A non-linear subtraction method for MRA

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Introduction:

Researchers have been pushing the limit to better reveal angiography with very high resolution MRI techniques. With reduced partial volume effects, it is possible to show smaller vessels with diameter on the scale as the voxel size [1]. However, one of the major issues of high resolution MRA is the greatly reduced SNR, which in turn leads to lower CNR between vessels and surrounding tissues. One theoretically promising way to enhance such CNR is to acquire both flow-rephased and -dephased images and subtract the latter from the former to drastically reduce the tissue signal [2]. However, since both arteries and veins will have hypo-intensity signal in the dephased images, the direct subtraction results will contain both vessels [2,3]. In this study, we proposed an interleaved-TR GRE TOF sequence with variable TE to simultaneously acquire both re- and dephased images, and a non-linear, self-squaring process to reduce contamination in the subtracted MRA.

Methods:

Our interleaved-TR sequence is shown in Fig.1. For the first TR, fully flow compensated echo was acquired with a shorter TE_1 for good TOF MRA; and for the second TR, a pair of bipolar gradients with 24mT/m amplitude and 10ms total duration (i.e. VENC ≈ 1cm/s) replaced the FC gradients to dephase the moving blood signal. With the bipolar gradient inserted, TE_2 is longer than TE_1. Non-contrast enhanced images were acquired with following protocol: voxel size = 0.5x0.5x1mm^3, 48 slices, BW = 150Hz/px, TR/TE1/TE2 = 25/8/15ms, FA = 15º, 2x GRAPPA. The scan was performed on a Siemens Verio 3T system using 32-ch head coil. For non-linear subtraction, all images were self-squared voxel-by-voxel, then the self-squared dephased images were subtracted from the self-squared rephased images and the finally the subtraction results were MIPped over 12 slices. The original images also underwent the same subtraction and MIP process and the results were compared.

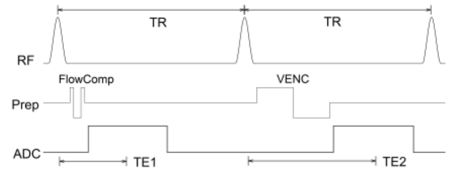

Fig.1 Illustration of interleaved-TR TOF sequence.

Results:

Fig.2 displays the original images and their MIP/mIP results, as well as the subtraction and the MIP of the subtraction of both original and self-squared data. The subtraction of the original images showed heavy contamination of veins (Fig.2e and 2g), while the subtraction of the self-squared images mostly showing only the arteries (Fig.2f and 2h). The veins are removed Fig.3 shows the cross section profiles of a vein and an artery from the linear subtraction (solid lines) and the self-squared subtraction (dash lines).

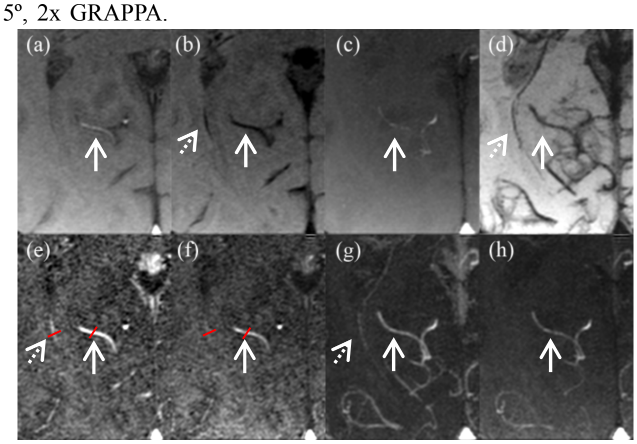

Fig.2 Original rephased (a) and dephased (b) images. (c) is the MIP result of (a), and (d) is the mIP result of (b). Self-squared results corresponding to (a)-(d) are similar in contrast and thus not shown here. (e) is the subtraction result of the original images, (f) is the subtraction result of the self-squared images, and (g) and (f) are the MIP result of (e) and (f) respectively. The solid arrow indicates an artery and the dotted arrow indicates a vein, and the red lines indicate the cross section profile location.

Discussion:

The incapability of separating arteries and veins has always been the major issue for the linear subtraction between rephase/dephase data. Due to the non-selective nature of the dephasing process in reducing all blood signals, a direct linear subtraction will show both veins and arteries with hyper-intensity signal (Fig.2g) relative to tissues.

For a specific tissue, the signal acquired in our interleaved-TR sequence can be expressed as $S_{TR1} = S_{ss}\exp(-TE_1/T_2^*)$ and $S_{TR2} = S_{ss}F(VENC)\exp(-TE_2/T_2^*)$, where S_{ss} is the steady state signal and F(VENC) is the flow dependent dephase function. Therefore, the final subtraction result is affected by the steady state, flow velocity and T_2*. In the linear subtraction, let S_{TR1}- S_{TR2}=Δ_1, then for the self-squared subtraction one will have

$$\Delta_2 = S_{TR1}^2 - S_{TR2}^2 = \Delta_1(S_{TR1} + S_{TR2}) \quad (1)$$

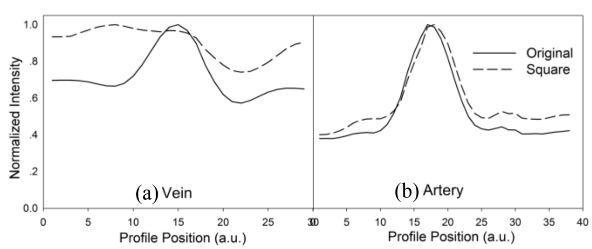

Fig.3 Cross section profiles of a vein (a) and an artery (b) for linear subtraction (solid lines) and non-linear self-squared subtraction (dash lines), obtained from positions indicated in Fig.2e and 2f.

Comparing veins and tissues, it's obvious that $\Delta_{1v} > \Delta_{1t}$, and as a result veins has higher signal in the linearly subtracted images (Figs.2e and 3a). However, because $S_{TR1v} < S_{TR1t}$ due to the faster T2* decay of venous blood and $S_{TR2v} < S_{TR2t}$ due to the dephasing, one have $S_{TR1v} + S_{TR2v} < S_{TR1t} + S_{TR2t}$. With proper VENC value and TEs, is it possible to realize $\Delta_{2v} < \Delta_{2t}$, thus making veins invisible in the self-squared subtraction results and the subsequent MIP, as demonstrated in Figs.2f, 2h and 3a. Arteries, on the other hand, will still have the highest signal after the self-squared subtraction due to the very large signal change between rephased/dephased images.

In summary, we have proposed a simple non-linear subtraction method by self-squaring the images prior to the subtraction, which not only can enhance the artery/tissue contrast as the linear subtraction, but also can greatly reduce the contamination from the venous side. Further studies will include quantitative modeling for CNR analysis, as well as optimizing the scanning protocol and post processing methodology.

References:

[1] Dagirmanjian *et al*, JCAT, 1995;19(5):700 [2] Kimura *et al*, MRM, 2009;62:450 [3] Gedat et al, MRI, 2011;29:835