Locating Arteriovenous Malformations using Magnetic Resonance Imaging Velocity Information

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1 Introduction

An arteriovenous malformation (AVM) is a congenital vascular defect where an artery is connected directly to a vein, with no intervening capillary network. While it is possible for an AVM to exist in other parts of the body, AVMs occur almost exclusively within the brain [6].

Since the AVM provides much less resistance to blood flow than the surrounding network of capillaries, a large amount of blood flows through the AVM, diverting blood away from the surrounding tissue. To compensate, the blood vessels in the surrounding tissue dilate, increasing blood flow to the tissue but also increasing flow to the AVM. The draining veins of the AVM also dilate, to handle the both increased volume of blood and the higher pressure of arterial blood. The constant strain on the vessels can cause them to leak, triggering dizziness, headaches, vision loss, loss of consciousness, or mental impairment. The increased pressure in the draining veins leads to the formation of aneurysms — balloon-like structures that are fatal if ruptured [6].

Successfully treating an AVM means removing its entire mass of swollen blood vessels, which is referred to collectively as the AVM’s nidus. If some portion of the nidus is not eliminated, there is a chance it can grow back, since the remaining vessels provide low resistance to blood flow, just as the original shunt did. There are three techniques for eliminating the AVM nidus: surgical removal, embolization, and gamma-knife radiation therapy [2].

Surgical removal is currently the preferred treatment for AVMs. In the surgical procedure, the physician attempts to seal off the nidus’ feeding and draining vessels before removing its entire mass. AVMs that lie deep in the brain or near sensitive regions are inoperable.

Embolization is a procedure wherein the physician uses an angiographic catheter to seal off a nidus’ feeding vessels with a liquid polymer. Embolization can reduce the AVM’s affect on blood flow, but it is difficult to embolize all the feeding vessels. Thus, embolization is usually performed to assist surgery [2, 5].
In gamma-knife (GK) radiation therapy, small beams of gamma radiation are shot through the brain from many different directions, converging on the AVM nidus. Over time, GK therapy can reduce the size of the nidus, eventually eliminating it. One of the problems with GK therapy is that the tissue damaged by the gamma radiation temporarily swells. Although the swelling is not serious for small irradiated volumetric regions, the swelling associated with larger regions can cause life-threatening damage. Thus, the swelling factor effectively places an upper bound on the volume of brain tissue that can safely be irradiated. For this reason, GK therapy is preferred only when the nidus is small and cannot be reached with ordinary surgery. Large niduses in hard-to-reach areas of the brain are difficult and risky to treat.

GK therapy could, however, treat a larger range of niduses than it currently does. Physicians must irradiate an enclosing volume to be sure that the entire nidus is eliminated. If the estimation of the nidus’ location could be made more accurate, the volume of the irradiated region could be reduced, increasing the range of treatable niduses. Currently, physicians estimate enclosing volumes visually from standard magnetic resonance imaging (MRI) scans. We hope to improve the accuracy of this process, thereby improving the safety and utility of GK therapy.

2 Goal

We would like to use MRI to locate the AVM nidus more accurately than is currently done. Since one of the distinguishing features of an AVM is the high velocity of blood flowing through it, we hypothesize that by augmenting the traditional angiographic and MRI images with MRI velocity data, we can locate the nidus with greater accuracy. The more accurately we can pinpoint the nidus, the more AVMs that can be safely eliminated using gamma-knife radiation therapy.

Using MRI velocity data to augment traditional MRI scans is the next logical step in imaging AVMs. Earlier research has used time-of-flight MR angiography (MRA), an early MRI velocity technique, to locate the AVM nidus. No research thus far recommends using MRA over traditional angiograms for radiation therapy planning, but one recent paper shows MRA can significantly improve the quality of an angiogram-based volumetric estimation [1].

3 Research Design

The velocity of blood is higher within the AVM nidus than in most of the surrounding tissue, so we expect that the velocity data will better reveal the nidus, although the best way of doing so is not at all obvious.

