Artifact Associated with Fat Suppression in Spin-Echo EPI

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Target audience: Researchers using spin echo EPI

Purpose: The spin echo technique provides higher sensitivity to microvasculature functional changes[1] and is less sensitive to susceptibility-related signal loss/artifacts[2] compared to gradient echo. Spin echo EPI (SE-EPI) has been used to detect functional activation[2,3], and is intrinsic to diffusion imaging. A common artifact associated with EPI sequences is the displacement, in the phase-encode direction, of chemically shifted signals from fat due to EPI's slow traverse along that direction. As such, effective fat suppression is crucial to acquiring clean EPI data. Spectral fat saturation (FatSat) is the most common fat suppression method used for EPI and consists of applying a chemical-shift selective but spatially non-selective RF pulse to excite fat and then dephasing the resulting fat signal via spoiler gradients[4]; the slice is then excited and acquired via an EPI traversal of k-space (see Figure 1). While FatSat works effectively for GE-EPI, we have found that when applied to SE-EPI sequences it results in a residual, but significant and highly structured artifact. The following presents our preliminary findings relating to this artifact.

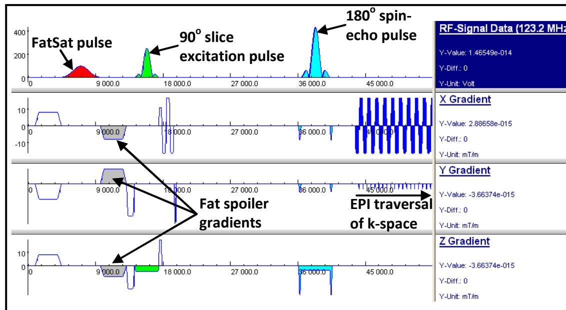

Fig 1: Sequence diagram of SE-EPI acquisition with FatSat

Methods: A variety of scans were conducted on a 3T Tim Trio scanner (Siemens, Erlangen, Germany) with a 32-channel head coil; Table 1 summarizes variations for both human and phantom experiments. *Human experiments*: 9 subjects were scanned in resting state for 6min20s using a SE-EPI sequence (TR = 2000ms, TE = 45ms, 26 slices, 4mm slices, 64x64 matrix, 3.44mm in-plane resolution, flip angle = 90°, bandwidth = 2170 Hz/px, echo spacing = 0.55ms, readout train = 35.2ms, GRAPPA acceleration factor = 2, 24 reference lines), as well as a GE-EPI sequence (same parameters except TE = 30ms, no GRAPPA), both with FatSat implemented. Another subject was scanned both with and without FatSat as well as using binomial excitation ("Water Excite"). Finally, we conducted a hypercapnic respiration task on one of the subjects to assess the relative magnitudes of task effect vs. artifact. *Phantom experiments*: A bottle phantom (1900ml; per 1000g H_2O dist.: 3.75g $NiSO_4$ x $6H_2O$ + 5g NaCl) lying on a small bag of mineral oil (to mimic subcutaneous fat in scalp) was scanned using the above SE-EPI protocol, as well as with variations indicated in Table 1. The phantom was also scanned with and without localized manual shimming. Subject data was slice time corrected, motion corrected, and spatially smoothed (5mm FWHM); human and phantom data were both high-pass filtered at 0.008Hz. Independent component analysis (ICA) was then carried out separately on all scans via FSL[5] MELODIC (Christian F. Beckmann, University of Oxford, Copyright(c) 2001-2008).

