A New High Resolution MR DSA Protocol for Intracranial Vascular Malformations

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Introduction: Intracranial vascular malformations (iVMs) represent a significant cause of hemorrhagic stroke. Accurate diagnosis, treatment, and follow up require detailed vascular imaging. X-Ray DSA is the clinical standard for time-resolved angiography due to its high spatial (0.2mm) and temporal resolution (up to 10 frames/sec) (1). However, the intraprocedural thromboembolic risk as well as utilization of ionizing radiation and nephrotoxic contrast media emphasizes the need for a less-invasive and safer medium. Application of time-resolved CE-MRA for assessment of AVM is not a novel idea. However, many clinical CE MRA techniques utilize 3D protocols such as Keyhole, TRICKS, and TWIST which sacrifice SNR for temporal resolution (2). MR-DSA or 2D Projection angiography, improves the spatial and temporal resolution of angiograms by eliminating 3D information, analogous to DSA (3). When used in conjunction with a static, high resolution MRA, 2D MR-DSA can provide a comprehensive exam which may eliminate the need for DSA at various stages of iVM treatment. In this study, we present the development of a novel 2D radial FLASH-based, MR DSA pulse sequence for use in assessing the treatment success in the setting of iVM. Initial protocol images displayed concentric circular banding artifacts. As a result, we propose a new approach to magnetization spoiling in 2D radial FLASH pulse sequences to eliminate these artifacts.

Materials and Methods:

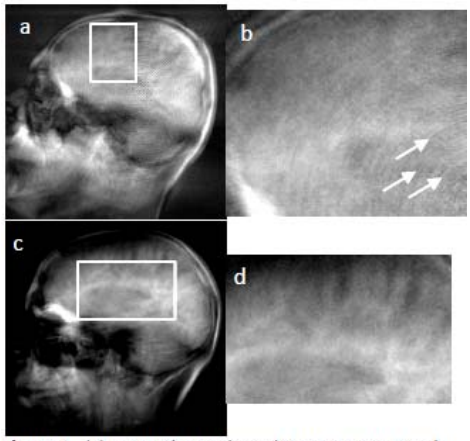

Figure 1. (a) Original pseudorandom FLASH protocol showing ring artifacts (arrows) in the enlarged ROI in (b). (c) Modified FLASH protocol with corresponding ROI (d) demonstrates elimination of ring artifacts.

We developed an MR-DSA pulse sequence based on a previously reported 3D CE MRA protocol (1) utilizing a radial FLASH acquisition with non-selective excitation, pseudorandom view ordering and sliding window reconstruction (5). This new pulse sequence is capable of producing 0.49 mm isotropic, in-plane spatial resolution projection angiograms at 10 frames/s.

Spoiling. We conducted Bloch Equation simulations and phantom studies to predict, explain, and quantify the appearance of artifacts associated with our radial MR-DSA protocol. Our results were used to develop the following gradient spoiling scheme in conjunction with RF-spoiling to eliminate these artifacts. In a standard radial trajectory, imaging gradients are given by $G_x(n) = Gx\cos\theta(n)$ $G_y(n) = Gy\sin\theta(n)$ where $\theta(n)$, the radial projection angle, varies such that $k_\theta = \tan^{-1}[G_y(n)/G_x(n)]$ for *n=0,…,N-1* radial views. We propose additional spoiler gradients calculated as a function of θ. That is spoilers $G_{s,x}$ and $G_{s,y}$ will be calculated as $G_{s,x}(n) = G - G\cos\theta(n)$ and $G_{s,y}(n) = G - G\sin\theta(n)$.

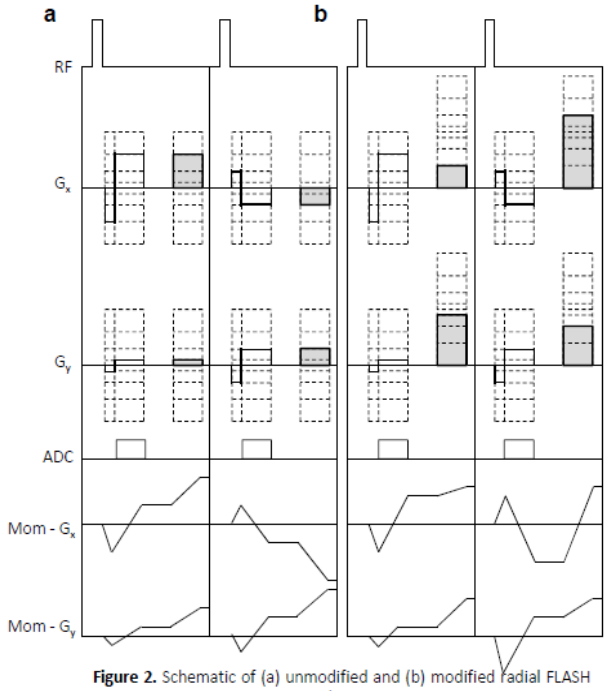

Figure 2. Schematic of (a) unmodified and (b) modified radial FLASH acquisition at two projection angles

