Relevance of morphological binary information for l2 and l1 total variation methods in quantitative susceptibility mapping and reconstruction quality assessment without presence of the ground truth

Diana Khabipova[1], Yves Wiaux[2,3], Rolf Gruetter[1,4], and José Pedro Marques[1,4]

[1]*LIFMET, EPFL, Lausanne, Switzerland,* [2]*Electrical Engineering, EPFL, Lausanne, Switzerland,* [3]*Radiology, UniGe, Geneva, Switzerland,* [4]*Radiology, UNIL, Lausanne, Switzerland*

INTRODUCTION: Phase imaging has been demonstrated to achieve a good contrast between and within brain tissues at 7T [1]. However, phase imaging suffers from a non-local contrast variation which can be overcome by calculating the underlying magnetic susceptibility maps [2]. As this problem is ill-posed, many regularization methods have been proposed over the past years [2-5]. In this abstract we do a thorough comparison of some of these methods, [2] and [4], focus on the impact of the prior information on the reconstructed susceptibility maps and propose a method to evaluate the quality of the susceptibility reconstruction in the absence of a ground truth.

THEORY: Two methodologies were evaluated: a) An l2 method [2] using a least-square conjugated algorithm to minimize $\left\|W\left(\boldsymbol{FT^{-1}CFT}\chi-\delta B\right)\right\|_2^2+\beta\|M_B\nabla\chi\|_2^2$, where W includes a white noise correction of the measured field map δB, **FT^{-1}CFT** represents the convolution with the dipole kernel, χ is the susceptibility distribution, β is a regularization parameter and M_B contains the morphological prior information.

b) An l1 TV method [4] minimizes the TV-norm of χ subject to the data consistency $\|M_B\nabla\chi\|_1 \;\text{ s.t. }\left\|W\left(\boldsymbol{FT^{-1}CFT}\chi-\delta B\right)\right\|_2^2<\varepsilon$, where ε can be measured from the data.

The morphological information, included in the magnitude images, is used to generate different kinds of Prior information by $M_{Bi}=\begin{cases}0,\text{if }\;\partial_i M_{\text{image}}>\text{n}\cdot\sigma\\1,\text{if }\;\partial_i M_{\text{image}}\le\text{n}\cdot\sigma\end{cases}$, where M_{image} is the magnitude image, σ the noise standard deviation, n a threshold parameter and the subscript *i* represents the different Cartesian directions.

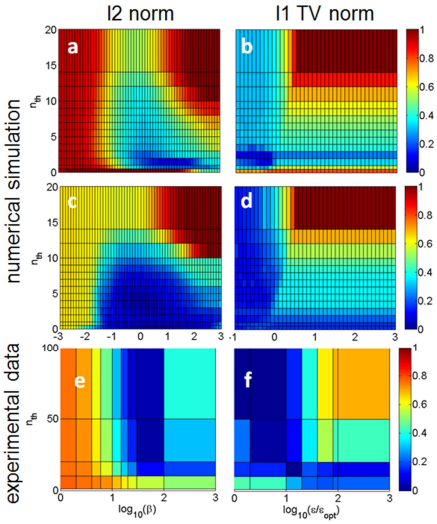

Fig 1 first and second rows, third show the reconstruction error of the numerical, simulated data (zero being the lowest reconstruction error) dependence on regularization parameters a),c),e) β and b),d),f) ε in the x-axis and threshold value n for Binary Priors

METHODS: Numerical Simulations: A numerical phantom with seven different susceptibility compartments with different susceptibility values was generated and the field map was calculated [6], random noise was added to achieve an SNR of 10. Exp. Protocol: One healthy volunteer, following a protocol approved by the local ethics committee, was scanned on a 7T (Siemens) scanner using a 32 channel receive coil (Nova Medical). A 3D GRE sequence was used with the following acquisition parameters: TR=49ms, TE=3.35-34.71ms (5 echoes), BW = 260Hz/Px, res=1x1x1mm^3, all echoes were flow compensated. The scan was repeated 3 times with the subject with the head oriented along different orientations. Data from the different coils was combined using a SVD factorization of the channel vs. echo time matrix. The phase images were unwrapped, the background fields were removed using the SHARP method [6] and a field map was computed. Susceptibility maps were calculated with both methods, while prior information parameter n as well as the parameters β and ε were varied systematically. The quality of the simulation reconstructions was measured as the power of the difference to the ground truth for the numerical data. As the ground truth is not available for experimental data, the quality of the reconstruction was evaluated in k-space using the following assumptions regarding the power of the reconstructed image in k-space: (i) in regions where abs(C(k))>2 It should have the same power as the nonregularized solution; (ii) should have the same power ratio between the regions where abs(C(k))<=2 as the T2* map (avoiding large amplitudes of $\chi(k)$ in regions close to the magic angle – under regularized case- or close to zero - over regularized case).

RESULTS: Both reconstruction methods, l2 and l1 TV, profit from a binary mask set at a low threshold value, excluding the highest gradient from the regularization, Fig. 1 a) ,b). Moreover, our quality measurement methods show similar results in simulations, Fig.1 a),c) and b),d): using the binary prior information, the optimum β value (β_{opt}) increases with the reduction of n while the reconstruction error remains constant throughout different n for the optimum ε value (ε_{opt}). Using the k-space quality measurement the susceptibility maps with the lowest reconstruction error are shown in Fig. 2 b), c) for the l1 TV and l2 method, showing a good agreement in a comparison to the COSMOS method [7], Fig.2 a).

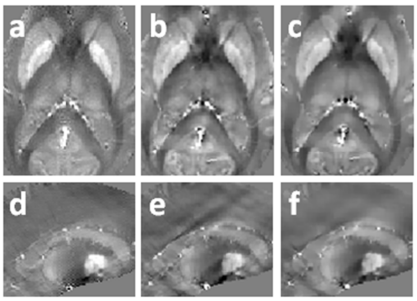

Fig. 2 first, second row shows the axial, sagittal susceptibility maps reconstructed with a),d) the COSMOS and b),e) l2 method, c),f) l1 TV with lowest reconstruction error estimation

DISCUSSION/CONCLUSION: The results show that l2 and l1 TV methods are effective at calculating susceptibility maps. The l1 TV reconstructions are less dependent on the prior information when noise has been correctly estimated. A selection of the optimum mask makes the l2 method more independent from its regularization parameters (and is substantially less time consuming). Including all edge information, even if contaminated with background noise, is more important than excluding noise and edge information from the prior information. This observation was supported both by our simulations and by our quality control methodology. The methodology used to evaluate the quality of the reconstruction based on the k-space distribution of the power is a promising alternative to the usage of a COSMOS reconstruction as ground truth for the susceptibility reconstruction.

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