Optimizing Peripheral Contrast-Enhanced MRA using a-priori Knowledge of Bolus Kinetics through the Optimal Choice of Imaging Parameters and Acquisition Time

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Introduction

Single injection moving table peripheral contrast enhanced MR angiography (pCE-MRA) is increasingly used to evaluate peripheral atherosclerotic occlusive disease (PAOD). Yet obtaining a high resolution CE-MRA with adequate SNR and no lower station venous enhancement is often elusive, particularly in patients with soft tissue ischemic disease. We propose that by the simple addition of an aortic timing bolus followed by a 3D lower station (calf) time-resolved MRA, useful timing information can be obtained. From this, *a priori* determination of individual patient hemodynamics (aorta-foot and arterio-venous transit times) allows the exam to be custom tailored by choosing the optimal acquisition time to stay with (or slightly behind) the bolus while still avoiding venous enhancement. The acceleration necessary to achieve this comes from parallel imaging using a prototype peripheral vascular coil. Furthermore, SNR for any acquisition time can be maximized through proper understanding of coil geometry characteristics and balancing the 2D SENSE factor (SF_{slice}, SF_{phase}), TR, TE, α, and bandwidth. Optimized parameters can then be preset and easily selected by the operator to provide optimal quality images in all patients.

Methods

Using a prototype eighteen channel, 3-station phased array peripheral vascular (pv) coil and an Intera 1.5T scanner (R11, Philips Medical Systems, Best, the Netherlands), geometry factor (g) maps for 2D SENSE up to a net factor of 6 were determined for all three stations using a test subject. Per the method of Weiger et al. [1], CE-MRA outer parameter (fixed) values of FOV, slice thickness, voxel size and desired scan time were first chosen. Using these fixed outer parameters, iterative software was used to find the optimal "inner parameter" values of BW, SF (phase and slice - including the g factor effects), TR, TE, and α to maximize SNR for any length acquisition (Matlab, the Mathworks, Natick, MA). Optimized protocols were pre-calculated and stored as protocols so that no calculations need be performed during the scan.

The protocol starts with a 1 cc Gd abdominal aortic timing bolus, followed by rapid dynamic 3D imaging of the calf station (Fig. 1 - 20 phases x 5 s, 1.7 x 1.7 x 3 mm^3, SF 2 slice/2.5 phase, 6 cc Gd). This dynamic series provides intermediate-resolution time-resolved calf arterial and venous arrival information. Using this in conjunction with the aortic arrival time, aorta to pedal artery and calf arterio-venous transit times are easily measured. From this, optimal upper and middle acquisition times are chosen such that lower station acquisition begins close to but prior to venous arrival. A previously stored, SNR-optimized protocol of the proper duration is then selected and 3 station moving table pCE-MRA performed using 34 cc Gd (Fig. 2). True acquired resolution is 1.2 x 2.1 x 2.6/1.2 x 2.1 x 2.0/1.0 x 1.0 x 1.0 mm^3 for the upper/middle/lower stations respectively. Upper and middle acquisition times range from 5 to 20 sec. Sub-systolic (60 mm Hg) thigh venous compression cuffs are inflated to provide additional robustness against venous enhancement.

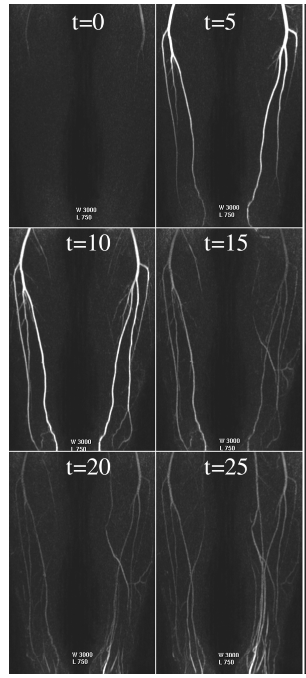

Figure 1. 6 frames dynamic 3D MRA lower station, every 5 sec starting at time contrast peaks in aorta. Note rapid venous at 15 s.

Figure 2. Resultant MRA from Fig. 1 - upper and middle 5 sec acq. with no venous.

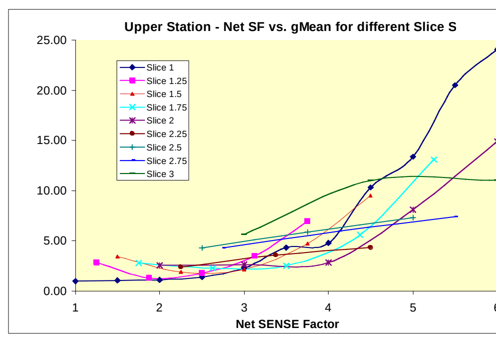

Figure 3. Mean geometry (g_{Mean}) factor for 2D SENSE for different slice SENSE factors vs "combined" 2D SENSE factor = SF_{slice}*SF_{phase}.

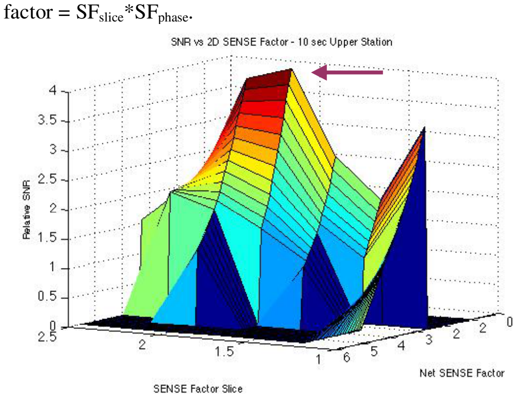

Figure 4. Surface plot SNR vs. slice SF and total SF. Maximum SNR (arrow) with a net SF 2.7/slice SF 1.75. (phase SF ~1.5). Upper station, 10 sec acquisition.

Findings

The imaging protocol has been successfully applied in over 40 patients (Fig. 2), with good SNR and no diagnosis-hindering venous enhancement. Observed pv coil mean geometric factors ranged up to 24/10/7 in the upper/middle/lower stations for some 2D SENSE combinations, but (for example) these values can be as low as 6/2/1.5 for a net 2D SF of 5. An upper station g-map is shown in Fig. 3 – note that as net SF increases, certain SENSE combinations are much more advantageous (lower g factor) – e.g. to achieve a net SF=5, best to use 2D SENSE rather than 1D SENSE in phase only (dark blue line with SF_{slice}=1). Using g-map data, three-dimensional graphs of SNR vs. 2D SF can be generated for each station and each desired acquisition time in order to choose the best SNR combination for that scan time (Fig. 4).

Discussion

MRA protocols are often constructed without careful attention to maximizing SNR – a particular problem as SNR decreases with increased acceleration. The goal of pCE-MRA is to obtain high resolution, high SNR images of the arterial system without venous enhancement. This is much more easily achievable when the individual patient's venous enhancement kinetics are known. With this knowledge, scan parameters can be optimized while utilizing the maximum possible acquisition time and still avoiding venous enhancement. This protocol adds a small amount of time for the timing run, but in return gains a time-resolved calf MRA, maximized SNR on the high resolution CE-MRA, and decreased risk of venous enhancement. A comparison study with DSA is ongoing.

In summary, the proposed acquisition optimization strategy allows for individualized scan parameters to achieve superior image quality for peripheral CE-MRA.

Reference

1.) Weiger M, Pruessmann K, Boesiger P. 2D SENSE for faster 3D MRI. MAGMA 2002;14:10-19.