	Parameter	Variations Tested	Result
Human Scans	Scan Type	SE-EPI, GE-EPI	Artifact only found in SE-EPI
Human Scans	Fat Suppression	None, FatSat, Water Excite	Artifact only found with FatSat
Human Scans	Task	Resting State, Hypercapnic Respiration	Variance accounted for by artifact more than ¼ that accounted for by hypercapnic task
Phantom Scans	TR (ms)	250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 3000	Artifact less evident with longer TR; frequency of artifact inversely proportional to TR
Phantom Scans	# of Slices	3, max possible for each TR	Artifact less evident with fewer slices
Phantom Scans	TE (ms)	35, 45, 55, 65, 75	No effect
Phantom Scans	GRAPPA	no GRAPPA, GRAPPA using: 12, 24, 26, 32 reference lines	No effect
Phantom Scans	Bandwidth (Hz/px)	1086, 2170, 3256	No effect

Table 1: Scan variations tested for human and phantom experiments

Results: For all SE-EPI scans in which FatSat was used, ICA produced a fat artifact component (see Figure 2), primarily with a single peak at 0.133/TR Hz (≈ $^{2}/_{15TR}$ Hz); this particular artifact was not found in the ICA of any GE-EPI data, nor SE-EPI data for which FatSat was not used (i.e. FatSat was off, or Water Excitation instead of FatSat used). While the hypercapnic task accounted for 6.6% of the total scan variance, the FatSat artifact accounted for 1.82% (~ 27% of the task-effect size). Of all scan parameters, only the TR and number of slices had an effect on the magnitude of the artifact (see Table 1 and Figure 3). Finally, the same FatSat artifact was found in our diffusion MRI data, which is effectively based on SE-EPI.

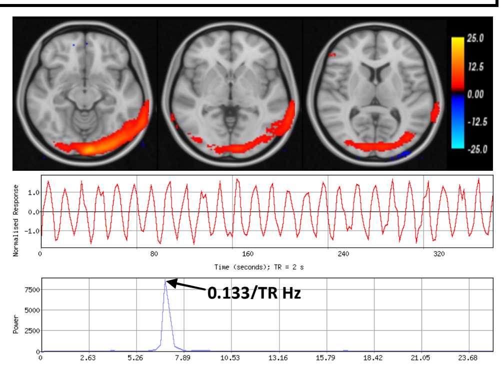

Fig 2: Typical FatSat artifact component: A) thesholded map (alternative hypothesis test at p > 0.5), B) time course, and C) power spectrum

Discussion: When applied to SE-EPI, FatSat fat suppression creates a time-varying fat artifact that oscillates at a predictable and TR dependent frequency. The total signal variance accounted for by this artifact was more than 1/4 of that accounted for by a hypercapnic task. As such, this artifact is not negligible, and would be of particular concern for analyses that rely on detecting small/non-task related signal fluctuations (e.g. resting-state functional analyses). As the artifact became weaker with longer TR, we postulate that it is caused by the FatSat excitation pulse. In addition, acquiring more slices per TR resulted in a stronger artifact, possibly because this intrinsically means implementing FatSat more frequently. However, further investigation is required to understand the mechanism causing this artifact. Water Excitation does not suffer from this artifact and would be an appropriate alternative form of fat suppression for SE-EPI.

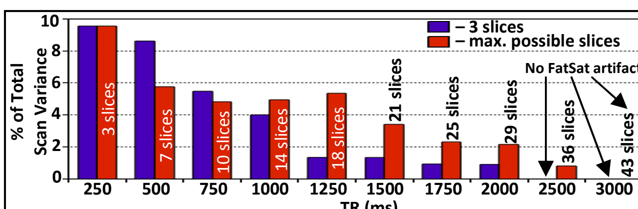

Fig 3: Effect of TR and number of slices on % of total variance in phantom scan accounted for by FatSat artifact component

Conclusion: When applied to SE-EPI scans, FatSat fat suppression produces a non-negligible fat artifact that oscillates at a predictable and TR dependent frequency. As such, on Siemens scanners for instance, it is recommended that Water Excitation rather than FatSat be used for SE-EPI sequences. Further investigation into the exact source and nature of this SE-EPI FatSat artifact is required.

References: **[1]** Biswal, B et al. Magn Res Med 1995; 34:537-41 **[2]** Khatamian, Y et al. Proc Intl Soc Mag Res Med 2013; 21:2234 **[3]** Majeed, W et al. Proc Intl Soc Mag Res Med 2009; 17:1666 **[4]** Haase, A et al. Phys Med Biol 1985; 30:341-344 **[5]** Jenkinson, M et al. NeuroImage 2012; 62:782-90