Acceleration Dependent Vascular Anatomy for Non-Contrast-Enhanced MRA (ADVANCE-MRA)

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Introduction

Non-contrast enhanced MR angiography (NCE-MRA) methods avoid the time and resolution limitations and associated with acquisition during the first pass of a contrast-agent bolus, and safety concerns due to NSF. Several recently demonstrated NCE-MRA methods [1–4] use motion-sensitised driven equilibrium (MSDE) preparation modules to suppress the signal from flowing blood. Angiograms are obtained by subtraction of bright- and dark-blood images, obtained without and with flow suppression. In the lower extremities, a significant drawback of this approach is incomplete discrimination between arteries and veins—even in healthy volunteers there may not be a specific velocity-encoding parameter (venc) at which all major arteries are clearly depicted with no venous contamination. To allow for variations in flow between individuals, multiple flow sensitivities must be acquired, or 'tuning' scans must be used to optimise the venc for each individual. In patients with reduced arterial flow [5], venous contamination of angiograms can be substantial.

An improved method, offering greater discrimination between arteries and veins, would be beneficial. This study investigates the use of an acceleration-dependent preparation module, which exploits the pulsatility of arterial flow, for NCE-MRA. This method is demonstrated in healthy volunteers, and compared with a velocity-dependent method.

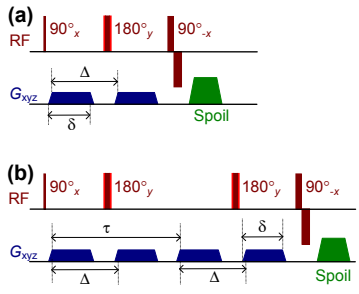

Fig. 1: velocity-sensitisation (a) and acceleration-sensitisation (b) modules.

Materials/Methods

Lower leg images were acquired in supine position using a 1.5 T Signa HDx scanner (GE Healthcare, Waukesha, WI) with an 8-channel cardiac coil. Ethical committee approval and informed consent were obtained.

Fig. 1 shows schematic pulse sequences for the velocity- and acceleration-sensitive preparation modules, which use motion-sensitising gradients (MSG) to dephase flowing magnetisation. The velocity-sensitive sequence has an effective first gradient moment $m_1 = G\delta\Delta$ and venc = $\pi/(\gamma m_1)$ (the velocity giving π phase change). The acceleration-sensitive sequence has an effective first-gradient moment of zero, giving no velocity sensitisation, but a second gradient moment $m_2 = 4G\delta\Delta\tau$, and an 'acceleration-encoding parameter' aenc = $2\pi/(\gamma m_2)$ (the acceleration giving π phase change). The preparation sequence parameters were δ = 8 ms, Δ = 13.1 ms, τ = 25 ms. 9 different MSG amplitudes were used – 0.05, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0, 10.0 and 20.0 mT/m – corresponding to venc of 224, 112, 56.0, 22.4, 11.2, 5.60, 2.24, 1.12 and 0.560 cm/s and aenc of 89.6, 44.8, 22.4, 8.96, 4.48, 2.24, 0.896, 0.448 and 0.224 m/s^2 respectively. Bright-blood images, with no MSG applied, were also acquired to allow calculation of subtraction angiograms.

The preparation sequence was placed 100 ms after the PPG trigger, corresponding to peak flow, with a further 200 ms delay before the 3D balanced-SSFP readout (coronal, flip angle 65°, TE/TR=1.6/3.4 ms, matrix 256×230, FoV 33.3×30 cm, ASSET factor 2, 2 segments per slice). Spectral fat suppression was applied before both the preparation module and the readout [5].

To compare the velocity- and acceleration-dependent sequences, series of images were acquired using both methods in 6 volunteers, using only 16 slices of thickness 3.6 mm. Signals were measured from regions of interest placed on maximum intensity projections from the left leg, for the popliteal, anterior tibial, posterior tibial and peroneal arteries and veins.

An additional scan protocol used the best four MSG amplitudes determined from the first acquisition (0.5, 1.0, 2.0, 5.0 mT/m) and was applied in 8 volunteers, using 28 slices of thickness 2.4 mm. An experienced radiologist assessed the MIP images for quality of arterial (scale 0–4: 0=not visualised; 1=poor/gaps in major vessels; 2=moderate/all major vessels depicted; 3=good/major vessels well depicted; 4=excellent/major & branching vessels well depicted) excluding up to 4 cm from the top of the image when there was off-resonance signal loss. Venous contamination, background signal, fluid and other artifacts were also assessed (scale 0–3: 0=none; 1=mild; 2=moderate; 3=severe).

