Effect of Orientation of 2D Phase High-Pass Filter on Susceptibility Mapping of Veins and Microbleeds

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Introduction: Homodyne high-pass filter (HP) is commonly used in Susceptibility Weighted Imaging (SWI) and susceptibility mapping, to remove the low spatial frequency phase induced by the background field variation [1-3]. This HP filter is typically used as a 2D filter [1]. It is known that HP filtering will lead to loss of phase information to variable extents depending on the filter size [1]. However, since it is applied in 2D mode, it is reasonable to expect that it will lead to different behavior when applied to saggital vs. axial direction on an isotropic phase volume [4]. Furthermore, due to rectilinear format of the acquired MR data, 2D HP filtering of phase in a particular slice orientation will lead to different extent of information loss for veins that are at different relative orientations to the main magnetic field. To evaluate this hypothesis, we examined the effects of different HP filtering of phase in different slice orientations (i.e. applied in axial, or saggital or coronal slices) on susceptibility quantification [2] for a sphere and cylinder at different relative orientations to the field.

Materials and Methods: Phase images of cylinders and spheres of different radii (1 to 32 voxels in increments of 1 voxel) were simulated in a 256x256x256 matrix. For the cylinders, the angles between the field direction and the cylinder's long axis were set to be 30º,45º, 60º and 90º. The susceptibility inside the object was set to 1ppm, and the susceptibility outside was set to 0, for both cylinders and spheres. High pass filters with sizes of 8x8, 16x16, 32x32 and 64x64 were applied to the axial, sagittal and coronal views of the simulated phase images Susceptibility maps were constructed using the original and HP filtered phase images in the same way as that described in Ref. [2]. Finally, the mean susceptibility values were measured from these susceptibility maps and their % errors relative to the expected 1ppm value were calculated. To verify whether we see similar effects in actual data, different orientation high-pass filters were applied on raw phase images containing multiple microbleeds (obtained from a TBI patient). HP filter with the size of 64x64 was applied in axial, coronal and sagittal views of this dataset and susceptibility maps were generated using these filtered phase images. Susceptibility values for selected vessels and micro-bleeds were measured and compared. Imaging Parameters: SWI sequence - TR/TE/FA/BW - 29ms/20ms/15º/120Hz/pix; voxel size – 0.5x0.5x2mm. Axial acquisition.

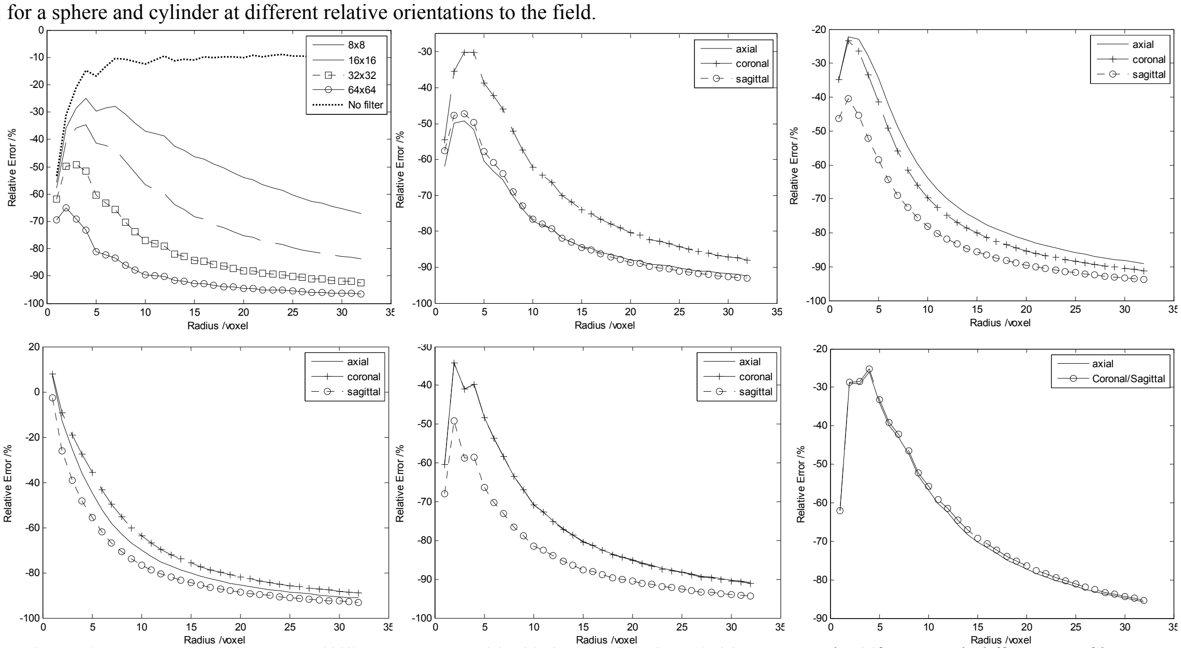
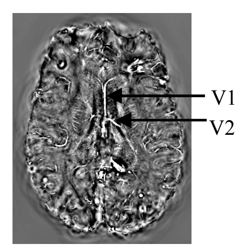