Intracranial MRA. Patients with DSA-confirmed iVMs in various stages of treatment with endovascular embolization underwent our MR-DSA sequence to assess treatment efficacy and residual lesions. Data was acquired on a 3T Trio (Siemens) MR imaging system using a single dose of Magnevist with the following protocol: TR/TE=7.5 ms/2.03 ms, θ=30°, BW=455 Hz/pixel, Nro=512, Nproj=512, FOV=250 mm. All human volunteer studies received IRB approval.

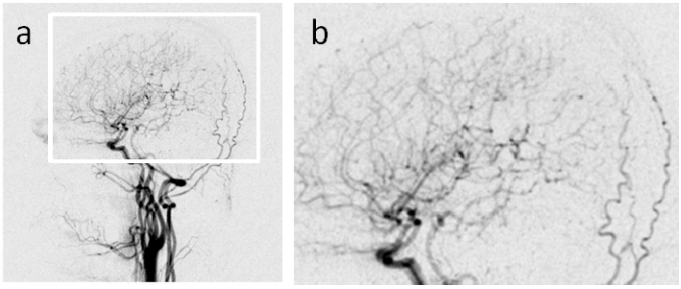

Figure 3. Single frame of cranial angiogram from human volunteer using high frame rate 2D MR-DSA protocol showing the high resolution of small vessels at 0.49 mm.

Results/Discussion: Our simulation and phantom studies predicted that a radial sampling trajectory in 2D FLASH sequences will produce spatial inhomogeneities in spoiled transverse magnetization resulting in the image artifacts shown in Fig. 1a-b (arrows). These are eliminated (Fig. 1c-d) with a modified spoiling strategy that balances gradient moments along each physical axis (Fig. 2). Figure 3 shows a single frame of a time-series 2D MR-DSA acquisition of intracranial vasculature in a healthy human volunteer at 0.49 mm in-plane resolution. Ring artifacts are not present and small vessels are resolved. Figure 4 shows a high spatial resolution MR angiogram at 0.57mm in-plane resolution of patient volunteer who had received stage 1 embolization treatment for a dural arteriovenous fistula (AVF). The post-treatment MR-DSA clearly displays the persistence of arteriovenous shunting and early venous drainage into the sigmoid sinus. The MR-DSA protocol was able to provide sufficient hemodynamic information to confirm persistence of the dural AVF and plan further treatment without the need for DSA.

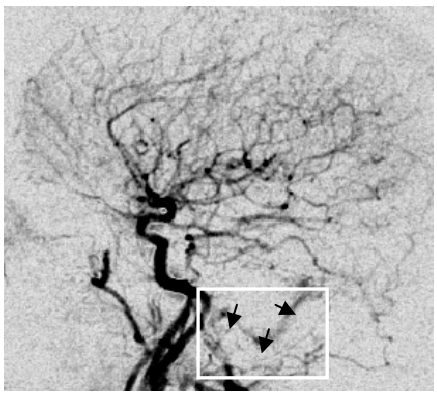

Figure 4. Single frame of MR-DSA cranial angiogram at 0.57mm resolution from a dural AVF patient volunteer demonstrating early venous drainage (arrows).

Conclusion: Our novel MR-DSA protocol exhibits markedly advanced spatial and temporal resolution approaching the standards of conventional DSA. Furthermore, our clinical studies with this technique demonstrate adequate visualization of neurovascular anatomy and hemodynamics of iVM for diagnostic evaluations, treatment planning, and/or follow-up assessments. We believe this new sequence has the potential to advance CE MRA as a non-invasive adjunct or substitute for X-ray DSA.

References: 1) Eddleman et al., *Stroke* 2009. **2)** Korosec et al., *MRM* 1996. **3)** Hennig et al., *MRM* 1997. **4)** Jeong et al., *MRM* 2009 **5)** Riederer et al., *JMRI* 1997