Automatic Artifact Detection and Image Quality Assessment for Quantitative Susceptibility Mapping

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Target audience: MRI Physicist, radiologist and investigator interested in QSM

Introduction: Previous studies showed that quantitative susceptibility mapping (QSM) is capable of quantifying susceptibility of brain tissues by solving magnetic field to source problem. With regard to scan time and patients' comfort, acquisition typically samples data along one single spatial orientation. And data from this type of scan are typically under influences of streaking artifacts due to due to the existence of zeros on double-cone shaped dipole kernel in Fourier domain [1]. Consequently, the degraded QSM likely fails to provide useful interpretation. Over past few years, several variants of QSM algorithms were proposed intending to alleviate the residual artifacts in susceptibility maps [2-6]. And the QSM quality is assessed and scored by experienced radiologists [2, 7], which could be time consuming and subjective. In this study, we propose automatic detection of residual artifact in QSM. Results show that the proposed method provides an objective way to evaluate QSM quality and may be used to help accelerate manual interpretation.

Method and Materials:

QSM reconstruction: Images from healthy volunteers were acquired with 3D multi-echo gradient echo sequence (TR = 45ms; TE = 6, 12, 18, 24, 30 and 36ms; FA = 15°, FOV = 224mm, slice = 2mm, matrix = 224x224x64) in a 3 Tesla scanner (Siemens, Erlangen, Germany). QSM images were reconstructed by solving inverse problem with L2-norm regularization [3]: $min_{\chi_{local}}(\|(F^H DF\chi_{local} - B_{local})\|_2^2 + \lambda^2 \|W_e G\chi_{local}\|_2^2)$. D is matrix expression of dipole kernel; B_{local} denotes local magnetic field generated by tissues [8]; λ is associated regularization parameter; G represents gradient operators in three directions (i.e., x, y, and z); and W_e is a binary mask containing non-edge regions of magnitude images. QSM results from two λ values are compared regarding residual artifact.

Streaking Artifact Analysis: Quantification of streaking artifacts was evaluated based on the reconstructed QSM with following steps. First, edge detection is performed by applying gradient operator to both dimensions of input images. Hough transform is then used to detect line-shaped streaking artifacts. In Hough transform, a straight line is represented by a point in polar coordinate as (r, θ), namely Hough space, where r is the shortest distance between the line and origin and θ is the angle of the line with respect to vertical axis (corresponding to B0 direction in sagittal and coronal slices). Theoretically, streaking artifacts would appear at some specific angles with respect to B0 due to the double-cone shaped dipole kernel function [2, 3]. Therefore, artifact searching in sagittal or coronal images may be limited to a range of θ between 40 and 60° in the Hough space. Peaks appear in the searching region were regarded as artifacts and were then inversely transformed back to streaking patterns in the image domain. Identical process was also applied on magnitude image for a reference in order to prevent misinterpretation from the linear border of anatomical structures. Total length of streaking patterns was finally calculated as an index to quantify the residual artifact level.

Results: Figure 1(a) is a T2*-weighted image (TE = 30 ms) from the subject in sagittal view. Susceptibility maps reconstructed with λ = 0.06, and 0.15 are shown in Fig. 1(b), and 1(c), respectively. Note that with more regularization, Fig. 1(c) presents fewer visually perceivable streaking artifacts and is smoother compared with Fig. 1(b). Fig. 1(d-f) are the images from upper row overlaid with the detected line patterns. In Fig. 1(d), several lines are detected. And they are supposed to correspond to anatomical structures such as a straight pattern pointed by the solid arrow, which also appears in Fig. 1(e) and 1(f). In contrast, the streaking pattern near circle of Willis (dashed arrow), are mainly results from artifacts, as they only appear in Fig. 1(e) and 1(f) but not in Fig. 1(d). The total length of streaking patterns (orange lines) is also calculated as following: Fig. 1(d) 182; 1(e) 1794; and 1(f) 723.

