

# AV Shunt Visualization With Arterial Spin Labeled Perfusion MR Imaging

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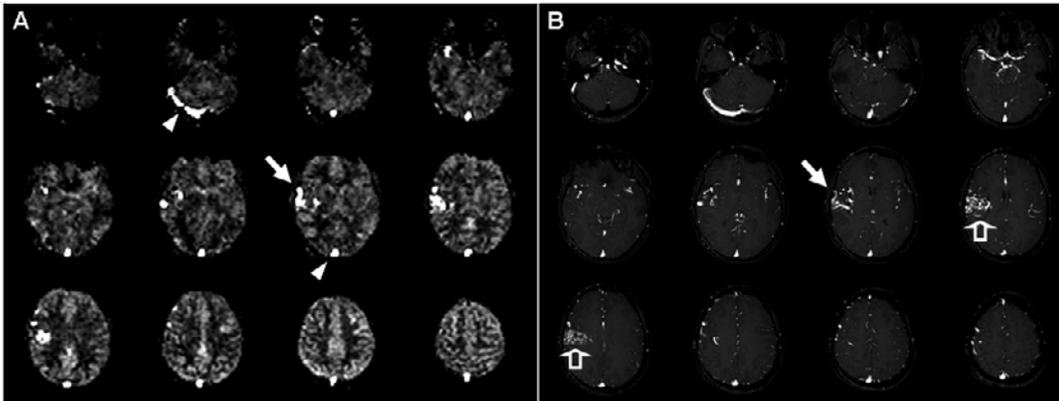
## Introduction

Arteriovenous malformations (AVMs) are congenital abnormalities in vascular development in which arteriovenous (AV) shunting is present. Symptoms may be acute or chronic, but the presenting event in about 50% of patients with AVMs is intracranial hemorrhage, with potentially significant morbidity and mortality. The vascular architecture and hemodynamics of AVMs are often complex, and the gold standard for evaluation is conventional digital subtraction angiography (DSA). MRA techniques provide a noninvasive alternative; however, the spatial and temporal resolution of DSA is not currently available. While spatial resolution can perhaps rival that of DSA and methods exist with temporal resolution of < 1 second, it is difficult to obtain both in the same acquisition. Undersampled back projection and keyhole imaging approaches [1-3] and also parallel imaging methods [4] may provide the means for a favorable comparison with DSA to the point where it is possible to obtain complete evaluation of AVM vascular architecture as well as dynamic characteristics including AV shunting, but current noninvasive imaging methods remain suboptimal. In studies of brain lesions such as neoplasms and AVMs where an arterial spin labeled (ASL) MR perfusion method was employed, a striking artifact was noted on perfusion studies of AVMs where labeled water appeared in the AVM nidus and/or draining veins. The purpose here was to investigate the hypothesis that this is a transit artifact reflecting AV shunting, which can potentially be exploited for detection of AVMs and perhaps quantification of AV shunting.

## Methods

Subjects were 5 patients (4 females, 1 male; mean age 34, range 23 to 49) with AVMs in whom continuous ASL (CASL) MR perfusion imaging studies were obtained as part of fMRI exams clinically requested for preoperative planning. Data were acquired within the guidelines of the local Institutional Review Board, and written consent obtained. Structural imaging in all patients included a 3D T1-weighted sequence (MP-RAGE), and in 4/5 subjects 2D or 3D time of flight (TOF) MRA of the AVM was also acquired. The remaining subject had only a conventional DSA for comparison. CASL perfusion MRI was acquired with the following parameters: TR/TE=4000/17msec, matrix=64x64, number of sections=12, section thickness=6mm (1.5mm gap), labeling delay=1200msec, and FOV=22x22cm<sup>2</sup>. A reduced RF amplitude of labeling pulses (2.25 $\mu$ T) along with a weaker 1.6mT/m labeling gradient were employed to remain within FDA guidelines for RF deposition at 3T. Labeling and sinusoidal control pulses (100Hz) were applied at the cervicomedullary junction. Total acquisition time was 5:28min. CBF was calculated as described previously [5], but the  $\Delta M$  image ( $\Delta M$  = difference between control and labeled image intensities) was sufficient to evaluate for the presence of AV shunting. A semiquantitative approximation of the degree of shunting was explored based on a simple threshold as follows: (1) a 33 voxel ROI was placed in the contralateral basal ganglia (BG) and mean (BG<sub>mean</sub>) and standard deviation (BG<sub>sd</sub>) were measured for each AVM patient; (2) the number of voxels with intensity greater than BG<sub>mean</sub> + 8\*BG<sub>sd</sub> was summed (threshold empirically chosen to exclude all voxels in normal cortex); and (3) compared with the total number of nonzero voxels in the  $\Delta M$  maps to generate an approximation of the percent of shunt voxels relative to all labeled voxels in the brain. For comparison, CASL perfusion data from 2 patients with cavernoma (which should not demonstrate AV shunt) and 10 patients with glioblastoma (GBM, which could potentially demonstrate AV shunting) were also reviewed.

