High Resolution Diffusion Weighted Imaging of Human Carotid Artery using 2D ss-rFOV-DWEPI at 3 Tesla

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INTRODUCTION: Magnetic resonance imaging (MRI) has been shown to be useful for visualizing disease in the carotid artery and for measuring vessel wall area. Many publications show that images of the carotid artery with multiple contrasts can help with plaque component identification.[(1,2)] Atherosclerotic plaque characterization by black blood MRI is generally based on the signal intensities and morphological appearance of plaque in T1, PD and T2 weighted images, but intraplaque thrombus cannot be detected by conventional contrast imaging. Recently it has been reported that diffusion weighted imaging of excised human specimens can enhance the contrast between thrombus and vessel wall.[(3,4)] In spite of the potential utility of DWI in the cervical carotid, motion and susceptibility problems generally make the application in vivo difficult. To attain high resolution DWI of human carotid, we have developed a 2D single shot (ss) reduced field of view (rFOV) in conjunction with an abbreviated EPI readout using a pair of slice selective refocusing RF pulses with the selection gradient in phase-encoding direction. [(5)]

METHODS: Figure 1-(A) shows the pulse sequence diagram of 2D ss-rFOV-DWEPI. Slice-selection gradients are applied in the slice direction for the 90^o excitation and in the phase direction for first two 180^o refocusing RF pulses. The 90^o RF pulse and the first 180^o RF pulse are used to limit the field of view (FOV) in the phase encoding direction. To allow interleaved acquisition, the second PE selective 180^o RF pulse immediately after EPI readout recovers the magnetization in the slices external to the currently imaged slice. This last RF pulse is followed by a spoiling gradient to destroy any remaining transverse magnetization. Figure 2 describes the magnetization evolution of the imaged and other slices in the volume of interest during one cycle of 2D ss-rFOV-DWEPI acquisition. The first PE selective 180^o RF pulse is applied to refocus the spins in the limited region of the image slice and at the same time inverts the spins in the out-of slice region. After the 2nd diffusion gradient and the EPI signal readout, the second PE selective inversion/refocusing RF pulse applied to return the spins in the non-imaged slices toward their preferred state, aligned along B_o. Thus the magnetization external to the imaged slice experiences two 180^o pulses separated by a short time period τ (about 42 ms for an ETL of 33) and therefore has only a small loss in value, enabling interleaved multiple-slice acquisition. All volunteer studies were performed on a Siemens Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with our home built four element bilateral phased array carotid coil. Carotid arteries of a normal subject centered at the bifurcation apex were scanned with 2D ss-rFOV-DWEPI. The imaging parameters were: receiver bandwidth = 1.086 kHz/pixel, FOV=192x50mm, imaging matrix = 192x33, 2 mm slice thickness, effective TE = 66 ms, TR = 4 s, 33 echoes per echotrain, 32 averages (magnitude) and interleave acquisition of 8 contiguous slices. The in-plane spatial resolution for data acquisition was 1.5x1.0mm with display resolution 1.0x1.0 mm^2, after zero-filled interpolation. Total scan time was 4:24 min for two b-values (0, 250 sec/mm^2). After two b value images were acquired, the ADC map was calculated and displayed using IDL. T1/T2 images were acquired with two or three interleaved TSE with our modified version of the double inversion preparation sequence[(6)] with TR=750ms/2s , TI=150/350 ms, TE=9.5/65.4 ms, acquisition matrix = 256x256 and, 13 cm FOV, 2 mm slice thickness, and 9 echotrain.

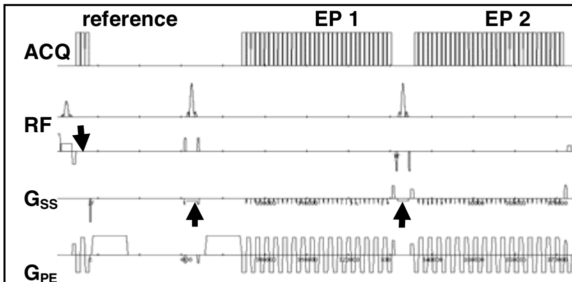

Figure 1 2D ss-rFOV-DWEPI pulse sequence diagram

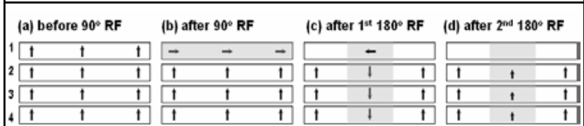

Figure 2 Magnetization evolution imaging slice 1; interleaved acquisition of four slices using 2D ss-rFOV-DWEPI.

RESULTS: DW Images of the carotid artery from a normal subject using 2D ss-rFOV DWEPI sequence are displayed in figure 3. Each column shows DWI (b=10, b=250 sec/mm^2) from identical locations. All of DW images demonstrate good blood suppression with decent SNR and less susceptibility artifact between tissue and air compared to the original DWI technique. Figure 4 shows the T1, T2, and diffusion (b=10, 250 s/mm^2) weighted images from a patient volunteer and the ADC map. Each column shows different contrast images from the same location. The plaque area is shown as hyperintense signal in all of the T1, T2 and DW images. Some plaque with high water content, such as necrosis or old hemorrhage may be very bright or of intermediate intensity with T2 weighting. The ADC of the plaque area (red arrow) was calculated as 2.48x 10^{-3} mm^2/sec. This value is close to the ADC value reported previously from an ex-vivo sample.

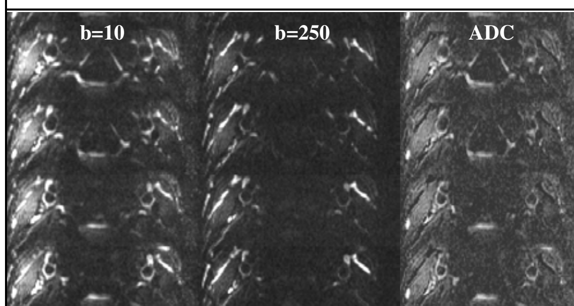

Figure 3 DWI from normal volunteer. The ADC map were calculated using b=0, 250 sec/mm^2. All DW images demonstrate the good blood suppression.

DISCUSSION: The high resolution and limited FOV readout results in reduced susceptibility artifacts while yielding relatively low image SNR on each shot. Because of the single shot acquisition, each image is free from phase errors caused by the diffusion gradients. To increase SNR multiple averages of the magnitude images are acquired. The results obtained indicate that DW imaging may be of substantial value as a new contrast for carotid plaque imaging. The results also indicate (Figure 3) that this single shot technique with a small b-value can be used to obtain reduced artifact and good blood suppression in black blood imaging.

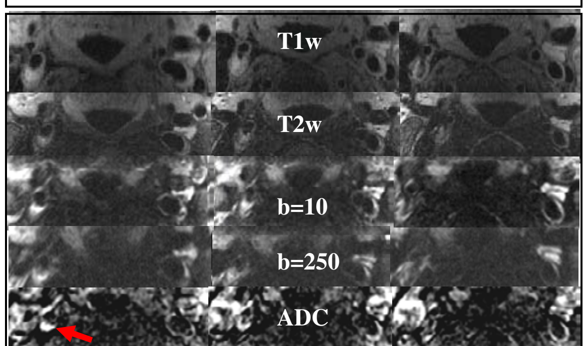

Figure 4 Multiple contrast black blood images including T1, T2, diffusion weighted images and ADC Map DWI ss-rFOV-DWEPI from a patient volunteer

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