# Bipolar TSE and Bipolar 3D GRASE for Rapid Multi-slice (Multi-slab) High Field Magnetic Resonance Imaging Acquisition of Carotid Artery Wall

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INTRODUCTION: MRI offers the capability to image both the vessel lumen and the arterial wall composition. Conventionally, when assessing the arterial wall, either double inversion recovery (DIR), inflow saturation, or motion sensitive driven equilibrium (MSDE) black blood (BB) preparations are employed to suppress the blood signal [(1)]. These modules have historically been added for BB enhancement to turbo spin echo (TSE) and gradient and spin-echo (GRASE) imaging protocols in order to assess carotid artery walls.. However, a common problem for all these BB preparation modules is that the employment of non-selective hard pulses prevents effective multi-slice (2D) or multi-slab (3D) imaging acquisition. This limitation results in long acquisition times when a large anatomical region (e.g., several cm of vessel wall coverage) needs to be studied in a clinical investigation. In this work, we demonstrate a possibility to avoid using any RF preparation pulses as part of a fast BB imaging acquisition. Instead, bipolar gradient pairs are introduced into 2D TSE and 3D GRASE pulse sequences for BB suppression, termed Bipolar TSE and Bipolar 3D GRASE. Preliminary results indicate that the final average imaging speed has been increased dramatically up to 5 sec/slice or even faster (at least 2 or 3 times faster than conventional methods) with acceptable BB imaging quality and comparable SNR.

THEORY:

Flow-crushing bipolar gradient pairs are introduced into each echo along the slice direction before and after signal acquisition, as shown in Fig. 1. Diastolic blood velocities in human carotid arteries range from 10-20 cm/s depending on the heart pulse rate and size of vessel. In spin-echo sequences, incomplete refocusing results from spins flowing through the imaging plane, causing blood signal loss, depending on the slice thickness and echo spacing. Bipolar gradients introduced immediately after the 180° pulses will enhance this effect by causing additional phase dispersion. A subsequent bipolar gradient pair introduced after signal acquisition minimizes unwanted motion-induced phase accumulation in static tissue.

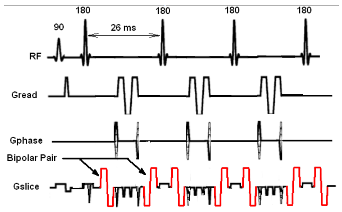



**Fig. 1**: Flow-crushing bipolar gradients inserted into a GRASE readout train

The bipolar pair within each echo refocuses not only the zeroth order moment but also the first order moment. In this way, every echo will have an equivalent effect in regard to flow suppression rather than every other echo[(3)]. Since there are no hard RF pulses involved in the imaging pulse sequence multi-slice imaging acquisition speeds can correspondingly increase by several factors compared with conventional DIR- or MSDE-prepared spin echo imaging methods. Additionally, the bipolar pairs prevent artefacts caused by the $T_1$ recovery of the blood signal. However, the disadvantage of this bipolar scheme is the relatively large echo spacing which may compromise image SNR and point spread function. This problem can be partially addressed with segmented 3D imaging acquisitions with multi-slab excitation. Here, we compared the new bipolar method with the standard DIR method. All experiments used a 3 Tesla Siemens Verio scanner, and five healthy subjects were studied.

RESULTS:

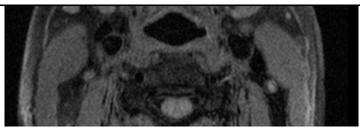
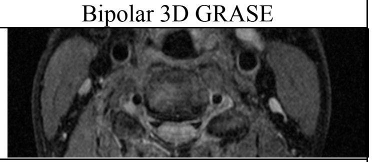
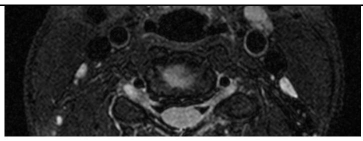
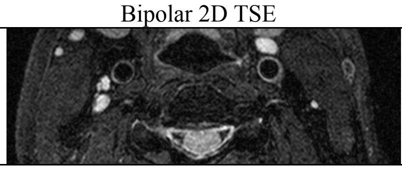
| | DIR 2D TSE | MSDE 2D TSE | Bipolar 3D GRASE |
|---|---|---|---|
| $T_1$ weighting<br>256×252<br>1 Average |  |  |  |
| Image parameters | TR=1s, TE=13 ms, ETL=9,<br>BW=130 Hz/pix<br>Acq speed = 28 sec/slice,<br>SNR = 13.8, $CNR_{ml}$ =12.1, **$CNR_{eff}$ = 2.3**<br>Single slice sequential acq | TR=1s, TE=9 ms, ETL=12,<br>BW=260Hz/pix<br>Acq speed = 10 sec/slice,<br>SNR = 8.4, $CNR_{ml}$ =6.8, **$CNR_{eff}$ = 2.15**<br>2 slice interleave acq | TR=1s, TE=26 ms, ETL=5,<br>BW=543 Hz/pix<br>Acq speed = 5.4 sec/slice,<br>SNR=13, $CNR_{ml}$=11.1, **$CNR_{eff}$ = 4.8**<br>5 slabs interleave acq, 8 slices/slab |
| | DIR 2D TSE | Bipolar 2D TSE | **Definitions** [(2)] |
| $T_2$ weighting<br>256×252<br>2 Averages |  |  | $SNR=aS/\sigma$<br>a: 0.695 to account for Rician noise<br>S: signal intensity; σ: standard deviation of noise<br>$CNR_{ml}=SNR_{muscle} - SNR_{lumen}$<br>**$CNR_{eff}$**$= CNR_{ml} / (T_{SA})^{1/2}$<br>$T_{SA}$: average scan time for each slice (in sec)<br>Note: All definitions are taken from ref 2 with the exception of $T_{SA}$ |
| Image parameters | TR=2s, TE=80 ms, ETL = 15,<br>Acq speed = 72 sec/slice,<br>SNR = 5, $CNR_{ml}$ =3.1, **$CNR_{eff}$ = 0.36**<br>Single slice sequential acq | TR=2s, TE=80 ms, ETL = 9,<br>Acq speed = 7sec/slice,<br>SNR = 5.6, $CNR_{ml}$=3.9, **$CNR_{eff}$ =1.5**,<br>16 slice interleave acq | |

**Figure 2**: Image quality and image acquisition efficiency ($CNR_{eff}$) comparison of DIR 2D TSE, bipolar 2D TSE and bipolar 3D GRASE

DISCUSSION: Compared with the conventional DIR BB prepared method, the imaging acquisition efficiency ($CNR_{eff}$) of bipolar 2D TSE and bipolar 3D GRASE has been increased dramatically (2-4 times that of conventional methods) since no hard pulses are required in the BB module. We conclude that bipolar gradients in spin-echo-based imaging sequences appear to be a very promising prospect for fast BB image acquisition.

REFERENCES: 1. R.R. Edelman et al. Radiology. 1991 181:655-660; 2. Wang J et al. J Magn Reson Imag. 2010 31(5):1256–1263; 3. Amar A, Blumich B. ChemPhysChem, 2010 11(12): 2630-2638

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