Susceptibility phase imaging of the basal ganglia: effects of phase filtering, slice orientation and ROI selection with comparison to T2* mapping

A. Walsh[1], M. Wieler[2], W. Martin[2], and A. Wilman[1]

[1]Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada, [2]Division of Adult Neurology, University of Alberta, Edmonton, Alberta, Canada

Introduction:
MRI has the potential to detect and indirectly quantify iron content in the brain by measuring phase or the relaxation rate R2*. A limitation of R2* mapping is the lack of specificity, since R2* is not only influenced by regional iron content but also by the diffusivity of a tissue. Phase imaging theoretically has a higher specificity to iron, however its robustness is still in question owing to its high sensitivity to filtering and slice orientation artifacts. Current methods in phase imaging require a high pass filter to remove phase wrap in the image and studies have differing views as to the effectiveness of this technique [1,2,3]. Many studies use anatomical landmarks to position imaging slices, however phase values can change significantly with slice orientation. This can confound the analysis of quantitative phase data in cross sectional and especially longitudinal studies if head placement is not exactly consistent between subjects. The purpose of our study is to investigate the potentially confounding effects of filtering and slice angulation on phase images and compare to R2* mapping.

Methods:
Phase filtering was first investigated with a 2D MATLAB simulation of the basal ganglia. The effect of region of interest (ROI) placement on phase values is examined in vivo using the MATLAB simulation as a guide. A high pass filtering effect to remove phase wrap is obtained by taking the original image matrix m x m and truncating it to the central n x n elements then zero padding it. The original image is complex divided by this zero padded truncation [4]. The filter width is defined as n/m. The effect of this filter width is examined with phase image simulations of the basal ganglia in MATLAB to produce 2D color map phase images and cross sectional phase representations. The phase images were constructed by outlining structures of the basal ganglia from phase MRI images and assigning a constant phase value to each voxel in a structure.

Using a 3T MRI scanner, with a standard gradient echo sequence (TR 500, 512f x 256p, 3mm thickness, 7 slices, no slice separation, FOV 25cm), the basal ganglia of 4 normal volunteers and 2 Parkinson's patients were imaged. R2* values for specific tissues were obtained by imaging at echo times TE = 9/16/26/40ms and fitting an exponential to each voxel. These R2* images were compared to the phase images computed from the TE=16ms image using a filter width of 0.125. ROI's, drawn using ImageJ, were placed around the whole structure in one phase experiment and around selected part of each structure in another phase experiment (fig 1). The selective ROI's are based on the highest and lowest phase values seen in structures observed in the MATLAB simulation (fig 2). These are the lateral aspect of the putamen and the medial aspect of the globus pallidus. The red nucles and substantia nigra do not have selective ROI's because their phase profile is not as severely affected by filtering. All phase values in this study represent phase measured from a small white mater area lateral to the red nucleus subtracted from the phase in a basal ganglia reported. Higher susceptibility is expressed as more positive phase in this study.

The effects of slice orientation on phase values were examined in the same 4 normal volunteers at oblique angles from the transverse plane at -10, -5, 0, 5, and 10 degrees using the same imaging parameters as above (fig 3). Central structures present in all angled images were examined. ROI's were drawn around entire structures and the measured phase values of the structures were compared between volunteers.

Results:
The phase filtering simulation showed a reduction in phase values within basal ganglia structures, especially parts of structures that are adjacent to other iron containing structures. As the filter width is increased, the phase values within structures are reduced and also decrease more rapidly across the structure. Invivo T2* vs. phase experiments showed a correlation between phase and T2* in basal ganglia structures red nucleus: R^2 = 0.658, globus pallidus: R^2 = 0.358, putamen: R^2 = 0.720. Spatial variation in the phase across the putamen and globus pallidus shown in Table 1, followed the same medial to lateral variation predicted from simulations (Fig 2). Images obtained at oblique angles show a change in phase values as the angles are rotated from -10 to 10 degrees (fig 3). The phase of the red nucleus, globus pallidus, and substantia nigra showed substantial change as the slices were angled but there was no defined pattern of change across all subjects.

Table 1: Selective ROI phase (radians) comparing medial and later aspects of the globus pallidus and putamen within each subject

Subject	Medial Put	Lateral Put	Lateral GP	Medial GP
1	-0.04	0.12	0.11	0.20
2	-0.02	0.24	0.11	0.16
3	-0.02	0.08	0.03	0.15
4	0.00	0.17	0.15	0.20

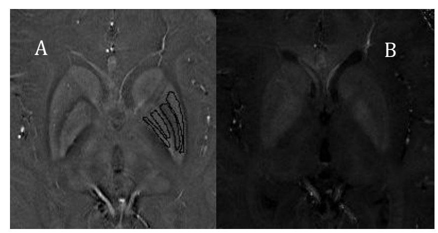

Fig 1. A) phase image showing the selective ROI's for measuring the lateral and medial parts of the globus pallidus and putamen (table 1). B) R2* image of the same globus pallidus and putamen.

Conclusion:
Quantitative phase MRI has the potential to investigate pathological iron disease with more precision than previous techniques. However, certain factors must be considered when applying the high pass phase filter to obtain consistent phase measurement. Since phase is artificially reduced in parts of structures adjacent to iron containing structures when using the described filtering technique, ROI placement should avoid these areas. The simulation and invivo data show that there is a substantial difference in measured phase in different parts of a structure. Filter width should ideally be the lowest possible value to remove the phase wrap so as to preserve a more homogenous phase over the whole structure. Cross sectional and especially longitudinal studies need to ensure the same head position and image slice orientation of subjects to ensure consistent phase analysis. In order to consistently compare image phase measurements, ROI placement, filter width and exact head position with slice angle, must all be carefully considered.

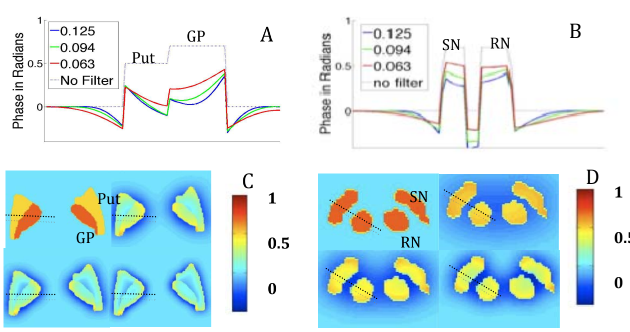

Fig 2. A,B) Simulated cross section of phase in globus pallidus/putamen (A) and substantia nigra/red nucleus (B) showing ideal (dotted) and filtered phase (solid). C,D) 2d phase images using filter widths: no filter top left, 0.125 top right, 0.094 bottom left, 0.063 bottom right. Cross section along dotted line. Color bar in radians.

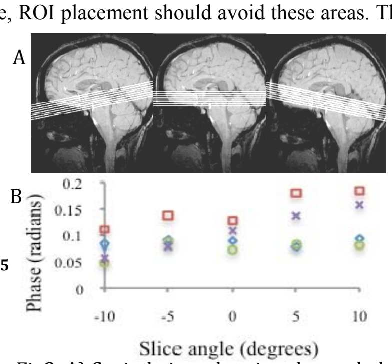

Fig3. A) Sagital view showing the angled phase slices 10,0,-10 from left to right. B) The measured phase with ROI over entire putamen of 4 volunteers, slice angles from -10 to 10 .

References: 1. Haacke, JMRI. 26:256–264 (2007) 2. Hammond KE, Ann Neurol. 64:707–713 (2008) 3. Schäfer, NeuroImage 48:126–137 (2009) 4. Haacke, AJNR. 30:19-30 (2009).