EFFECT OF FLIP ANGLE EVOLUTION ON FLOW SENSITIVITIES IN ECG-GATED FAST SPIN ECHO MRA METHODS AT 3T

I. P. Atanasova[1,2], P. Storey[1], R. P. Lim[1], J. Xu[1], Q. Chen[1], A. Laine[2], and V. S. Lee[1]

[1]Department of Radiology, New York University Medical Center, New York, New York, United States, [2]Columbia University, New York, New York, United States

Introduction ECG-gated spin-echo based techniques for non-contrast-enhanced MRA applications [1-4] exploit differences in arterial and venous flow during systole and diastole (Fig.1). Arteries demonstrate flow void during systole and high signal during diastole, while veins exhibit similar signal in systole and diastole and cancel out on subtraction This method became clinically practical with half-Fourier fast spin echo implementation [2-4]. Replacing the constant flip angle (CFL) echo-train of conventional FSE with a variable (VFL) one [5] decreases acquisition time with shortened interecho spacing, and lower SAR, and potentially improves image quality with reduced blurring and improved small vessel depiction [4]. Appropriate flow sensitivity characteristics of these sequences determine image quality. Our hypothesis is that CFL and VFL echo-train approaches have different flow sensitivities and that these impact the image quality at different stations of the peripheral vasculature.

Materials and Methods *a) Phantom Experiment:* A CardioFlow 5000 MR pump (Shelley Medical Technologies, Canada) was used to drive a blood-mimicking fluid (4% glycerol, 96% distilled water, doped with 0.1ml Gd/L for T1 1600ms, T2 230ms) through a braid-reinforced Tygon tube with inner diameter of 1.6 cm at 10 constant flow rates ranging from 0 to 60ml/s. The phantom was imaged with a body phased array coil with the same system and sequence parameters used for the human studies. CFL was performed with 180° and 120° flip angles. Flow velocities corresponding to the pump flow settings were estimated by phase contrast quantification and correlated to the resultant signal intensities of the imaged fluid.

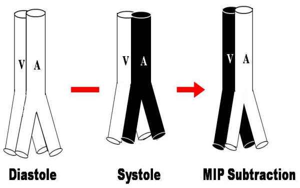

Fig. 1 Subtraction technique principle

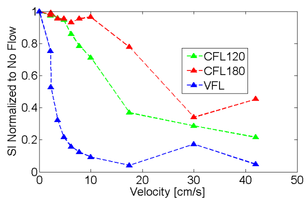

Fig. 2 Relationship between flow velocity and signal intensity. Phantom

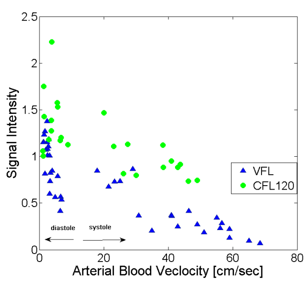

Fig. 3 Relationship between flow velocity and arterial signal intensity. Human Data

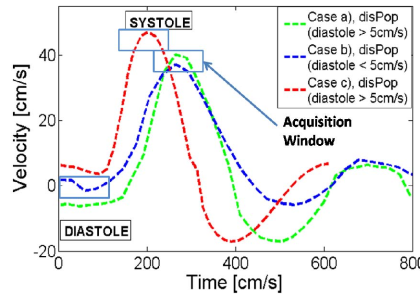

Fig. 4 In vivo phase contrast curves corresponding to images in Fig. 5

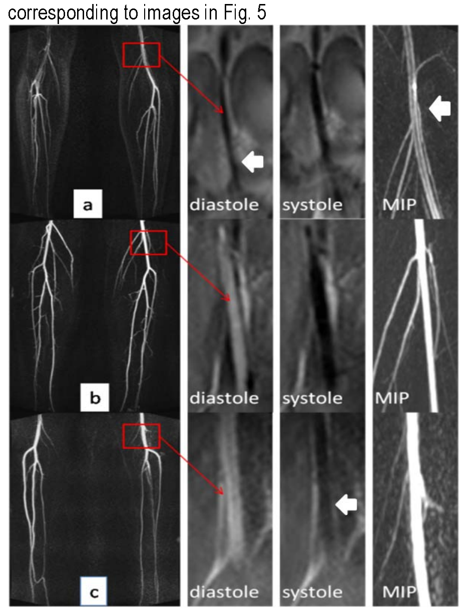

Fig. 5 Flow sensitivity effects. From left to right: overall MIP subtraction images of the calf, cropped diastole source image, systole source, and subtraction MIP of the disPop. a) VFL with dark artery in diastole b) VFL with bright artery in diastole c) CFL with incomplete flow void (arrow)

