Increased Slice Coverage for Black-Blood Arterial-Wall Imaging with Double-Inversion FSE

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Introduction: The most commonly used method for black-blood MR imaging of atherosclerotic plaque is a fast-spin-echo (FSE) pulse sequence with double-inversion pulses employed to achieve T_1-nulling of flowing blood. This has the drawback of optimally suppressing blood signals for only one slice when a multi-slice sequence is executed (e.g., Fig. 1). Various schemes have been proposed [1-5] to fit more slices into the same imaging time, including one [5] which reorders the slice acquisition [6] to insure that the center of *k* space is crossed at the T_1-null point for each slice. We propose here a new method for producing a relatively large number of slices while suppressing both high and low-spatial-frequency signals from flowing blood.

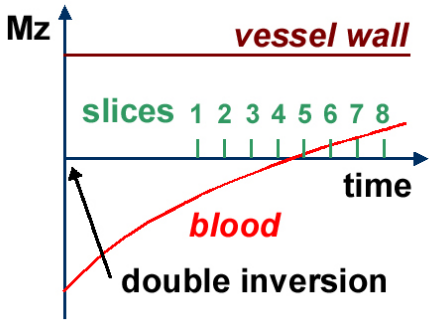

Figure 1. Mz behavior after double inversion.

Methods: This technique is based on a cardiac-gated multi-slice double-inversion FSE pulse sequence played out with the slice timing shown schematically in Fig. 1, for the example of an 8-slice sequence. The first four slices are acquired before the T_1-null, and have progressively diminishing negative residual blood signals, while the last four slices have progressively increasing positive blood signals. The vessel wall, however, which experiences both inversion pulses, is left unaffected.

To better suppress the residual blood signal, two steps are taken: First, the slice order shown in Fig. 1 is used for echo trains acquired from the bottom half of *k* space but, for the top half, the order is reversed (8, 7, 6, 5, 4, 3, 2, 1 in this example). This means that, to first order, the residual blood signal from each slice will have its phase inverted in the top half of *k* space relative to the bottom half (i.e. the *k*-space image is modulated by a signum function in the phase-encode direction). When a complex 2DFFT is applied, the signal from the blood will therefore be pushed into the quadrature (Q) component (assuming an image which is nominally in the in-phase (I) component). The second step then is to form the image from the in-phase component alone, leaving the residual blood signal suppressed. In practice, there can be some phase bias across the image, from various sources. An estimate of the phase bias is formed using an Expectation-Maximization algorithm jointly estimating the phase roll and class (flowing blood or static tissue) of each pixel [7]. A phase-bias estimate is formed for each coil individually; class membership is formed jointly from all of the coils. The algorithm iteratively estimates the class membership of each pixel (E-step) then estimates the phase bias (M-step) from the smoothed residuals of the E-step, yielding an estimate of each coil's phase bias and class memberships for each pixel.

Results: The above technique was used with a phased array (4-elements, each 2"x2", overlapped in transverse direction) to acquire carotid images from normal volunteers (FOV 90mm, 256x256, ETL 8, 6-8 slices, 4 mm slice) Figures 2a-b show phase images acquired simultaneously from 2 of the 4 phased-array elements. Figures 2c-d show the same phases after unwrapping, and Fig. 2e shows an estimate of the phase-bias field from the second coil. Figure 2f shows the arterial-blood class probability based on the phase from all coils. Figures 2g-h show the phased-array magnitude image before and after suppressing the residual blood signal, respectively. Suppression factors for arterial blood were around 10, on average.

Discussion: Slice reordering with phase correction shows promise for producing a relatively large number of slices while suppressing signals from flowing blood. It should be possible to combine this method with other techniques [3-4] for increasing the number of slices. While a signum modulation of *k* space was used here, any odd function that can be achieved through slice reordering (e.g. a ramp crossing zero in the center of *k* space) is compatible with this method.

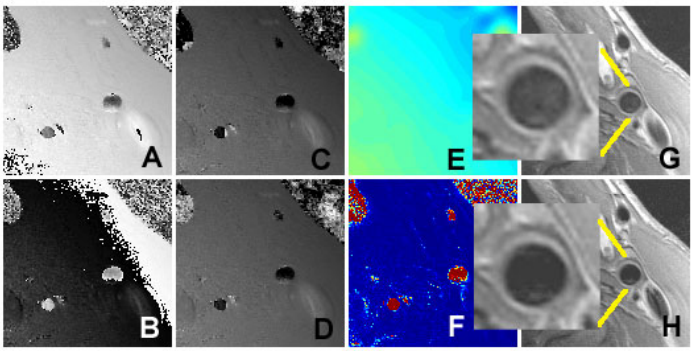

Figure 2. Common carotid images. A-B) Phase images from 2 of the 4 coils, C-D) after unwrapping. E) Phase bias for coil of B) and D). F) Arterial-blood class probability. G-H) Phased-array image before and after suppression, respectively.

References

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