Suppression of Large Scale Susceptibility Artifacts in Positive Contrast Images

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Introduction The detection of contrast agents based on iron oxides (e.g. super paramagnetic iron oxide SPIO particles) is hampered by the fact that they induce negative image contrast. SPIOs are usually imaged via T2 or T2* weighted sequences, which show signal losses at the site of contrast agent accumulation, due to field disturbances induced by the susceptibility of the SPIOs. Several MR sequences have been proposed to convert this dark signal into a positive contrast [1-3]. The different approaches show bright positive contrast images, but prior knowledge about the strength of the field disturbance is required in order to optimize positive image contrast. These approaches are also sensitive to large-scale susceptibility artifacts as they e.g. occur at air/water interfaces. We developed a method for positive contrast imaging by means of susceptibility gradient mapping (SGM) [4]. This post-processing technique calculates a vector map of the susceptibility gradient, i.e. for each voxel the direction and the amplitude of the changes in susceptibility are given. The SGM technique does not require any prior adaptation and can be performed without the use of special sequences, i.e. via a conventional single gradient echo 3D examination. We demonstrate that, by using appropriate filtering, the information about the direction of the susceptibility gradient can be used to suppress large-scale susceptibility artifacts in positive contrast images. This enlarges the selectivity of the method for e.g. the detection of iron oxide labeled cells.

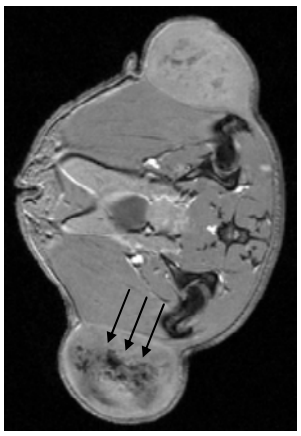

Fig. 1: Gradient echo image of a rat bearing flank tumors. Arrows indicate the SPIO labeled cells.

Theory An object with a magnetic susceptibility that deviates from the surrounding creates a local inhomogeneous magnetic field. During the acquisition of a gradient echo based image, these susceptibility gradients locally alter the imaging gradients that are applied. In addition to the well-known geometric distortion, this leads to a shift of the affected echo in k-space [5]. The SGM method determines this echo shift for every voxel in all spatial dimensions by means of local one-dimensional FFTs, that generate a coarsely resolved k-space, which can be used to measure the shift of the echo, and therefore measure the strength of the susceptibility gradient. A three-dimensional vector is generated for each voxel that contains the strength of the susceptibility gradient for all spatial dimensions [4]. The information that is contained in the direction of this vector field can be used to suppress large-scale susceptibilities in the following way: All vectors near an air/tissue interface point in a similar direction as can be seen in Fig. 1c, the vectors induced by distributed labeled cells point in more random directions as shown in Fig. 1d. Calculating a vector sum in e.g. a 3x3x3 voxel volume that surrounds the voxel of interest, will therefore give a large absolute value for air/water susceptibilities and a smaller absolute value for distributed cells. Applying this vector sum calculation to all voxels generates a vector sum value for each voxel that contains information about the local homogeneity of the susceptibility influence. This allows setting a threshold value to suppress large-scale susceptibilities in a positive contrast image and only displaying positive contrast values that are below this threshold.

Materials and Methods In vivo experiments were performed on nude rats on a 3T whole-body scanner (Philips Intera) using a dedicated 7cm rat solenoid RF-coil. C6 glioma cells were labeled with Ferumoxides-protamine sulfate (FEPro) complexes using procedures previously described [6]. The rats were implanted subcutaneously with 1×10^6 FEPro labeled C6 glioma cells and on the other flank with the same amount of unlabeled C6 glioma cells. The tumors were imaged 14 days after implantation by means of 3D gradient echo imaging, which was performed with: TR=15ms, TE=4.6ms, flip angle: 20°, Matrix: 256x256x32, FOV: 60x60x28.8 mm. The large-scale susceptibility filter applied was calculated for each voxel by using a 3x3x3 matrix surrounding the voxel.

