Predicting Patient Outcomes After Radiosurgery For Arteriovenous Malformation

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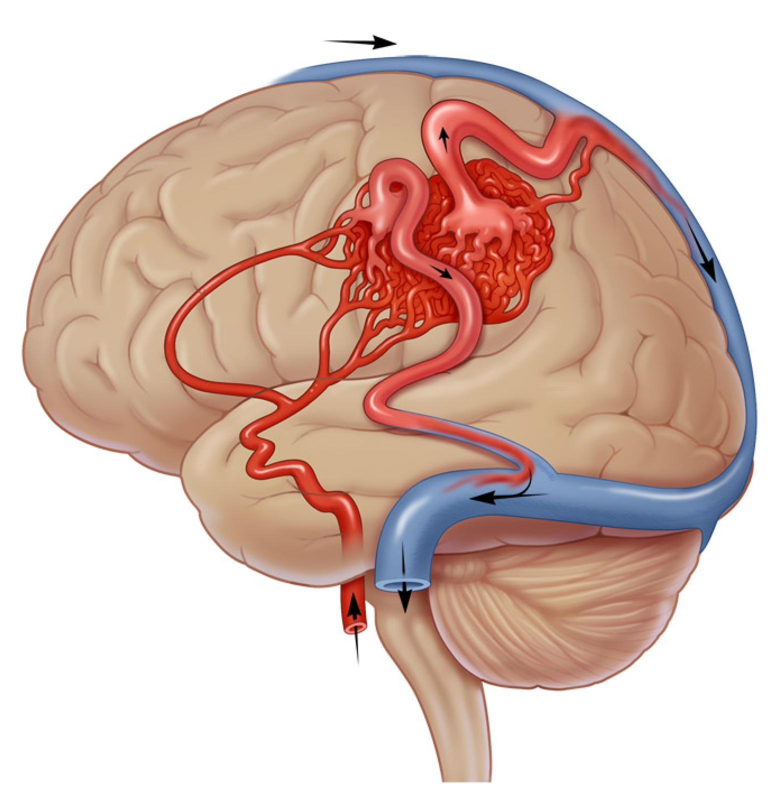
What's an AVM?

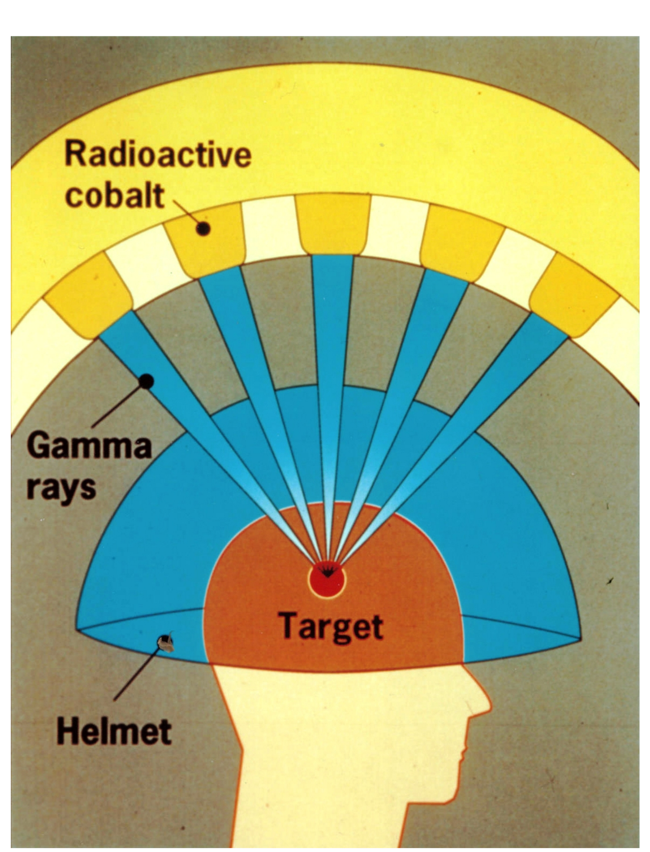
Intracranial *arteriovenous malformations* (AVMs) are collections of "short-circuited" arteries and veins in the brain which have become interconnected, leading to the creation of a high-flow, high-pressure system with a propensity for rupturing.



