Removing air-tissue artifacts in phase images by modulating the air susceptibility

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Introduction: In recent years the appearance of susceptibility weighted imaging (SWI)[1] and of phase imaging [2], led to increased interest in the information present in the phase of gradient-echo images. It has been shown that tissue contrast in phase images [3] between tissues can be superior to that found in normal magnitude images. Nevertheless, to obtain such high quality images, some post.processing is necessary to remove the effects of slowly spatially varying phase drifts arising from susceptibility differences between air and tissues. The application of such filters makes the analysis of the data more subjective and often fails in regions proximal to air-tissue interfaces. Recently it has been proposed that the field generated by the ear canal, nasal and frontal sinuses could be computed using information from anatomical scans [4]. The aim of this study was to evaluate the possibility of directly measuring the effect of air-tissue interfaces via the modification of the air susceptibility, achieved by variying the oxygen content of the air in the magnet bore.

Theory & Methods: Air susceptibility, $\chi_{v,air}$, is ~0.35ppm while χ_{tissue} is close to χ_{water}: -9.04ppm. The main constituents of air are O_2 and N_2 which have a susceptibility of 0.37ppm and -5.06×10^{-3}ppm at 0.21 and 0.78 atm respectively. Changing the oxygen fraction from 20 to 60% allows a variation of χ_{air} of 1.06ppm. This implies a 0.71ppm variation of the air-tissue susceptibility difference compared to the initial 9.39 ppm difference (~7.5%).

Phantom and volunteer experiments were performed on a 7T MR scanner (Siemens Medical Solutions, Erlangen, Germany) with a head gradient insert and a birdcage RF-coil (Invivo). The imaging protocol consisted of a multi-slice multi-echo GRE sequences with TR=260ms, TE=4:4.87:28.35 , BW=260, mm slice-thickness, in-plane resolution $0.8\times0.8mm^2$. 8 slices of 2mm thickness acquired in 44 secs.

The oxygen fraction of the air was modulated using compressed air and oxygen. During both phantom and volunteer experiments, the oxygen content of the bore was monitored with an oximeter (Polytron2, Dräger, Germany). O_2 in the bore was increased from 20.7% to 62% in approximately 20 minutes. During the oxygen modulation period, low-resolution images (sagittal and transversal) of regions close to the sphenoid sinus were acquired. Frequency maps, $\Delta\omega$, from the multiple echo images were calculated for each time point. Subsequently, a oxygen frequency map, $\Delta\omega_{oxy}$, was calculated as $\Delta\omega_{air60} - \Delta\omega_{air20}$. $\Delta\omega_{oxy}$ was used together with polynomials representing 2nd order shims, used to compensate numerically the frequency shift inhomogeneities at all time points by means of matrix inversion.

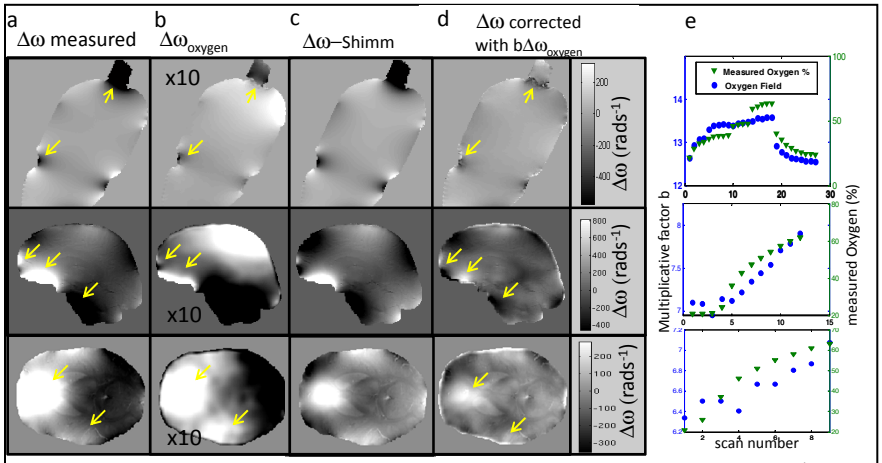

Figure 1 Sagittal slices of a phantom (1st row) and sagittal and axial slices of two subjects (2nd and3rd row) representing the: (a) frequency shift maps, $\Delta\omega$, as measured from the multiple echo before oxygen modulation; (b) frequency shift map attributed to oxygen, $\Delta\omega_{oxy}$ (difference between $\Delta\omega$ at minimum and maximum oxygen concentration, multiplied by 10 facilitate visualization); (c) frequency shift map before oxygen modulation corrected with polynomials corresponding to first and second order shimm terms; (d) field map as measured from the multiple echo before oxygen modulation corrected with polynomials corresponding to first and second order shimm terms and $\Delta\omega_{oxy}$. On the right it is possible to visualize the good correlation between the measured oxygen fraction (green triangles) and the amplitude of the multiplicative factor (blue circles) needed to cancel the spatial inhomogeneities from the original frequency shift maps.

Results & Conclusions Results showing that introducing the field attributed to air, helps explaining frequency shift inhomogeneities observed both on human and phantom data are shown in Figure 1. It should be noted the tissue phase contrast remains unchanged in the process. From the timecourses in figure 1 it can be concluded that modulation of the air-susceptibility allows to calculation of a fieldmap associated with air-tissue interfaces, $\Delta\omega_{oxy}$, which forms a good predictor of the oxygen concentration at any time point. Furthermore, this fieldmap can be used to remove nasal sinus artifacts from phase images (figure 1d, middle and bottom panel). Such a correction should allow improved visualization of vessels and structures closer to boundaries [4]. The multiplicative factor on Figure 1e is closer to the expected 9.39/0.71 (see theory section) on the phantom data, suggesting that in the human data $\Delta\omega_{oxy}$ also partially fits frequency shift effects due to bone-soft tissue interfaces.

We propose that such fieldmaps should improve the calculation of tissue-susceptibility distributions for the following reason. Because the air-tissue susceptibility differences are larger then tissue-tissue susceptibility differences by a factor of ~187 (χ_{GM}=-9.04ppm and χ_{WM} =-8.99ppm=> $\delta\chi_{WM,GM}$=0.05ppm [5]), iterative methods [6] are likely to spend most of their convergence effort on the air tissue boundary instead of more accurately assessing the tissues susceptibility difference.

References & Acknowledgements [1] Haacke et al ., MRM., 52, 612-18, 2004 [2] Rauscher et al., AJNR, 26, 736-42, 2005 [3] Duyn et al, PNAS, 104, 11796-801, 2007 [4] Neelvali et al., JMRI, 29, 937-48, 2009 [5] Schafer et al., Neuroimage, 48, 126-37, 2009. [6] Rochefort, L. et al., Proc. ISMRM, 463, 2009; This work was supported by the Centre d'Imagerie BioMédicale (CIBM) of the UNIL, UNIGE, HUG, CHUV, EPFL and the Leenaards and Jeantet Foundations.