Identification and removal of residual signal from slow flowing blood in 3D volume selective TSE arterial wall imaging using a velocity sensitive phase reconstruction method

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Aim

Improvement of 3D volume selective TSE artery wall imaging by introducing velocity sensitivity and using the resulting phase reconstruction images to assist in post-processing removal of residual blood signal.

Introduction

The majority of vessel wall imaging of the carotid artery has focussed on 2D techniques.[1-4] This is partly due to time constraints and because of the problems with blood suppression over a large 3D slab. In some subjects, slow recirculating flow, believed to be a feature of carotid bulb geometry,[5] can affect the efficiency of double inversion blood suppression in 3D TSE scans of the carotid arteries. Here, we present a method for identifying residual blood signal in 3D TSE 'black-blood' images. This is needed to give the true vessel wall structure and show residual flow as distinct from true luminal encroachment due to atherosclerotic disease. Velocity sensitive phase images assist in defining clearer lumen/wall boundaries.

Methods

Images were acquired on a Siemens Magnetom Sonata 1.5T scanner. 3D volume selective TSE[6] scans of the arterial wall were acquired in healthy volunteers and patients as well as a straight tube flow phantom with a flow velocity of 30 cm/s. The FOV used was 120 x 24mm and imaging matrix size was 256x52 giving a true pixel size of 0.47 x 0.47mm (which was reconstructed to higher resolution). A slab of 28 2mm thick slices were acquired, with the central slices located around the bifurcation. An echo train length of 11 echoes per cardiac cycle was used to fit the scan within the desired acquisition window (65ms) to avoid motion blurring of the vessel wall due to pulsatility. Inversion time was 600ms and, for T_1 weighting, TE was 11ms. A velocity encoding bipolar gradient pulse was added to the sequence and magnitude and phase image reconstruction was carried out. Some minor velocity sensitivity was observed in the standard sequence and the bipolar pulse, with a venc of 36cm/s, was added with the correct polarity to increase sensitivity. MATLAB was used to threshold the phase images to identify regions of motion and subsequently remove blood signal from affected magnitude images by multiplication of the magnitude and threshold phase images. Distinction between slow moving or recirculating blood and diseased tissue can then be clarified.

Results

In a flow phantom study the addition of the velocity sensitive bipolar pulse alone was sufficient to reduce the observed flow artefact from the magnitude image (figure 1 B&C). Post-processing correction using phase reconstruction intensities removes the artefactual signal further (D).

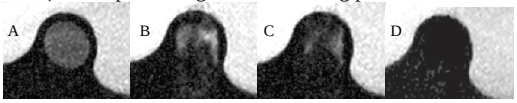
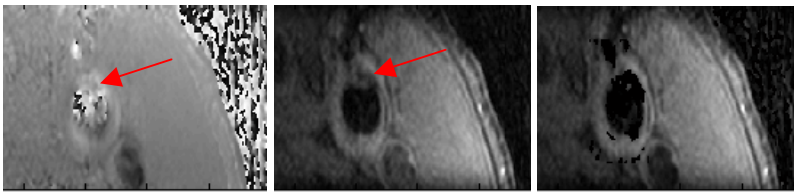


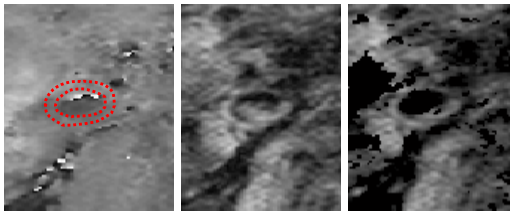
Figure 1. A: static fluid; B: conventional DIR; C: DIR and bipolar pulse; D: corrected image

Flow artefacts are seen in 3D images of both healthy and diseased vessel and, in some cases, faster flow in the region of a stenosis will help to reduce this effect. However, the clarity of the lumen can be improved by this method as illustrated in figures 2 and 3 for the carotid bulb and internal carotid artery. Lumen encroachment by disease is not affected and images remain unchanged when correction is applied.



'Phase' 'Magnitude' 'Corrected'

Figure 2. Residual blood signal in bulb



'Phase' 'Magnitude' 'Corrected'

Figure 3. Residual blood signal in ICA.

Discussion

Optimisation of the velocity sensitivity is needed to achieve the required phase differences for thresholding depending on the flow rates involved. Fast flowing blood will be suppressed by the double inversion preparation. Typical mean and peak velocities in the common carotid are 20 and 40cm/s respectively, giving complete washout from the slab in less than 300ms. For very slow flow the maximum bipolar gradient moment possible in the time available would be the ideal case, but the velocity encoding gradient sensitive to velocities in the range ±36cm/s should be able to detect the recirculating blood with a velocity of perhaps less than 10cm/s,[5] which does not wash out of the slab. A limitation is, of course, that any truly stationary blood will not be affected by this technique and will always be difficult to remove from such images. High resolution is needed as partial volume effects at the boundary may be observed, but these boundary pixels should be more easily identified with automatic segmentation. In regions of static tissue with low signal, phase noise causes the threshold method to produce signal loss in the final images. It is likely that these will be improved by combination with an automatic vessel segmentation technique to focus correction on the vessel of interest. Despite these limitations we have shown in the above examples that regions of plaque and flow can be shown as distinct.

Conclusions

After addition of a velocity sensitive pulse to the 3D volume selective TSE imaging sequence, magnitude and phase reconstruction and post processing can be used to identify and remove residual signal from slow moving or recirculating blood to improve image clarity and assist conclusions about the disease state of the vessel wall.

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