Phase-Adjusted Fresh Blood Imaging (PA-FBI) as a Non-Contrast Peripheral MRA Technique

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INTRODUCTION

Flow-spoiled fresh blood imaging (FS-FBI), a non-contrast MRA technique, allows separation of arteries from veins to provide arterial and venous images by subtracting two images acquired with different cardiac phases [1]. The technique using half-Fourier 3D FSE was designed to implement the read-out (RO) spoiler gradient pulse to spoil arterial signals during systole and to maintain bright blood signals during diastole so that only arterial vessels were depicted after subtraction and an MIP processing. In order to make a high signal difference between diastole and systole, fast flow arteries during systole should be depicted as dark blood or minimum signal, when an appropriate strength of RO spoiler gradient pulses are applied. However, this condition perturbs a CPMG condition and coherence of both echoes is separated to have two pathways, and thus in a result, severe N/2 artifacts appear in the PE direction. In this study, we investigate the effects of flow in terms of signal coherence in FS-FBI and propose a new method to maximize signal difference between diastole and systole so that high signal of MRA images can be obtained without introducing flow-related N/2 artifacts.

MATERIALS and METHODS

Theory In FSE, velocity-induced phase changes of two coherence pathways are described in detail by Norris, et al [2] and Machida, et al [3]. In reference [2], the velocity-induced phase difference between two components are stated as; $\phi_v = \gamma G v(TE^2)$, where flow (v) in the RO direction, inter-echo spacing (TE) and the RO spoiler gradient (Gspoil). From ref. [2], Signal intensity, $S=S(\phi)=\text{sqrt}(A^2 + B^2 + 2AB\cos\phi)$ (1), where ϕ is a phase difference, magnitude of two echo systems, A and B. When flow is slow, ϕ_v is considered to be relatively small. However, as in FS-FBI, relatively fast flow especially during systole causes significant phase difference, during the first refocusing pulse. In order to have an ideal condition of systole and diastole, intentionally offsetting the phase of RF refocusing pulse is considered, according to the flow velocity. Then, this phase difference can be stated as phaseOffset, ϕ_{RF}. Now the equation (1) can be written as $\phi = \phi_v + \phi_{RF}$ (2).

Proposed Technique The proposed method, phase-adjusted fresh blood imaging (PA-FBI), allows optimization of the phaseOffset, ϕ_{RF}, to improve the depiction of arteries in non-contrast FS-FBI. On the other words, based on calculation on eqn. (2) $\phi = \phi_v + \phi_{RF}$, arterial blood signal S(ϕ) difference between diastole and systole is optimized using phaseOffset, ϕ_{RF}.

Experiments Prior to data acquisitions, a simulation study was carried out to predict appropriate RF phase difference ϕ_{RF} for particular flow velocities of diastole and systole. To control the ϕ_{RF}, the phase of an RF refocusing pulse was adjusted according to the velocity of vessels. All experiments were performed using a 1.5-T imager (Excelart/Vantage, Toshiba, Japan) with an 8-channel (16 elements) torso QD SPEEDER coil [4]. Typical parameters of 3D acquisition were as follows: TR/TEeff = 3 R-R intervals/80 ms, echo-train-spacing (ETS) of 5 ms, matrix of 256x256, TI of 130 ms, NAQ of 1, 26 slice partitions with a 4-mm thick slice (interpolated to a 2-mm slice), FOV of 40x40 cm, and a total (simultaneous peripheral pulse-gating (PPG) acquisition of diastole and systole) scan time of about 3:30-4:00 min. A flow phantom study was also performed to investigate basic property of N/2 artifacts and difference of signal intensity due to flow direction.

