4D contrast enhanced MRA using single dose dual injections and constrained reconstruction

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INTRODUCTION: Time-resolved contrast-enhanced magnetic resonance angiography (TR CE MRA) of the brain is challenging due to the need for rapid imaging and high spatial resolution. Moreover, the significant dispersion of the intravenous contrast bolus as it passes through the heart and lungs increases the overlap between arterial and venous structures, regardless of the "temporal aperture" [1-2]. Low dose HYBRID HYPR technique [3] is able to decouple the high spatial resolution and SNR, which require relative long scan time, from high temporal resolution, which demands for fast data acquisitions, and used HYPR constrained reconstruction to achieve high temporal and spatial resolution and high SNR using contrast dose as little as 1 ml. One of the disadvantages of the HYBRID HYPR technique is that the composite image (either phase contrast or TOF) is susceptible to signal loss due to dephasing from complex flow or saturation of slow flow, which in turn will degrade the final images. An innovative technique is presented to split a single dose contrast into two injections. The first small contrast volume (2~3 ml) will be used for acquiring time-resolved weighting images with high frame rate and the rest of contrast agent will be used for a high resolution CE MRA as the spatial constraint. Using HYPR reconstruction, the final images (HYPR CE) will have both high temporal and spatial resolution, but not suffer the flow-sensitive artifacts and increase of contrast dosage. Furthermore, volunteer studies demonstrate that reduced contrast dose from the first injection significantly improves the arterial and venous separation.

METHODS: HYPR CE exams were obtained in seven normal volunteers, two patients with intracranial aneurysms and two patients with brain arteriovenous malformations (AVM). For each study, a single dose (0.1 mmol/kg) of gadolinium-based contrast agent was split into two injections. The first small injection (2~3 ml) was administrated at 3ml/s followed by a 25 ml saline flush, starting simultaneously with a highly undersampled time-resolved multi-echo VIPR (ME VIPR) acquisition (acquired voxel size was 1.7x1.7x1.7 mm^3 with 0.5 s frame update time). The second injection (the remainder of the single dose of the contrast agent) was administrated at 0.5ml/s followed by a 20 ml saline flush. A high resolution CE MRA was acquired with elliptical centric view ordering and fluoro-trigger technique. Factor of 2x2 parallel imaging was applied to reduce the scan time to within 90 sec (acquired voxe size was 0.57x0.57x1 mm^3). Final images were reconstructed using the HYBRID HYPR technique [3] to achieve the high temporal and spatial resolution simultaneously.

RESULTS AND DISCUSSION: All HYPR CE exams were successfully acquired and reconstructed. Figure 1 shows representative arterial, mixed and venous phases in coronal and oblique views from a patient with Dual arteriaovenous fistula (DAVF). The frame update time was 0.5 s with 0.75 s temporal reconstruction window. The apparent spatial resolution was 0.57x0.57x1 mm^3. Figure 2 shows a mid basilar artery aneurysm previously treated using detachable coils. a) The PC HYPRFlow image does not clearly demonstrate the residual flow within the aneurysm due to susceptibility artifacts from the coils and slow flow within the aneurysm. (b) The HYPR CE image is able to detect the residual aneurysm lumen. Figure 3 compares venous phase images at corresponding times from (a) PC HYPRFlow with full single dose injected during the dynamic acquisition and (b) HYPR CE exams with single dose dual injections. The shorter bolus resulting from the smaller contrast volume of the HYPR CE technique improves the arterial venous separation. Note that arterial signal from the longer contrast bolus is present in the PC HYPRFlow image.

HYPR CE utilizes high resolution contrast enhanced MRA as the spatial constraint to reconstruct the time-resolved contrast enhanced image series without increase of contrast material. Unlike other HYPR techniques (PC HYPRFlow and HYPR TOF), HYPR CE does not suffer from signal ambiguities due to the different contrast mechanisms. Therefore it provides accurate filling dynamics and vascular anatomy. Small volume of contrast in the dynamic acquisition provides a shorter bolus, which in turn improves the arterial venous separation. Iterative reconstruction [4-5] can be applied to further improve the reconstruction accuracy. Both dynamic weighting images and the high resolution contrast enhanced constraining images do not depend on the sampling strategy and can be acquired with the best available sequences. Usually, motion is not expected to happen between scans within such short scan time (totally less than 4 mins). However, if motion occurs, image registration should be performed before the HYBRID HYPR reconstruction. In the future, high resolution CE VIPR with parallel imaging and matched filter reconstruction will be explored as a substitute for the fluoro-triggered CE MRA to simplify the clinical procedure.

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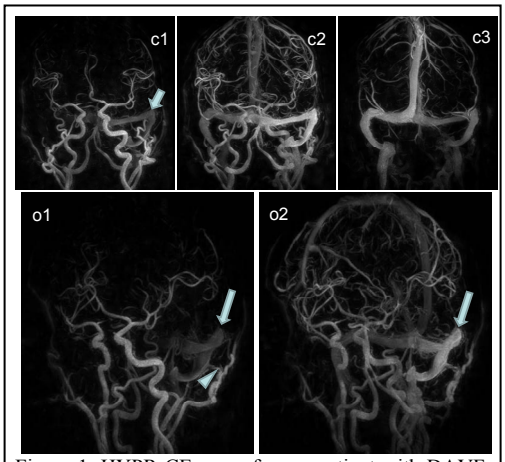

Figure 1. HYPR CE exam from a patient with DAVF. Note the rapid enhancement of the left transverse sinus (arrows) and a branch of the occipital artery supplying the DAVF (arrowhead) can be identified.

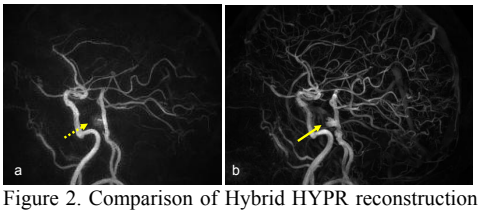

Figure 2. Comparison of Hybrid HYPR reconstruction using (a) the PC VIPR as the constraint and (b) using the CE MRA as the constraint. The patient's residual aneurysm lumen (arrow) is better appreciated when the CE MRA is used as the constraint.

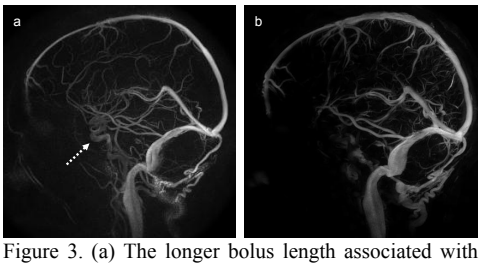

Figure 3. (a) The longer bolus length associated with the full dose injection for PC HYPRFLow results in partial overlap of the arterial and venous structures in this venous phase image (arrow). (b) HYPR CE acquisition uses only 2 mL of contrast resulting in a shorter bolus and improved arterial to venous separation.