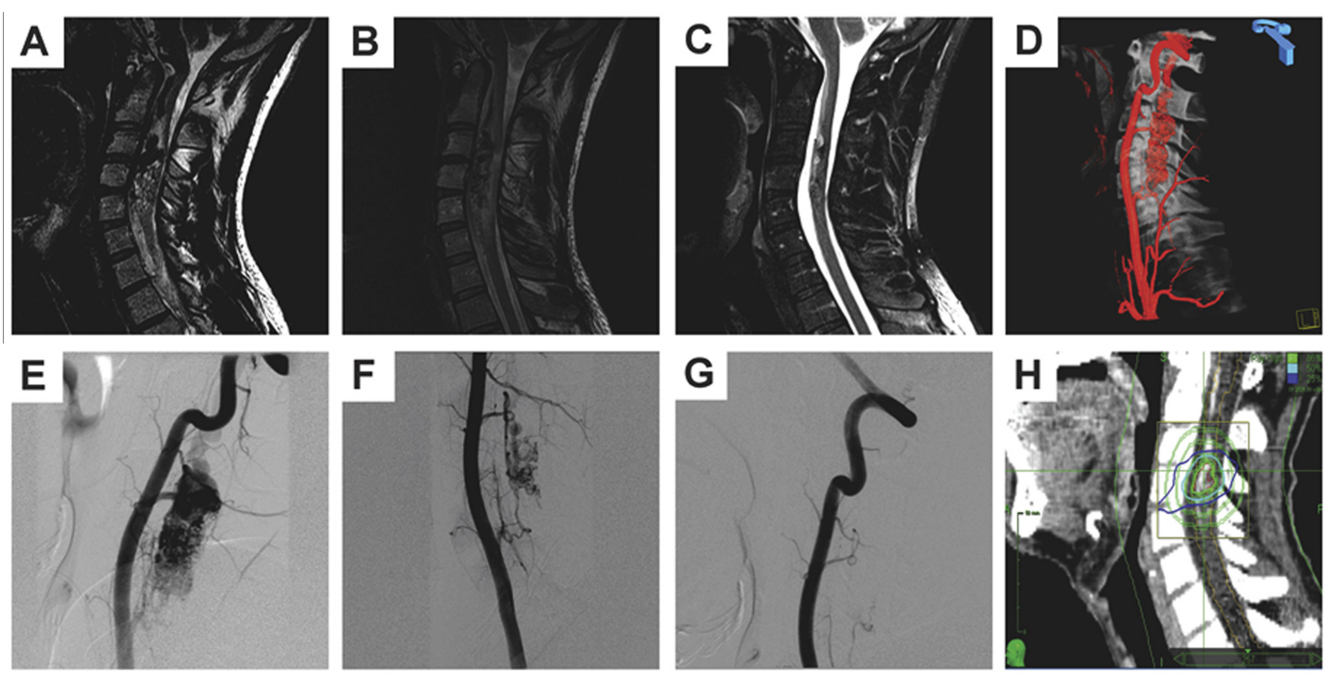


**Fig. 1.** Radiosurgery of a C3–C5 intramedullary Type II arteriovenous malformation (AVM) in an 18-year-old man. (A) Sagittal T2-weighted pretreatment MRI of the cervical spine demonstrating intramedullary flow voids from C3–C5 expanding the spinal cord. (B) Sagittal cervical spine MRI 3 years post-radiosurgery to the AVM. (C) Sagittal T2-weighted MRI showing obliteration of >95% of AVM flow voids 3 years following the second treatment. (D) Three-dimensional (3D) angiogram of the left vertebral artery demonstrating the AVM nidus and its relationship with spinal bony anatomy. Treatment planning completed based on these 3D images. (E) Lateral projection left vertebral artery angiogram with a segmental radiculomedullary feeder supplying the AVM nidus. (F) Left vertebral artery angiogram showing significant decrease (>75%) in size of AVM nidus. The patient was subsequently treated with another radiosurgery session. (G) Left vertebral artery angiogram showing complete obliteration of AVM nidus after the second treatment. (H) Sagittal post-contrast CT scan with CyberKnife (Accuray, Sunnyvale, CA, USA) treatment planning contours with 80% (green) and 50% (light blue) isodose lines.