Spectral characterization of subvoxel magnetic susceptibility deviations

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Introduction –In MRI, small objects with a magnetic susceptibility that deviates from the background susceptibility will show up as signal voids in gradient-echo (GE) imaging due to intra-voxel dephasing of the MR signal. For studies in which presumably small metal fragments [1] or small iron deposits as a remainder of past microbleeds [2] are observed, characterization and discrimination of the artifacts can be necessary or instructive. Besides, signal decay curves, which are actually the inverse Fourier descriptions of spectra [3], can be used to determine the volume fraction and/or amount of distorting material. In order to quantify and/or characterize sub-voxel susceptibility artifacts, most methods, for example height measurements of the spin echo artifact [4], or phase mapping [5] and spin-tagging [6], fail to describe such small objects satisfactorily because of limited spatial resolution. However, since the underlying phenomenon of all observed susceptibility artifacts is spectral broadening, measurement of the frequencies around the distorting particle, i.e. the spectrum, is thought to be a more reliable and less acquisition dependent way to characterize small susceptibility artifacts. The only study reported sofar that described the spectrum of a dipole field distortion employed a spherical voxel [3]. In this study, by simulations and experiments, we describe and characterize the spectrum of cubical voxels containing magnetic susceptibility deviations of subvoxel size that differ in volume fraction or strength.

Materials and Methods – *Simulations:* The spectrum of a subvoxel was calculated by assuming a spherical particle of certain strength $\Delta\chi V$, where $\Delta\chi$ is the difference in susceptibility with the background and V is the particle's volume. The 3D analytical value of the magnetic field [7] of this spherical distortion was numerically evaluated within a given volume of interest (VOI) and translated to a spectrum p(f) in arbitrary units. The VOI was cubical or spherical and the numerical spectrum of the latter was compared to a known analytical expression [3] as was calculated for a spherical voxel. The difference between a spherical and cubical voxel was determined by calculation of the signal decay curves, corresponding to a given particle and VOI. By varying the volume fraction and strength of the subvoxel distortion, spectra were assessed for their usefulness of characterizing and discrimination. *Experiments:* To verify the theoretically determined spectra, a spherical air cavity was mounted in the middle of a large cylindrical cup filled with manganese doped water and imaged at a clinical 1.5 T system with a quadrature birdcage receive coil. The volume of interest (VOI) was chosen such, that the cavity encompassed VOI fractions of 0.5, 0.25, 0.10, and 0.05. Acquisition parameters: single isotropic VOI, 48 measurements, TR/TE = 2000/136 msec, readout of 0.98 Hz/point, bandwidth 4 kHz, no water suppression or shimming applied. Then, an aluminum sphere with same strength of distortion ($\Delta\chi V = 2.5\times10^{-3}mm^3$) was investigated with the same VOI's as used for the air cavity.

Results - *Simulations:* The spectra and signal decay curves for a spherical and cubical VOI differed significantly (Fig 1), even for a moderate $\Delta\chi V$'s or small volume fractions. Comparison of spectra of different particles showed that distinct differences exist at higher frequencies (Fig 2). For larger VOI fractions, the spectrum narrowed and for stronger deviations, spectral broadening was observed. Depending on the strength of the deviation, clear maxima of the present frequencies were observed, which related to field distortions at or near the surface of the particle. *Experiments*: Measured and calculated spectra showed a good correspondence of their shape (Fig 3). Observed differences most probably related to spatial positioning of the experimental VOI. The aluminum sphere showed a broader spectrum with higher maxima as compared to the air cavity.

Discussion – To avoid inaccuracies in quantification or characterization of subvoxel particles due to insufficient spatial resolution, a spectral description of subvoxel magnetic susceptibility deviation was investigated. A major finding was that cubical and spherical VOI's significantly differed, e.g. 20% of the original signal at short echo times. If used for quantification purposes this can result in inaccurate determinations of the actual amount of distorting material. Discrimination between differently sized particles with equal strength of distortion especially was based on differences in higher frequency regions that are spatially close to the particle. Because spectral information of these high frequency regions is only a small fraction of the total signal, the signal-to-noise ratio should be high to distinguish high frequency differences. In this perspective, the volume fractions of the objects to discern should not be too small and preferably encompass at least a tenth of a VOI. In future studies we will investigate the shape dependence of the spectral description apply this to distinguish between several possible shapes of the distorting objects.