Figure 1. Percent Error in susceptibility maps caused by high-pass filtering. A. *% Errors in the 90º case with different HP filters sizes. The field was set to be in z direction, and the cylinder lies along x direction. HP filter was applied in the axial direction (x-y plane) In.* ***B*** *to* ***F*** *a 32x32 high-pass filter was applied in axial, coronal and saggital directions for cylinders:* ***B*** *The error in 90º case.* ***(C)*** *the 30º case,****(D)*** *the 60º case, and* ***(E)*** *the 45º case.****(F)*** *shows the error in the spherical case.(Note: Y-axis scale is not same for all)*

Results and Discussions: Figure 1A plots the % error in susceptibility vs. object size for different filter sizes for a cylinder perpendicular to the main magnetic field (90º case). The HP filter is applied along the axial direction (i.e. we see the cylinder along its length in the axial slice, not its cross section). As expected, the larger the filter size, the greater is the under-estimation in the quantified susceptibility values (Figure 1A). Figures 1B through 1E plot the % error in susceptibility as a function of vessel size for a 32x32 HP filter applied in axial, saggital and coronal directions for vessels making 90º, 30º, 60º and 45º degrees respectively, with the main magnetic field. For cylindrical objects, only when the HP filter is applied in the direction which is perpendicular to the long axis of the cylinder, will we have the least error. As shown in Figure 1B, when the HP filter is applied to the sagittal view of the dataset (y-z plane), the error is smaller than HP filtering in other views. For the 60, 30 and 45 degree cases, none of the slice orientations is perpendicular the long axis of the cylinders. Hence we see varying error profiles for each case, as shown in Figure 1C to 1E. We observe that, when the HP filter is applied in a slice orientation which is closest to the direction perpendicular to the axis of the cylinder provides least error (see 1C vs 1D). In 1C, the least error is obtained when the HP filter is applied to the sagittal view while in 1D to the coronal view.



When the angle between the field direction and axis of the cylinder is 45º, both axial and coronal views give us the same error profile as would be expected (Fig 1E). Interestingly, the effect of orientation of the HP filtering is not that evident in spherical objects (1F). For human datasets, measurements from two vessels and two microbleeds are given in Table I. Clearly, filtering along one of the three orientations provides the maximum value (i.e. minimum underestimation) in agreement with the results from simulations. To obtain the minimum possible underestimation in the susceptibility values we propose to apply the HP filter in all 3 slice orientations first and then, for a given slice, take the maximum intensity projection across the 3 SMs generated for the 3 different filter orientations.

Table 1: Susceptibility values measured from two vessels and microbleeds (mean/std) in ppm

HP Filter applied in	Vessel 1	Vessel 2	Microbleed 1	Microbleed2
Axial view	0.376/0.11	0.145/0.04	0.189/0.02	0.513/0.08
Coronal view	0.408/0.10	0.167/0.05	0.165/0.03	0.516/0.08
Sagittal view	0.380/0.12	0.178/0.04	0.164/0.03	0.566/0.08

Conclusions: 2D High-pass filtering leads to strong underestimation of χ values in susceptibility mapping. Apart from the size of the HP filter and size of the object, this error is also related to the orientation in which the HP filter is applied. The underestimation can be minimized by applying the HP filter in all 3 orientations take the maximum value obtained for a voxel. Furthermore, if the relative orientations of blood vessels (or microbleeds), the main field and HP filter are known, it may be possible account for this systematic underestimation using the results from these simulations. Future work will look at advantages, if any, of 3D HP filtering.

References: [1] Haacke et al., MRM; 52:612. [2] Haacke et al. JMRI;32:663-676. [3] Neelavalli et al., JMRI;29:938. [4] Schafer et al., Neuroimage ;48:126.