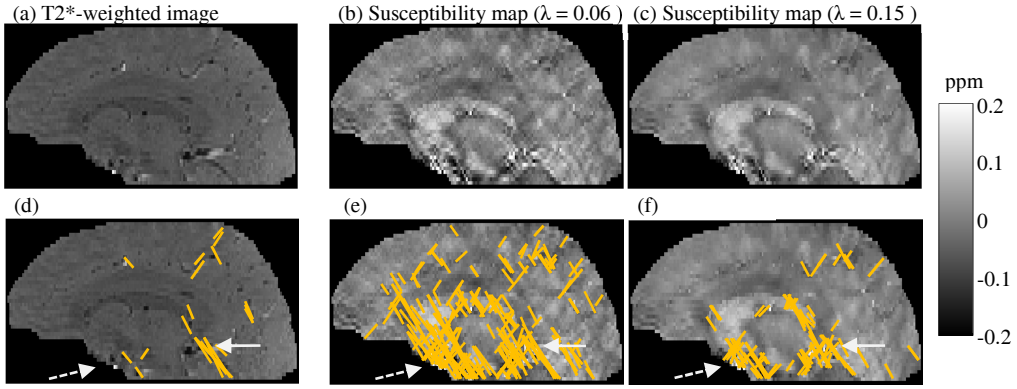

Figure 1. Automatic detection of streaking artifact in susceptibility maps. Fig. 1(a) T2*-weighted image. Fig. 1(b) and 1(c) are susceptibility maps reconstructed with regularization parameter λ = 0.06 and 0.15, separately. Note that with higher degree of regularization, Fig. 1 (c) presents lower level of streaking artifact from visual inspection and is also smoother compared with Fig. 1(b). Streaking patterns in Fig. 1(a), 1(b), and 1(c) are detected by the proposed method as shown in Fig. 1(d), 1(e), and 1(f), respectively. A straight pattern is detected in Fig. 1(d), 1(e) and 1(f) as pointed by solid arrows. In contrast, the streaking pattern near circle of Willis, suspected to be artifact, is only detected in Fig. 1(e) and 1(f) but not in Fig. 1(d) as pointed by dashed arrows. The total length of streaking patterns (orange lines) is also calculated as following: Fig. 1(d) 182; 1(e) 1794; and 1(f) 723

Discussion: Ideally, a susceptibility map would have similar tissue boundaries to its corresponding T2*-weighted image. The ill-posed inverse problem for QSM reconstruction usually leads to the streaking patterns (either dark or bright). However, visual detection of streaking artifacts requires much experience as it is usually overlapped with brain structures. Results from this study demonstrate the feasibility of automatic artifact detection, which could potentially facilitate assessment of QSM quality. Total line length is used as an index for overall artifact level instead of line counts because a line can be divided into multiple segments through smoothing. With comparison to the edges detected on T2*-weighted image, some suspected line patterns (in Fig. 1(e) and (f)) can be excluded for more accurate assessment. The presented comparisons on susceptibility maps using two different regularization parameters reveals better artifact suppression with larger regularization (Fig. c). And the proposed automatic artifact quantification also reflects consistent findings. Although current work was only done on a single slice, it should be noted that streaking artifact distributes in three-dimensional space and a more thorough evaluation taking the entire volume into account will be necessary for more accurate comparison.

Conclusion: The proposed method is capable of automatic detection of streaking artifact in susceptibility maps, resulting in better interpretation of QSM results.

Reference: [1] Liu, et al., MRM, 2009; [2] Liu T et al., MRM, 2011; [3] de Rochefort et al., MRM, 2010; [4] Shmueli, et al., MRM, 2009; [5] Li, et al., Neuroimage, 2011; [6] Wu, et al., MRM, 2012; [7] Wang et al., IEEE Trans Biomed Eng., 2013; [8] Liu T et al., NMR Biomed, 2011;