Comparative evaluation of three different filters for phase unwrapping from SWAN imaging in calcified neurocysticercosis

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Introduction: Phase images obtained from susceptibility angiography weighted or 3-D T2* weighted angiography (SWAN) imaging contains information about susceptibility changes between tissues and measures substance which changes the local field of magnetization such as iron, calcium etc. The phase images are useful in differentiating diamagnetic from paramagnetic susceptibility effects of calcium and iron respectively. Phase image obtained from scanner has predominantly effects of other background magnetic field which obscure useful phase information. Various filters are used for removing the spatially slowly varying phase effect that obscure the local inter tissue phase differences of interest. Linear filters like Gaussian, Hanning etc are known to reduce truncation artifact, produce good contrast image, improves the signal to noise ratio by removing high frequency noise from the signal however Kaiser filter has not been explored much for creating filtered phase image. In this study we explored three different filters: Gaussian, Hanning and Kaiser to compare useful information obtained from different filters on calcified neurocysticercosis (NCC). NCC is a parasite of the brain, present with single or multiple cysts especially in endemic regions across the world. A quantitative study in calcified NCC have shown that phase correlates substantially with CT-HU and R2* values with use of 64 × 64 low pass filter to remove the low spatial frequency component of background field[1]. Post-processed phase image using Gaussian filter is known to demonstrate enhancement of contrast between grey and white matter[2]. In the present study we intend to look for correlation of phase with CT-HU values in calcified NCC with three filters and phase difference among them.

Material and Methods: A total of seventy four calcified cyst from patients with a diagnosis of NCC on the basis of approved guidelines[3], were included in the study.

Data acquisition: All the patients underwent conventional MRI on a 3T MR scanner (General Electric, USA), using a 12 channel head coil after the approval from the institutional ethics committee. Conventional MRI was performed in the axial plane with a field of view (FOV) = 240 × 240 mm^2, slice thickness = 3 mm, inter-slice gap = 0.0 mm. In addition, SWAN sequence with TR/ TE/ Flip Angle/ slice thickness: 47/ 25/ 15/ 2.4 mm and acquisition matrix of 320 x 224 was also performed for the detection of these lesions. The data was acquired using 7 echoes with a central-echo time of 25.024 ms and an echo-spacing of 4.008 ms (the 7 acquired echo times used were: 13 ms, 17.008 ms, 21.016 ms, 25.024 ms, 29.032 ms, 33.04 ms and 37.048 ms). CT data was acquired with 3 mm slice thickness on 40 slice scanner (Siemens Healthcare, Germany).

MRI data processing and quantitative analysis Complex data consisting of real and imaginary parts was collected using a multi-echo SWAN imaging. The phase calculation removing the susceptibility artifacts was done according to Haacke et al using a low pass filter to remove the low spatial frequency component of background field [4]. The Gaussian (22 × 22) function can be used for a lowpass filter to obtain the smoother fall-off charetericticts of pass band and form of Gaussian low pass filter in the frequency domain is defined by the following equation: $H(u,v) = \exp(-D^2(u,v)/2\sigma^2)$, where *D(u,v)*is the distance from the origin in the frequency domain and σ is the standard deviation of the Gaussian function which is a measure of spread of the function about the origin. The Hanning (38 × 38) low pass filter in the frequency domain is defines as $H(u,v) = (1/4) * \left(1 + \cos\left(\pi * \sqrt{u^2 + v^2}/D_0\right)\right)\left(1 + \cos\left(\pi * \sqrt{u^2 + v^2}/D_0\right)\right)$, where D_0 is the cut-off frequency. The Kaiser Bessel (64 × 64) low pass filter in the frequency domain is defined as: $H(u,v) = I_0\left(\pi\alpha\sqrt{1-(2*u/D_0)^2}\right)\Big/I_0(\pi\alpha) * I_0\left(\pi\alpha\sqrt{1-(2*v/D_0)^2}\right)\Big/I_0(\pi\alpha)$ where I_0 is the zeroth order modified Bessel function of the first kind and is given by $I_0(x) = \sum_{j=0}^{\infty}[(x/2)^j / j!]^2$, α (=2) an arbitrary real number that determines the shape of the filter and D_0 is the cut-off frequency. The MRI and CT data sets were registered using mutual information based registration technique[5, 6]. To compare phase values obtain from three different filters, a threshold of 22 was observed to give comparable result in all three filters.

Statistical analysis: Spearman's correlation was performed to see the correlation between quantitative phase and CT-HU values using Gaussian, Hanning and Kaiser Filter. Kruskal-Wallis test was used to look for differences in values of positive and negative phase and corresponding CT-HU among Gaussian, Hanning and Kaiser Filter from corresponding positive and negative phase regions.

Results: In a volume of lesion, both positive and negative phases were observed. From the regions with positive & negative phase, CT values were calculated separately. A significant positive correlation was observed between positive phase values with corresponding CT-HU values in all the filters used (Fig.1). Each of the three filters showed significant negative correlation among negative phase values and corresponding CT-HU values (Fig.1). Kruskal-Wallis test showed no significant difference among various filter in positive phase, negative phase values and their corresponding CT-HU values (Table 1).

Table 1: Showing median and range of positive and negative phase values obtained from Gaussian, Hannning and Kaiser filters.

	Gaussian (22 × 22) Median(Range)	Hanning (38× 38) Median(Range)	Kaiser (64× 64) Median(Range)	p values
Positive Phase	0.735 (0.09 - 1.57)	0.792 (0.02 - 1.52)	0.7185(0.08 - 1.48)	0.908
Negative Phase	-0.264 (-1.21 -0.00)	-0.2705 [-1.56 - (-0.02)]	-0.2335[-1.45 - (-0.02)]	0.687

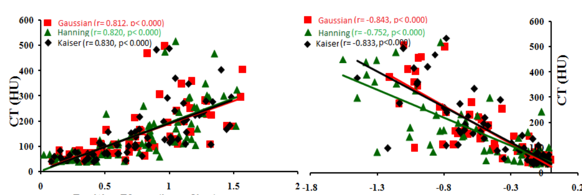

Fig. 1: Illustrates correlation between positive phase(in radian) and negative phase(in radian) with CT(HU) values in three filters

Discussion: On comparing three filters we found no significant difference of positive and negative phase values derived from each of the filters on the basis of statistical analysis. Median values of positive and negative phase obtained from Gaussian, Hanning and Kaiser filters (Table1) shows insignificant difference in the values. All filters showed significant positive correlation of positive phase with CT-HU and significant negative correlation of negative phase with CT-HU. We observed that best correlation result was obtained for positive phase and corresponding CT-HU values (r = 0.830, p < 0.000) using Kaiser filter [Gaussian (r = 0.812, p < 0.000), Hanning (r = 0.820, p < 0.000)] however Gaussian filter showed good correlation among all the filters used while comparing negative phase and corresponding CT-HU (r = -0.843, p < 0.000) [Hanning (r = -0.752, p < 0.000), Kaiser (r = -0.833, p < 0.000)] (Fig. 1). Hence we conclude that irrespective of the size of the filters used for phase quantification we obtain consistent result.

References: 1.Roy et al. 2011 JMRI;34:1060-1064, 2. Abduljalil et al.2003 JMRI;18:284-290, 3. Del Brutto OH. 2005 Semin Neurol;25:243-51, 4. Haacke et al. 2004 MRM;52: 612-618,5. Awasthi et al. 2010 JCAT;34:82-8. 6. Verma, et al. 2008 ESMRMB, 25th Annual Meeting, Valencia.