RESULTS and DISCUSSION

From the flow phantom study, N/2 artifacts appear with increasing the flow velocity as a result of the phase difference of two echo components. This phenomenon was agreed with the analysis by ref. [3]. From the volunteer images, reduction of N/2 artifacts, appeared relatively faster flow during systole, can be achieved when the phase difference of two echo components (ϕ) is within approximately 120 degree and maintaining the relative signal intensity of more than 0.4. Under the condition of using Gspoil of -10, Figure 1 is a simulation result (S.I. vs. flow velocity) of two echo systems (A and B) using A = B = 0.5, neglecting the dephasing effect within a voxel. The original method (phaseOffset = 0) presents the signal intensity in arbitrary units in dotted line and the new method with phseOffset ϕ_{RF} = -30 deg shows signal intensity in solid line. Flow velocities of the iliac arteries and veins during systole and diastole are indicated by arrows. Notes that the new method with ϕ_{RF} = -30 deg gains 36% more signal intensity between diastole and systole or (dSI_new) as compared to the original method (dSI_org). In addition, the new method with ϕ_{RF} = -30 deg gives similar signal intensities of veins for systole and diastole – venous signal is at relatively plateau in both systole and diastole – so that venous signals were eliminated after subtraction. Figure 2 shows MIP images acquired with the new method with ϕ_{RF} = -30 deg and the original method (ϕ_{RF}=0) on the iliac region of a healthy volunteer. The new method permits not only increase in signal intensity of an entire arterial tree, but provides prominent reduction of N/2 artifacts. Figure 3 presents the popliteal trifurcation artery vessels obtained using the new and the original methods with Gspoil = +10%. The new method shows significantly improved arterial image as compared to the original method. In addition, marked reduction of venous signals is seen. Note that flow direction of veins oppose to the arteries can be far suppressed by applying a suitable phaseOffset, as shown in Fig. 1. In the original method, there was only Gspoil and TE to control differentiation of arterial signal during systole and diastole. With adjustment of phaseOffset, it is easier to have better signal difference.

In conclusion, application of phaseOffset in FA-FBI permits significant improvement in arterial depiction with marked reduction of N/2 artifacts and veins.

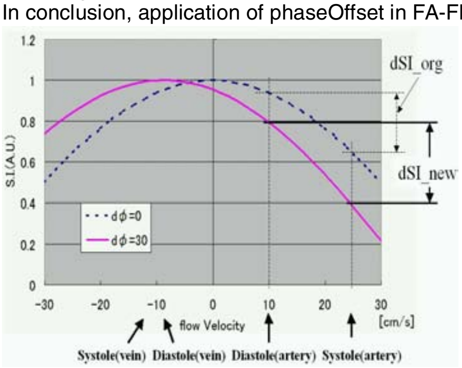

Fig. 1 Simulation result of A and B echo systems using G=-10%. The dotted line is the original method and the solid line is the new method with phaseOffset = -30.

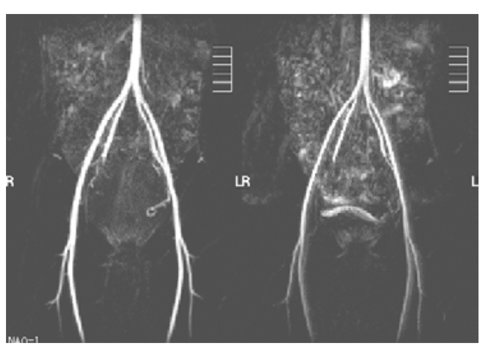

Fig. 2 The new method with phaseOffset (left) and the original method (right). Note that the new method shows higher arterial signal as compared to the original method.

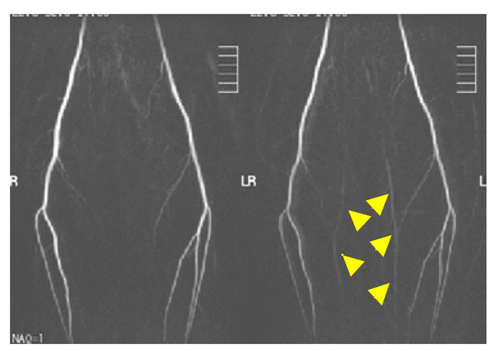

Fig. 3 The new method (left) and original (right)
The new method shows better delineation of an entire arterial trees and marked reduction

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