b) Human Experiments: The distal and proximal lower extremities of 6 healthy volunteers were scanned at 3T (Siemens Tim Trio) with the VFL (Siemens SPACE, Sampling Perfection with Application optimized Contrasts by using different flip angle Evolutions) sequence; 3 of these subjects were also imaged with the CFL-approach with the following parameters: matrix 320x240, parallel factor 3, reference lines 24, BW 977Hz/px, phase half Fourier, TR = 2 R-R intervals, FOV 400x272 with 2mm-thick slices and 90-104 partitions for the thigh, and 1.5mm slices with 80-88 partitions for the calf, with centric reordering and using a multichannel peripheral phased array coil. For VFL, additional parameters were TE 18ms, echo spacing 2.44ms, turbo factor 72, echo-train duration 88ms. For CFL, images were acquired with a 120° flip angle with TE 2.7ms, echo spacing 2.84ms, turbo factor 72, echo-train duration 102ms. All acquisitions were single-shot and ECG triggered with trigger delay (TD) of 0ms for diastole and 200-300ms for systole, determined based on velocity vs time curves (Fig. 4) obtained by phase contrast flow quantification (2D FLASH, TR 70.3ms, TE 3.79ms, FA 20°, venc 100cm/s). The arterial CFL and VFL signal intensities (normalized to adjacent muscle) and corresponding velocities (based on phase contrast) were compared for 6 different anatomical regions spanning the entire leg from the femoral heads to the ankle.

Results In healthy subjects, arterial velocity patterns ranged considerably (Fig.4) resulting in MRA images of variable quality (Fig.5). Peak systolic velocities were consistently > 15cm/s and varied from 15 to 90 cm/s. Diastolic velocities ranged from 1-8 cm/s, with higher velocities observed in the common femoral (CFA) and distal popliteal (disPop) arteries. Phantom data (Fig.2), supported by similar in vivo results (Fig.3), demonstrate that flow sensitivities for CFL and VFL vary significantly and explain MRA appearances in subjects (Fig.5). At all velocities CFL shows relatively high signal, compared with VFL. Velocity sensitivities depend on the flip angle, with smaller sensitivity range (i.e. velocities over which SI falls rapidly) for lower flip angles (12-30ml/s for 180° and 8-18cm/s for 120°). VFL, which uses even lower FA magnitudes (40°-140°), exhibits a much smaller range of sensitivity with the highest SI below a threshold velocity of 5 cm/s, above which, near complete signal void occurs. With the VFL approach, vessels such as CFA and disPop, where diastolic velocity exceeded 5 cm/s, appear hollow on subtraction MRA (Fig.5a MIP) due to the diastolic signal void centrally in the artery (Fig. 5a diastole). With CFL the arterial SI is relatively high even at high velocities (Fig. 5c systole). This could potentially impair image quality due to minimal SI differentiation between systole and diastole, but implementation with flow spoiling gradients, as is typically performed [3], improves the image contrast.

Conclusion Optimal arterial visualization with the ECG-gated fast spin echo is achieved when the difference between the systolic and diastolic arterial signal is maximized. Our results illustrate the important dependence of flow sensitivity on flip angles used in echo train spin echo methods. With flow voids at velocities as low as 4-5 cm/sec, the VFL-approach we used is suboptimal for imaging vessels where diastolic flow exceeds this threshold. Optimizing the flip angle evolution and use of flow compensation to achieve appropriate flow sensitivities for healthy and diseased vessels requires further investigation.

References [1] VJ Wedeen, et al., Science 1985, 4728, 946-948 [2] Miyazaki M, et al., Radiology 2003, 227:890-896 [3] Miyazaki M, et al., J Magn Reson Imaging 2000, 12(5): 776-783 [4] Xu J, et al., ISMRM, Toronto 2008 [5] Mugler JP, et al., ISMRM 2003: 203.

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