Flow-dependent Arterial and Venous Imaging by Non-Contrast-Enhanced Subtraction Angiography

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Introduction

Recent concerns over the safety of some MR contrast agents have increased the interest in Non-Contrast Enhanced (NCE) MR angiography techniques, such as time of flight, fresh-blood imaging (1) and flow-independent angiography (2). Some dependence of the image signal on blood flow could be beneficial in assessing vessel patency. However, in many potential applications, there is a need for high-resolution 3D imaging of vessels which does not rely on inflow into the imaging volume, and is effective even when the flow is parallel to the imaging plane.

Recently developed dark-blood sequences for vessel-wall imaging (3) suppress the flowing blood signal using a 'diffusion weighting' or motion-sensitising gradient (MSG) preparation module, applied before a fast segmented 3D readout using balanced SSFP or FSE. The ability to influence the blood-suppression independently of the image readout could be used to separate the flowing blood from static tissues. This work aims to investigate the dependence of vascular signals on the MSG properties, and thus to generate high-resolution 3D subtraction images of the vascular anatomy.

Materials/Methods

The lower legs of 4 healthy volunteers (who gave informed consent) were imaged at 1.5T (HDx, GE Healthcare, Waukesha, WI) using an 8-channel cardiac array coil. A MSG prepared, segmented, 3D, balanced SSFP sequence (TE/TR = 1.8/3.8 ms, FOV $30\times12\times12$ cm^3) was used with $1.2\times1.2\times1.2$ mm^3 resolution (interpolated to $0.6\times0.6\times0.6$ mm^3). The gated acquisition was triggered to begin immediately after the peripheral-pulse signal, with one plane of k-space acquired per heartbeat, giving a scan time of ~100 heartbeats. Each shot was preceded by a spectral fat suppression pulse and 10 discarded repetitions with a sinusoidally increasing flip angle, and a centric k-space data acquisition order was used.

The MSG preparation module (3) consisted of 90_x-180_y-90_{-x} non-selective RF pulses, with two matching motion-sensitising gradients after the first two pulses applied along all three gradient axes simultaneously.

For each volunteer the sequence was repeated for several different gradient strengths and durations (0, 1, 2, 4 and 10 mT/m for 8 ms; and 4 mT/m for 12 ms and 16 ms) to assess the effect of the MSG on the arterial and venous blood signal. Subtraction images were constructed from pairs of images to view selectively (a) arteries; (b) veins; and (c) all vessels combined. Images intended for subtraction were acquired close together within a few minutes of one another, to minimise the effects of motion. Longer duration, low-amplitude gradients gave better subtraction images and so were preferred to shorter, larger-amplitude gradients (possibly due to eddy-current effects).

Additional images were acquired using a long-duration (160ms) preparation module designed to suppress venous signal due to the lower T2 of venous blood compared to fully oxygenated arterial blood. This preparation used 4 refocusing pulses.

Results

In all volunteers, the same pattern was observed. Arterial blood appears bright when no gradient is applied, but is suppressed by even very small MSGs due to the pulsatile nature of the blood flow combined with end-systolic image acquisition. By contrast, the slower flowing venous blood and was suppressed only by stronger MSGs.

Subtraction images (shown as maximum intensity projections in Figure 1) were constructed as follows:

- (MSG_0 – MSG_{low}) gives (primarily) arterial images
- (MSG_{low} – MSG_{high}) gives (primarily) venous images
- (MSG_0 – MSG_{high}) depicts all vessels

In each case, MSG_0 represents the images acquired with no motion sensitising gradient, MSG_{low} represents the images acquired with a low MSG area (1 mT/m, 8 ms) and MSG_{high} represents the images acquired with a high gradient area (4 mT/m, 16ms). In all volunteers, the images provided an excellent depiction of the arterial anatomy including small branch vessels. Venous anatomy was also well depicted, although the degree of venous suppression varied, suggesting that further optimisation could be
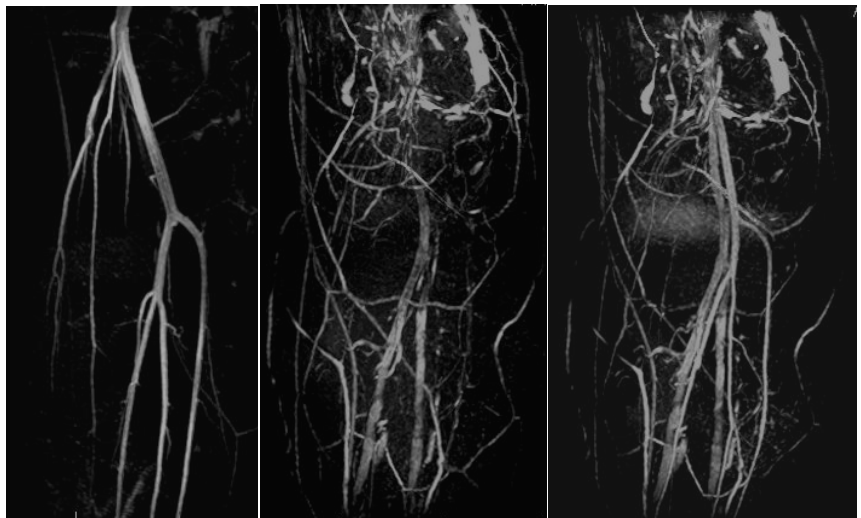

Figure 1: Examples MIPs of around the popliteal trifurcation showing (a) an arterial image; (b) a venous image; and (c) all vessels, in the same volunteer as (b).

possible using an improved choice of MSG areas. Some additional bright regions due to other fluids were also seen.

It was also possible to distinguish slower from faster flowing veins by making an appropriate choice of gradient strengths to subtract (images not shown). Finally, good depictions of the arterial anatomy were also achieved using the 160ms preparation module (images not shown).

Discussion and Conclusions

This work exploits the differences in systolic flow velocities to demonstrate the feasibility of selective arterial and venous imaging, by subtracting different image datasets with varying degrees of flow suppression. In healthy volunteers, an excellent depiction of the vascular anatomy was achieved; after further studies this method might therefore replace contrast-enhanced angiography scans in some clinical situations. This approach could be extended to facilitate selective depiction of pathologically increased or decreased flow situations. Incorporation into a real-time scanning environment could also allow for fine-tuning of the MSG areas on a per-patient basis. Furthermore, comparison of these flow-dependent images obtained with flow-independent angiography methods (2) could facilitate an assessment of vessel patency.

Some further optimisation of the technique is needed, particularly in the selection of appropriate gradients to image the venous anatomy reliably. For example, not all venous signal was adequately suppressed in the MSG_{high} images, so stronger gradients might be used in future.

The technique could be improved by interleaving the acquisition of images to be subtracted, reducing the risk of mismatched images in the subtraction. This might help reduce the residual background signal (seen e.g. in Figure 2c) resulting imperfect subtraction of subcutaneous lipid. An additional benefit of this technique is that vessel-wall diseases such as atheroma could also be assessed using the blood-suppressed (MSG_{high}) images.

References   1. Miyazaki M, et al. JMRI 12:776 (2000).   2. Brittain J et al, MRM 33:689 (1995).   3. Koktzoglou I et al. J Cardiovasc Magn Reson 9:33 (2007).