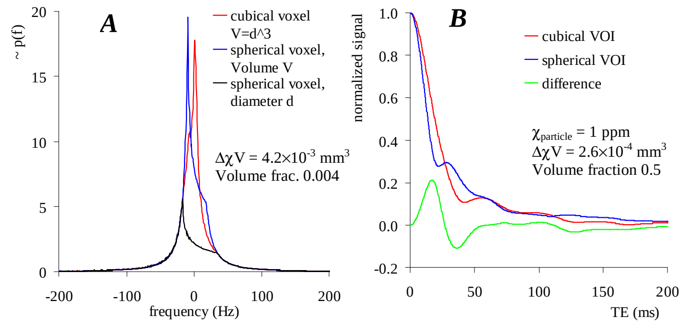

Figure 1: *Comparison of (a) the spectra and (b) normalized signal decay curves for respectively a cubical and spherical voxel. The green line represents the difference in the normalized signal.*

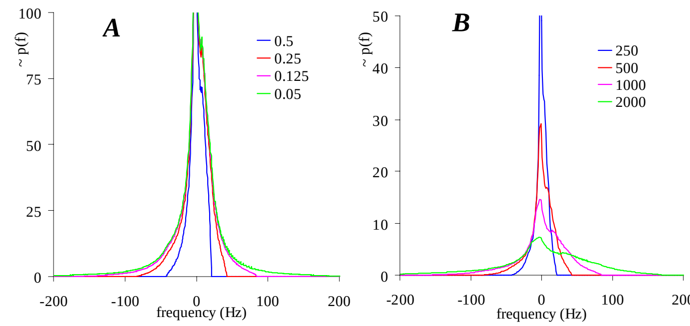

Figure 2 *Comparison of (a) spectra for different volume fractions at constant $\Delta\chi V$ of $5.0\times10^{-4}mm^3$ and (b) spectra for different strength $\Delta\chi V$ ($\times10^{-6}mm^3$) at a constant volume fraction of 0.5, both evaluated for a cubical voxel*

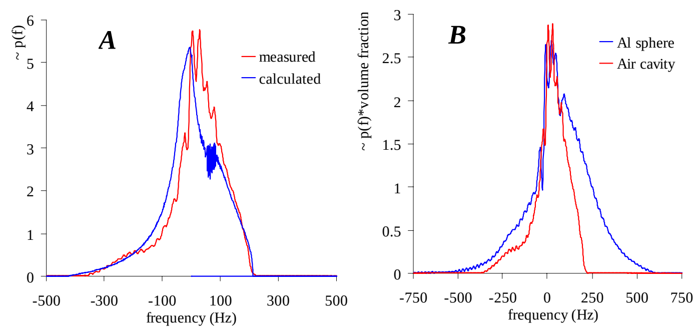

Figure 3 *(a) Measured versus calculated spectrum for a spherical air cavity encompassing half a VOI. (b) Comparison of spectra for an air cavity and an aluminum sphere with equal strength $\Delta\chi V$. Spectra are scaled to the maximum achievable signal in the VOI (=1-Volume fraction).*

References: [1] Wingerchuk D, Neurology 1997: p. 1451-1453; [2] Fazekas F, Am J Neuroradiol, 1999: p. 637-643; [3] Cheng YC, Magn.Reson.Imag. 2001: p. 1017-23; [4] Beuf O, J Magn Reson B, 1996: p. 111-118; [5] Yamada N, Radiology 1990: p. 561-565; [6] Mosher TJ, Magn.Reson Med, 1991: p. 251-255; [7] Baghwandien R, Magn Reson Imag 1994: p. 101-107;