Limitations of Accelerated QSM by FOV Restriction to Deep Gray Matter

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Introduction: Quantitative Susceptibility Mapping (QSM) has been introduced for assessing iron levels in deep Gray Matter (GM) [1], and used in multiple sclerosis as a sensitive marker for tissue changes [2,3]. However, the widespread use of QSM in the clinic is limited by the extra temporal cost. Field of View (FOV) restriction to deep GM only would enable substantial time savings; however the non-local dipole nature of field effects necessitates careful investigation. Axial acquisitions are found to be particularly sensitive to non-local effects of symmetric FOV restriction, compared to sagittal/coronal acquisitions.

Materials and Methods: *Numerical Simulations*: Analytical field solutions of a unity susceptibility sphere (**Fig. 1a**), 32-pixel in diameter, were generated, then the FOV was incrementally symmetrically increased relative to the sphere size (FOV increase = $(\text{length}_{FOV}\text{-Diameter}_{sphere})/\text{Diameter}_{sphere}$) to populate a 256x256x256 matrix, and the mean susceptibility of the sphere relative to background was calculated using compressed sensing compensated (CSC) inversion [4].

Human Brain Experiments: 2D axial phase imaging covering the whole brain was acquired at 4.7T (Varian, Palo Alto, CA) for five healthy subjects using single gradient echo with FOV = 192.5 x 256 x 100 mm, spatial resolution = 0.5 x 0.5 x 2 mm, flip angle = 70°, TE/TR = 15/1540 ms.

QSM & FOV Truncation: Susceptibility maps (**Fig. 2**) were calculated using the following procedure: unwrapping using PRELUDE/FSL, brain extraction using BET, Background Field Removal (BFR) using regularized sophisticated harmonic artifact reduction for phase data (RESHARP) [5], then CSC inversion [4]. Caudate Nucleus (CN), Putamen (PU), Globus Pallidus (GP) susceptibility values relative to the Internal

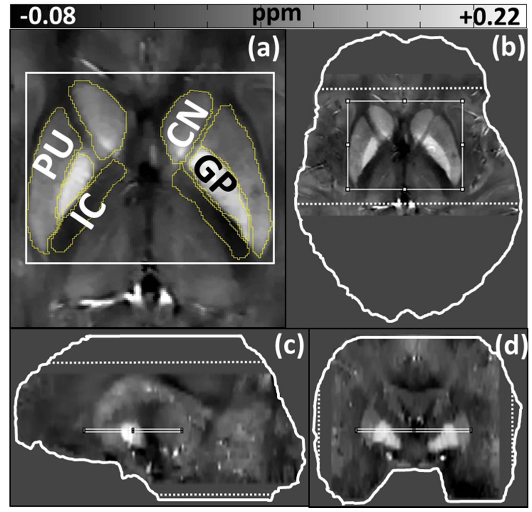

Figure 2 *ROIs of deep GM in QSM (a) were quantified after iterative FOV increase of 220% (example) relative to structures of interest (white box size 64(x)*50(y)*2(z) mm) in a direction orthogonal to coronal (b), 3400% for axial (c), and 65% for sagittal (d) planes.*

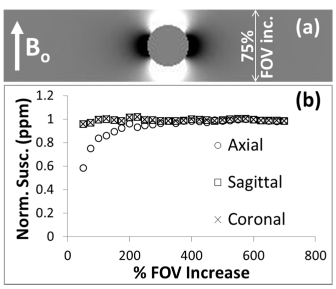

Figure 1 *Field of a sphere with unity susceptibility (a), and corresponding normalized susceptibility (b) calculated after FOV increase relative to sphere size in orthogonal direction to axial, sagittal, and coronal planes.*

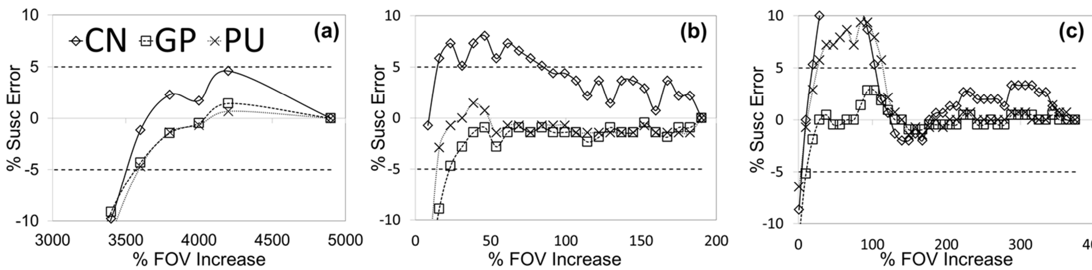

Figure 3 *Susceptibility quantification errors from deep GM ROIs of a healthy subject for % FOV increase in orthogonal direction to axial (a), sagittal (b) and coronal (c) planes.*

Capsule (IC) were quantified using ROIs (**Fig. 2a**) after iterative symmetric FOV increase relative to the structures of interest (white box in **Fig. 2**), and corresponding quantification errors relative to the full FOV dataset (384 x 512 x 50) were computed (**Fig. 3**).

Results: Normalized susceptibility of the CN, GP, and PT for iterative axial, sagittal and coronal FOV increase (**Fig. 3**), demonstrate that coronal acquisitions are the most suitable for accelerated QSM using restricted FOV (**Table 1**), with optimal restricted FOV = 121 (x) * 133 (y) * 85 (z) mm (dotted lines in **Fig. 2**).

Discussion: Two crucial FOV dependent steps in QSM are BFR and phase inversion. For the inversion process, it has been previously shown that the forward calculation of phase from susceptibility may be accurately solved to an isotropic FOV increase of 150% [6]. However, the inverse problem is dependent on the axis of FOV restriction, where FOV restriction parallel to the main magnetic field is the most sensitive, as shown by simulations (**Fig. 1b**) and *in vivo* results (**Fig. 3a**). Similarly, BFR (data not shown) was also significantly affected for axial FOV restriction. This may impact choice of acquisition orientation when performing accelerated QSM, with preference for coronal acquisitions (**Table 1**). While 3D acquisitions are most advantageous because they yield linear time savings with slice reduction, 2D acquisitions may also be used for restricted FOV QSM acceleration by reducing the dead time within TR.

Table 1 *Optimal FOV increase for accelerated QSM with 95% accuracy from 5 subjects.*

Axial (z FOV increase)	*Sagittal (x FOV increase)*	*Coronal (y FOV increase)*
4140±736%	89±34%	166±63%
85±17mm	121±86mm	133±82mm

Conclusion: Accelerated QSM by FOV restriction to deep GM only is feasible, but non-local effects limit the degree of FOV restriction. With coronal acquisitions, FOV restriction limits (y-axis) require 133 mm or more without sacrificing QSM accuracy.

References: [1] Deistung et al. 2013 Neuroimage 65:299; [2] Langkammer et al. 2013 Radiology 267:551; [3] Chen et al. 2014 Radiology 271:183; [4] Wu et al. 2012 MRM 67:137; [5] Sun et al. 2014 MRM 71:1151; [6] Cheng et al. 2009 Phys. Med. Biol. 54:1169.