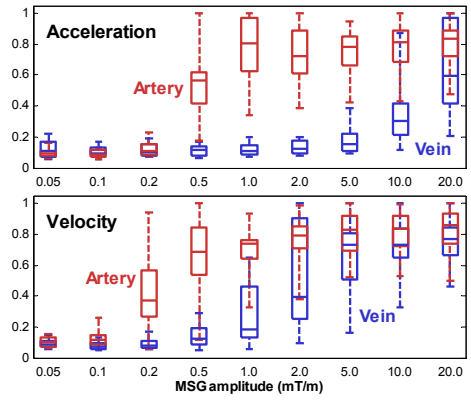

Fig. 3: Boxplot of arterial (red) and venous (blue) signal ranges as a function of MSG amplitude. Between 0.5-5.0 mT/m, good separation is achieved for the acceleration-dependent method (upper plot), but not the velocity-dependent method (lower plot).

Results

Fig. 2 compares example images as a function of MSG amplitude. Venous contamination is widely observed for the velocity-dependent images, but not the acceleration-dependent images.

Fig. 3 shows box-plots comparing normalised signals (median, inter-quartile range, max-min) in arteries and veins. A clear separation is achieved between arterial and venous signals for the acceleration-dependent technique over a wide range of MSG amplitudes (~0.5–5.0 mT/m), whereas separation is incomplete for all MSG amplitudes using the velocity-dependent method.

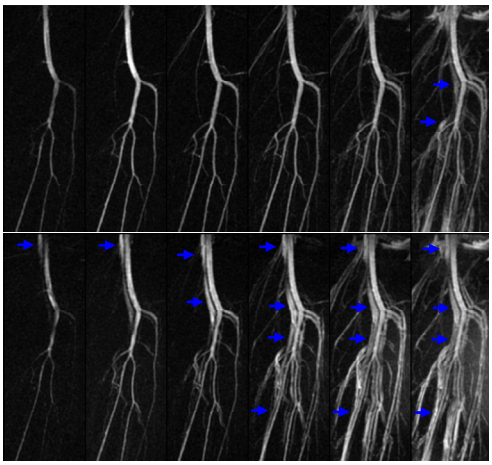

Fig. 2: Comparison of left leg subtraction angiograms (cropped) obtained with the acceleration-sensitive (top) and velocity-sensitive (bottom) sequences. Venous contamination is indicated by blue arrows. MSG amplitudes of 0.5, 1.0, 2.0, 5.0, 10.0 and 20.0 mT/m are shown (almost no vascular signal is seen for lower amplitudes).

MSG amplitude (mT/m)	0.5	1.0	2.0	5.0
Artery depiction (0–4) [min–max]	**2.0** [1–3]	**2.8** [1-4]	**3.6** [2–4]	**3.9** [2–4]
Venous contam. (0–3) [min–max]	**0.06** [0–1]	**0.13** [0–1]	**0.13** [0–1]	**0.88** [0–2]
Background (0–3) [min–max]	**0.19** [0–1]	**0.06** [0–1]	**0.00** [0–0]	**0.25** [0–1]
Fluid (0–3) [min–max]	**0.00** [0–0]	**0.00** [0–0]	**0.00** [0–0]	**0.13** [0–1]
Other artifacts (0–3) [min–max]	**0.00** [0–0]	**0.00** [0–0]	**0.00** [0–0]	**0.00** [0–0]

Table 1: Qualitative assessments of image quality.

The results of the qualitative assessment are shown in Table 1. The best arterial depiction occurred for the highest two MSG amplitudes. Venous contamination was negligible except for all except the highest assessed MSG amplitude. Background, fluid contamination and other artifacts were mild or absent for all images.

Discussion & Conclusions

Acceleration-dependent preparation does not dephase magnetisation at constant flow [7] but does when flow is pulsatile. This was be used to achieve good artery-vein separation, which could greatly simplify this method for possible future clinical use. The optimal MSG amplitude is around 2 mT/m (aenc 8.96 m/s^2). This method, and the impact of flow profile distortions, are currently being assessed in patients.

References
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