Flow-independent subtractive non-contrast enhanced MRA using flow insensitive and sensitive SSFP-echo

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Introduction: Computer tomographic angiography (CTA) is the gold standard for visualizing the arteries in patients with severe peripheral artery disease (PAD) that require revascularization. However, x-ray dye used in CTA should be avoided in patients with kidney diseases or severe diabetes, which is equally the case for gadolinium contrast agents. Further, CTA exposes patients to ionizing radiation and significantly increases lifetime risk for cancer[1], thus it is not suited for serial studies in response to a therapy. For these reasons there is a strong demand for non-contrast enhanced (NCE) MRA[2]. In this work we describe a new flow-independent subtractive NCE-MRA based on the SSFP-echo signal, which can be made either flow sensitive[3] (signal suppressed from moving spins) or flow insensitive[4]. The subtraction between the two data sets will only yield signal from blood and the contrast between the venous and arterial blood is achieved by appropriate T2-weighting.

Methods: In the proposed NCE-MRA, two 3D SSFP-echo data sets are acquired. The flow-sensitive SSFP-echo signal is acquired with the pulse sequence[5] shown in **Fig 1**. The gradient pulse along the slab-select direction (blood flow direction), which follows immediately after the RF excitation, eliminates the FID and enhances flow sensitivity, which arises from the fact that the phase of the transverse magnetization of the moving spins increases quadratically from one pulse cycle to next due to displacement[4]. On the other hand, flow-insensitive 3D SSFP-echo data is obtained by performing 1D Fourier transformation of multiple phase-cycled bSSFP data with various linear phase increments[4]. In brief, as the phase-cycling mimics the phase precession per TR interval of the transverse magnetization, the phase-cycling allows one to "sample" the bSSFP spectral signal with different phase precession rates (frequency from 0 to 1/TR) whose Fourier conjugate is time. Thus, the 1D FT of the phase-cycled data sets will resolve the modes of the SSFP that are normally coalesced in a bSSFP pulse sequence, including the desired -1 mode, i.e. the flow-insensitive SSFP-echo. The other modes (e.g. n=1, n=-2, etc.) inherently have much lower signal and are unusable, thereby allowing acquisition of only a few different phase cycles (6~8) to resolve the SSFP-echo mode without interferences from aliased higher modes. The sequence parameters of bSSFP and SSFP are identical: TE/TR=3.7/7.4 ms, flip angle=30°, FOV = 352 ×128 × 360 mm^3, matrix size=352×20×120, zero padded to 352×40×240 and the total acquisition time is 2 mins 20 s. After image reconstruction the flow-sensitive SSFP-echo data was subtracted from the flow-insensitive SSFP-echo and maximum intensity projection (MIP) was taken along the anterior-posterior direction, where the subjects were scanned in feet-first supine position. A single-station (pelvis and upper thigh) MRA was acquired from three healthy subjects (26, 27 and 30 yrs).

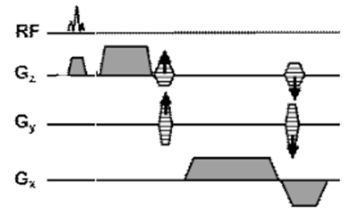

Fig 1 Flow-sensitive 3D SSFP-echo pulse sequence.

Results: In the grayscale-inverted MIP images (**Fig 2**) muscle tissue and fat are well suppressed by the subtraction. Even the synovial fluid, which has much longer T2 (>700 ms)[6] than arterial blood, are also removed. Signal from the venous blood is still visible but the major arteries can readily be identified.

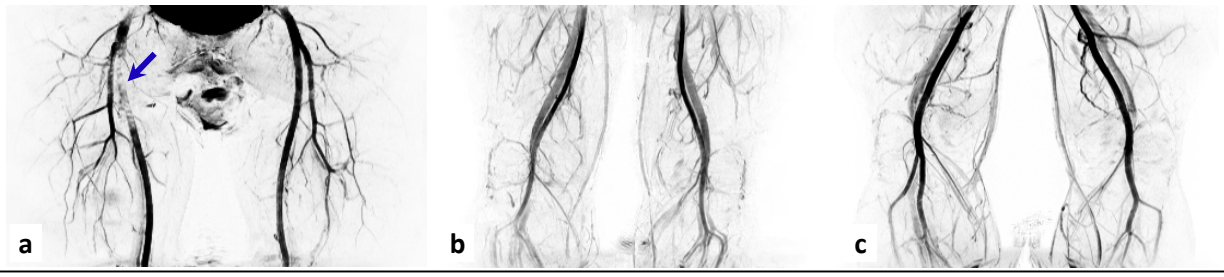

Fig 2 Inverted MIP images of three healthy subjects. The single station bi-lateral MRA display of **a**) the bifurcation of the common femoral artery and superficial and deep femoral arteries; **b** ,**c**) superficial femoral arteries, popliteal arteries and tibial and peroneal arteries. The source of the artifact (blue arrow) in **a**) is under investigation.

Conclusions: A new approach to bi-lateral flow-independent MRA capable of isolating intravascular signal over a large FOV was demonstrated in healthy subjects. The current method does not require cardiac gating thus avoids effects of arrhythmia and trigger delay calibration errors[2]. Concerns such as inadequate suppression of veins require further investigation. Although the method is efficient and straightforward to implement but it's full potential requires evaluation in patients with PAD in comparison with CE MRA or CTA.

References: [1] Einstein et al, JAMA 2007, [2] Wheaton A and Miyazaki M, JMRI 2012, [3] Gyngell M, MRI 1988, [4] Zur et al, MRM 1990, [5] Ganter C, MRM 2006, [6] Gold et al, AJR 2004.

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