AVM (source: www.taafonline.org)

Treatment

Treatment attempts to obliterate the center of the AVM, thereby eliminating the risk of hemorrhage. This can be accomplished either directly through surgery, or indirectly via minimally invasive treatments (radiosurgery or embolization). While non-invasive, radiosurgery is associated with delayed and occasionally failed obliteration, placing the patient at continued risk for hemorrhage.



Predicting Radiosurgery Outcomes

In order to assess patients for radiosurgical treatment of their AVM, several clinical scoring systems are utilized to predict obliteration (success) after treatment: the Flickinger-Pollock Score, the Spetzler-Martin Score, and the Virginia Radiosurgery Assessment Score. Our evaluation of these scoring systems found them to be weakly predictive of radiosurgery success.

We show that using a larger set of features, in combination with any machine learning algorithm, can significantly outperform the existing predictive clinical models.

Dataset

1400 AVM patients with a variety of demographic and clinical covariates were retrospectively entered into an IRB approved database. After filtering out patients with missing values or insufficient follow-up, we were left with a dataset of 958 patients and 15 features.

Features:

- Sex
- Age
- Spetzler-Martin Score
- Max Diameter of AVM
- Volume
- History of Hemorrhage
- Embolization
- Number of Draining Veins
- Draining Vein Depth
- Aneurysm
- Max Radiation Dose
- Marginal Radiation Dose
- Average Radiation Dose
- Number of Radiation Foci
- Radiation Induced Complications

Clinical Scoring Systems

Flickinger-Pollock Score

$$0.1 \cdot \text{volume} + 0.02 \cdot \text{age} + 0.3 \cdot (\text{location} \in \{\text{ganglia}, \text{thalamus}, \text{brainstem}\})$$

Spetzler-Martin Score

$$\text{SizeScore} + \text{DeepVenousDrainage} + (\text{location} \notin \{\text{frontal}, \text{temporal}, \text{cerebellum}\})$$

$$\text{SizeScore} = \begin{cases} 1, & \text{diameter} < 3\text{cm} \\ 2, & 3\text{cm} <= \text{diameter} < 6\text{cm} \\ 3, & \text{otherwise} \end{cases}$$

Virginia Radiosurgery Assessment Score

$$\text{VolumeScore} + \text{HistoryOfHemorrhage} + (\text{location} \notin \{\text{frontal}, \text{temporal}, \text{cerebellum}\})$$

$$\text{VolumeScore} = \begin{cases} 0, & \text{volume} < 2\text{cm}^3 \\ 1, & 2\text{cm}^3 <= \text{volume} <= 4\text{cm}^3 \\ 2, & \text{otherwise} \end{cases}$$

All scoring systems and learning algorithms evaluated on their ability to predict the obliteration of each patient's AVM within 4 years of radiosurgery.

Clinical Scoring System	95% confidence interval for AUC
Flickinger-Pollock Score	$0.583 - 0.659$
Spetzler-Martin Score	$0.568 - 0.648$
Virginia Radiosurgery Assessment Score	$0.622 - 0.696$

Learning Algorithms

Algorithm	Hyperparameters	AUC ± std
Logistic Regression	penalty $= \{L_1, L_2\}$, $C = 10^{-4} \dots 10^2$	0.761 ± 0.057
Support Vector Machine	$C = 10^{-4} \dots 10^2$, $\gamma = 10^{-4} \dots 10^2$	0.755 ± 0.058
k-Nearest Neighbors	$k = 1 \dots 31$	0.750 ± 0.053
AdaBoost	# trees $= 25 \dots 400$, rate $= 0.001 \dots 1$	0.752 ± 0.055
Random Forest	# trees $= 25 \dots 400$, depth $= \{10, 20, 30\}$	0.751 ± 0.062
Extra-Trees	# trees $= 25 \dots 400$, depth $= \{10, 20, 30\}$	0.753 ± 0.062

AUC scores determined by 10-fold cross validation, hyperparameters chosen for each fold by nested cross validation.