## Results and Discussion



**Fig. 1.** (A) CASL perfusion difference ( $\Delta M$ ) maps and (B) registered 2D TOF MRA source images from a patient with right hemisphere AVM. Bright signal in sagittal sinus and right transverse sinus (arrowheads) and in draining veins (arrows) adjacent to nidus (open arrows) is evident on CASL  $\Delta M$  images indicating AV shunting, in this case primarily superficial drainage. This complements the vascular anatomic information provided by the MRA, which shows arteries, veins and nidus (in this case, no superior saturation band was applied).

In all 5 cases, striking increased intensity was seen on CASL perfusion  $\Delta M$  maps in venous structures draining the AVM. Figure 1 illustrates typical findings in one of the AVM patients. Approximations of percent AV shunt ranged from 2% for the largest AVM to 0.14% for the smallest. One of the GBM patients showed apparent AV shunting in the sagittal sinus, but none of the other comparison patients demonstrated this effect. In this small group of relatively young patients, a static depiction of relative AV shunt was created based on a delay of 1200msec, chosen empirically to allow time for labeled spins time to move from larger arteries into the microvasculature and avoid excessive T1 decay. A more comprehensive evaluation could be obtained by collecting multiple datasets with different delay times or by modifying the ASL technique to measure transit time [6,7]. The practical utility of this effect may be as a complement to standard AVM evaluation. For example, one of the AVM patients showed a moderately large hematoma adjacent to the AVM, but the AVM was still visible on conventional DSA and MRA. However, small AVMs may be difficult to detect with any technique in the acute setting when significant hemorrhage is present, and simply demonstrating presence or absence of AV shunting could be beneficial. The sensitivity of this approach is unclear in this small sample.

## Conclusion

ASL perfusion MR techniques can demonstrate AV shunting, providing a potentially complementary method for evaluation of AVMs as a simple means of detecting the presence of an AVM, and perhaps also quantifying the extent of AV shunting.

## References:

1. Korosec FR, Frayne R, Grist TM, Mistretta CA. Magn Reson Med 36: 345-351 (1996).
2. Mistretta CA, Grist TM, Korosec FR, Frayne R, Peters DC, Mazaheri Y, Carrol TJ. Magn Reson Med 40: 571-581 (1998).
3. Peters DC, Korosec FR, Grist TM, Block WF, Holden JE, Vigen KK, and Mistretta CA. Magn Reson Med 42:91-101 (2000).
4. Tsuchiya K, Aoki C, Fujikawa A, Hachiya J. Eur Radiol 14: 1494-1497 (2004).
5. Wolf RL, Wang J, Wang S, Melhem ER, ORourke DM, Judy KD, Detre JA. JMRI 22:475-482 (2005).
6. Hendrikse J, van Osch MJP, Rutgers DR, Bakker CJG, Kappelle LJ, Golay X, van der Grond J. Radiology 233:899-904 (2004).
7. Wang J, Alsop DC, Song H, Maldjian JA, Tang K, Salvucci AE, Detre JA. Magn Reson Med 50:599-607 (2003).