Niduses are small relative to the MRI voxel resolution; if we wish to establish an accurate nidus volumetric region, we should attempt to identify the region with sub-voxel precision. While each voxel gives us only a value to represent
its contents, we can use the values of surrounding voxels to infer both the likely mixture of materials and their relative locations within the voxel, using the technique presented in Laidlaw, et al. [3]. Though this algorithm operates on densities, not velocities, we believe it can be modified to fit the AVM classification problem.

To test our hypotheses, we will need MRI velocity scans of actual AVM cases. Ideally, we would like our velocity data to be in the “3D Phase Contrast CINE” (3D PC CINE) format, which is output by a new scanning technique developed at Caltech [4]. Unfortunately, acquiring such data is logistically difficult. In addition to a consenting AVM patient and physician, we also require a custom scanning sequence for acquiring the data, a facility with an MR scanner that can accept custom scanning sequences, and an MR technician that can run such sequences. For this reason, the 3D PC CINE data may not be available before the scheduled completion date of this project.

We may not need a format as advanced as 3D PC CINE, though. The advantage of the CINE format is that it produces several images of velocity over time. 3D PC CINE images are more accurate than standard 3D PC images in regions of the body where velocity is pulsatile, or dependent on the phase of the heartbeat. We know that regions of the brain are pulsatile, but we do not know if AVMs occur in pulsatile regions or are themselves pulsatile. If AVMs and their surrounding regions are not pulsatile, then we can use 3D PC velocity data, which is a built-in scanning sequence in many MRI scanners.

Thus, we first need to determine how pulsatile AVMs are. To do this, we will compare 2D PC and 2D PC CINE slices of the brain; both 2D formats are also available on many MRI scanners.

Regardless of whether or not we must use the CINE format, acquiring a scan of an AVM in the correct format is difficult and may take a long time. Therefore, to test our approach before we acquire real data, we will create synthetic data sets based on standard MRI scans of AVM patients and our intuition about the structure.

4 Evaluation

To evaluate the accuracy of our model and generated sample data, we will consult with a neurologist, as well as compare the data to existing MRI scans. Once the sample data is evaluated, we can compare the volumetric region identified by our algorithm with the actual AVM region in the model to evaluate the performance of our algorithm.

Such a comparison, though, only tells us the performance of our algorithm on the generated data. Our algorithm may perform quite differently on real data, since we may fail to account for some noise, distortion, or subtle scanning artifact in the construction of our sample data. Therefore, if real data becomes available during the project, we will test our algorithm with it. Evaluating the results of a real test is more difficult than a test with the sample data, though, since it is impossible to know the exact boundary of the AVM at the time of
the MRI scan. The best evaluation available to us is, again, to consult with a neurologist. If the algorithm's discovered volume is consistent with other MRI and angiogram images of the AVM, we will know that our algorithm at least produces plausible volumes. If, as in Bednarz et al. [1], our algorithm produces a volume that includes regions obscured by artifacts in other imaging techniques, we will know that our algorithm may be clinically useful.

Unfortunately, we will not know how well our algorithm actually finds AVM volumes until it shows statistically better results than current methods when used for radiation therapy planning. Such an evaluation would require a much longer time, as it requires a number of consenting AVM patients and physicians, as well as months of treatment and post-treatment evaluation. A practical evaluation, however, would be a good future research topic, provided the algorithm performs well on the simulated and real data.

5 Timeline

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<td></td>
<td>Decide if 3D CINE is needed, or if 2D is sufficient.</td>
<td>Begin the process of acquiring data.</td>
<td>Construct a phantom based on existing images/intuition.</td>
<td>Adapt the subvoxel algorithm to velocity data.</td>
<td>Implement the algorithm and test it on the model.</td>
<td>If real data is available, test algorithm on it.</td>
<td>Evaluate results with physician.</td>
<td>Write paper.</td>
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References