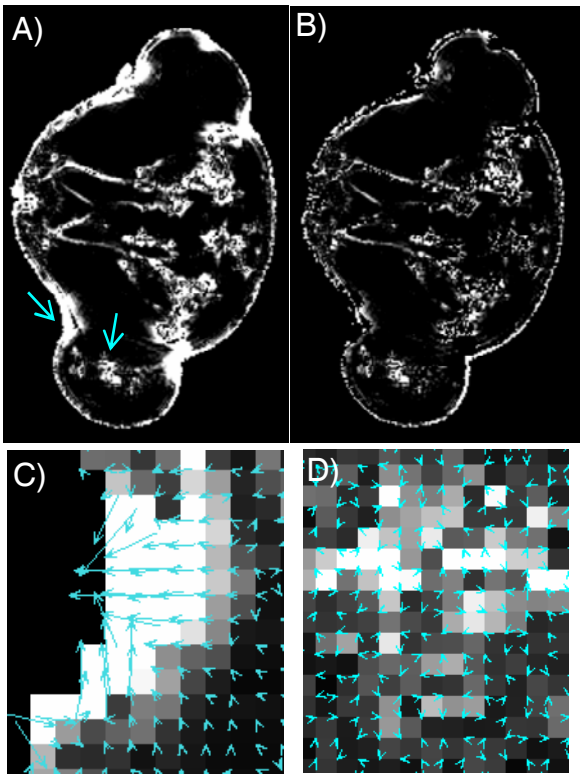

Fig. 2: A) Susceptibility gradient map calculated form gradient echo image in Fig. 1., depicting positive contrast induced by large-scale susceptibility and by SPIO labeled cells in flank rat tumor. B) Application of the threshold-based filter that only shows areas, in which the heterogeneity of the susceptibility gradients is high, i.e. the vector sum over a 3x3x3 matrix for each voxel is below a defined threshold. The zoomed images (location indicated by arrows) show the in-plane direction of susceptibility gradients for air/tissue interface C) and for labeled cells D).

Results and Discussion Two weeks after implantation, the SPIO nanoparticles in the tumor cells have been diluted with each cell division resulting in isointense signal intensity in the tumor as shown in Fig. 1, the position of the cells is indicated by arrows. The corresponding positive contrast image (Fig. 2a) shows that the labeled cells can be imaged and that the non-labeled tumor does not show positive contrast. This example shows that relatively low concentrations of SPIO labeled cells can be selectively imaged with the SGM method. Nevertheless large areas of positive contrast are visible, which are not induced by SPIO labeled cells, but by susceptibility gradients that are induced due to air/tissue interfaces. Fig 1c/d shows a cutout of the tumor area with an overlay of the in-plane components of the susceptibility gradient vector. It visualizes the more homogeneous direction at the large-scale air/tissue interfaces (Fig. 1c), and the more random distribution of the vector directions in the vicinity of labeled cells (Fig. 1d). Fig 1b shows the application of a vector sum based filter to the positive contrast image. It shows that a threshold can be chosen to selectively suppress the air/tissue induced susceptibility gradients while not affecting the positive contrast generated by the SPIO labeled cells. Since the filter only affects voxels that are above the threshold, the delineation of positive contrast of SPIO labeled cells is not altered. The filtered image also shows that small-scale inhomogeneities close to the intestine are only partly suppressed by the vector sum based filtering. Other strategies of analyzing the inhomogeneities are currently investigated and might lead to an even more selective suppression.

Conclusion We demonstrate a method that enlarges the selectivity of positive contrast imaging, by exploiting the direction of the susceptibility gradient vectors. Areas that are affected by large-scale inhomogeneities like air/tissue boundaries can be selectively suppressed by using a filter that applies a threshold depending on the heterogeneity of the susceptibility gradient vector field. All data needed to generate the positive contrast image as well as the selective filter are retrospectively calculated from a regular gradient-echo image dataset. Apart from visualizing labeled cells the proposed method can be applied to other applications, where local susceptibility changes have to be detected, e.g. positive contrast of stents and interventional devices.

References [1] JH Seppenwoolde et al, MRM 2003;50:784–790. [3]CH Cunningham et al, MRM 2005;53:999–1005. [3] M Stuber e al. ISMRM 2005, #2608. [4] H Dahnke et al. ISMRM 2006, #361. [5] JR Reichenbach et al, JMRI 1997;7:266-279. [6]A Arbab at al, Blood 2004;104:1217-1223.