Black-Blood Imaging Using a Spin-Echo Spiral Sequence with Flow-Spoiling Gradients

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Introductions: In black-blood MRI, the blood signal is suppressed to allow clear delineation of the vessel wall and identification of atherosclerotic plaque both in animals and in humans. There are two popular black-blood techniques: double inversion-recovery and spatial presaturation. These techniques either invert or saturate upstream flow spins, which subsequently become the source of the black blood in the imaging region. It has been reported that the flow-spoiling gradients can be used in a turbo spin-echo sequence to differentiate veins from arteries based on the decreased signal intensity [1], and they have been incorporated in a gradient-echo sequence to suppress intravascular signal [2]. In this work, we investigated the feasibility of black-blood imaging of peripheral arteries using a spin-echo spiral sequence with flow-spoiling gradients. Instead of upstream spin inversion or saturation, the black blood is caused by the dephasing effect from the moments of the flow-spoiling gradients in the imaging region. Spin-echo sequences with diffusion gradients straddling the RF refocusing pulse typically require motion artifact correction using navigators. Even with flow-spoiling gradients, however, motion artifacts may not be severe in peripheral artery imaging because it is relatively easy to restrain the motion of patient extremities. A spin-echo spiral sequence may therefore be a good choice for black-blood imaging of peripheral arteries because spiral sequences are inherently insensitive to motion artifacts.

Methods: The spin-echo spiral sequence was implemented with flow-spoiling gradients placed in the slice select direction around the RF refocusing pulse to spoil flow signal. To reduce the echo time, the flow-spoiling gradients are superimposed on the crusher gradients. In the presence of the flow-spoiling gradients, the change in the resonance frequency leads to an accumulated phase for the flowing spins, $\phi = \int \Delta\omega dt = \gamma \int \dot{r} G t\, dt + high order terms$, where γ is the gyromagnetic ratio, $\int G t\, dt$ is the first moment of the gradient *G*, and $\dot{r}$ is the velocity of the spin. The expression of the phase indicates that the gradient-induced dephasing for the flowing spins is dependent on the spin velocity and the first moment of the gradients. For the pulsatile blood flow in peripheral arteries, the flow speed can have ten-fold variation. If the gradient first moment is not big enough, flow signal suppression will vary according to the flow speed variation, leading to data inconsistency. The data inconsistency manifests as motion artifacts in the phase-encoding direction in 2D Fourier transform (FT) imaging and ringing artifacts in spiral imaging.

The spin-echo spiral sequence was implemented on a Siemens Avanto 1.5T MR system and it had 40 spiral interleaves with 8192 data points/interleaf. Transverse images were acquired from the superficial femoral artery (SFA) of a healthy volunteer using a linear array of four surface coils. In addition to pulse triggering and fat saturation, the imaging parameters included field-of-view (FOV) of 256 mm, flip angle of 90°, and voxel size of 0.5×0.5×5mm. For comparison, images were also acquired using a spin-echo spiral sequence with regular crusher gradients, which have a first moment M_1 of 24.7×10^{-6}mT·s^2/m. Since the blood flow is mainly in through-plane direction for the transverse SFA images, the flow-spoiling gradients are placed in slice select direction. The maximum gradient amplitude of 40 mT/m was used and the total times of the gradients were increased so that the first moment increases as a multiple of M_1, i.e. $12M_1$, $30M_1$, $60M_1$, $100M_1$, and $150M_1$. The corresponding minimum TEs of 3.2, 6.6, 10, 13.4, 16.8, 20.2 ms were used.

Results and Discussion: In Figure 1, SFA images were acquired with flow-spoiling gradients of different first moments. No signal averaging was used. Without flow-spoiling gradients, shown in (A), blood flow appears to be bright because of very little flow-signal dephasing effect. In (B, C), applying flow-spoiling gradients of moderate first moments ($12M_1$, $30M_1$) causes severe ringing artifacts, as expected. In (B), fast flowing spins in the SFA (solid arrow) are better dephased than the slow flowing spins in the vein (open arrow), because dephasing depends on both the gradient first moment and flow velocity. However, the pulsation of the arterial flow causes variation in the dephasing effect, leading to data inconsistency and ringing artifacts. As the first moment increases from $12M_1$ to $30M_1$, the severity of the ringing artifacts reduces. With further increased first moments ($60M_1$, $100M_1$, $159M_1$), shown in (D-F), the blood signal appears to be dark without obvious ringing artifacts. While variation of the dephasing due to flow pulsation still exists, the dephasing is now dominated by the large first moment of the gradients, which means that there is good flow dephasing no matter how the flow velocity changes during pulsation. The well-preserved dephasing during flow pulsation leads to reduced data inconsistency and thus ringing artifacts. However, increasing the first moment of the flow-spoiling gradients also leads to a longer TE, which in turn decreases the image signal-to-noise ratio (SNR). The image SNR can be improved by using signal averaging, while maintaining a reasonable scan time.

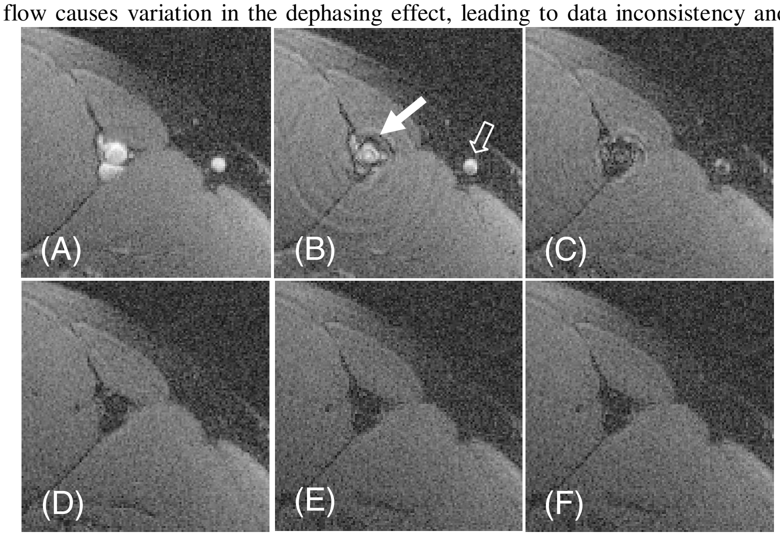

Figure 1. Peripheral artery images acquired using spin-echo spiral sequence with flow-spoiling gradients. From (A)-(F), the corresponding first moment of the gradients is 1, 12, 30, 60, 100, and 150 times of M_1.

Conclusion: We have demonstrated that black-blood imaging using a spin-echo spiral sequence with flow-spoiling gradients is feasible and tested the scheme on SFA imaging. It is shown that, with gradients of moderate first moment, flow speed variation can cause significant ringing artifacts. Using gradients with a large first moment can better dephase the flow signal at the cost of a longer echo time.

References:

[1] Miyazaki et al., Radiology, pp890-896, June 2003
[2] Fayad et al., Circulation, pp2890-2896, June 2004