# Fusion of magnitude and phase images and its applications in ultra-short TE MR imaging

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**Introduction:** Phase information is often neglected in clinical MR imaging except in a few applications such as flow quantification and susceptibility-weighted imaging (SWI).[1] SWI usually acquires gradient echo images with long echo times (TEs) (e.g. 20ms at 3T) to create susceptibility weighed magnitude images sensitive to local susceptibility changes between tissues. More recently, phase contrasts have been reported in images acquired with ultra-short TEs (UTE) in several tissue types[2-4]. In this work, we demonstrate that phase images obtained with ultra-short echo times provide important additional contrasts in both knee and lung imaging applications. A new approach for visualizing both the magnitude and phase information simultaneously without information loss is presented to facilitate the assessment of tissues using all the information available.

**Materials and methods:** Imaging experiments were performed using a 3D radial UTE sequence implemented in a spoiled gradient echo mode on a Toshiba Vantage Titan 3T scanner (Otawara, Japan). IRB approval was obtained for all healthy human studies. Common acquisition parameters include: FA= 5°, equivalent readout matrix 424×424×424, ADC pitch time = 4µs, TE/TR = 0.19ms/5.0ms. For knee imaging, 76800 radial lines were sampled in 6'24''and the image resolution was 0.63 mm isotropic. For lung imaging, 38400 radial lines were sampled with respiratory gating in 7'24''. The image resolution was 1.18 mm isotropic. No contrast agent was administrated.

Image reconstruction was performed using gridding followed by complex Fourier transform. The actual k-space trajectories on the three orthogonal axes were measured and used to correct for gradient system imperfections such as eddy currents.[5] To generate the phase images, a set of low-resolution complex images ($\rho_l$) were reconstructed from the same k-space data after a 3D low-pass filter was applied. The conjugates of $\rho_l$ were then multiplied by the high-resolution images, and the final phase images were obtained from the phases of the product. The corresponding magnitude and phase images were then used as inputs to different color channels (e.g., magnitude→cyan, phase→ magenta) to create composite color images using ImageJ.[6] The dynamic range and contrast for each individual channel were adjusted independently to achieve the desired composite image contrast.

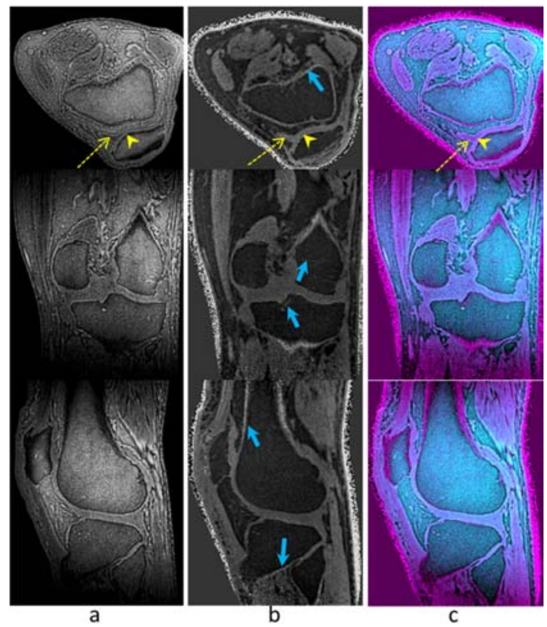


**Fig. 1** Reformatted (a) magnitude, (b) phase and (c) composite knee images acquired using the UTE sequence.

**Results and discussion**: Representative reformatted knee images are shown in **Fig. 1**. Knee cartilages are depicted in great detail in all images. The magnitude images (**Fig. 1a)** show slightly brighter fat signal than muscle. The visualization of the cartilage is obscured by the fat signal (arrow heads). Despite the relatively flat contrast, the phase images (**Fig. 1b)** show good differentiation between fat (dark) and water (gray) signals and better visualization of some structural features (short arrows). The composite images (**Fig. 1c**) allow easy visualization of all details from both magnitude and phase images simultaneously. Differentiation of fat/water-dominant voxels is easily appreciated, which enables better visualization of the cartilage (arrow heads) and synovial fluid (long arrows) as compared to the magnitude images.

**Fig. 2** shows several representative lung images of a volunteer. The magnitude images (**Fig. 2a**) depict the lung parenchyma, large fissures (arrow) and vessels nicely owing to the ultra-short TE used. The phase images (**Fig. 2b**) show very different contrasts and provide complementary information to the magnitude images. Some vessel walls are nicely visualized in especially the axial phase image as the blood signals within them appear dark. The airways are shown with positive contrast likely due to the presence of tissues such as cricoid cartilage. The phase images also show excellent visualization of the lung parenchyma. Large fissures are visible in the phase images with negative contrast (arrow). Again, the composite images show details from both magnitude and phase images. Lung parenchyma is readily visualized and vessels with different phase behaviors are shown in with different color.

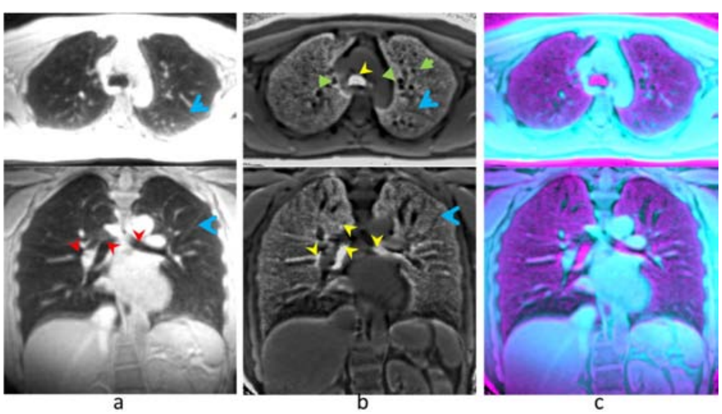


**Fig. 2** Representative magnitude (a), phase (b) and merged composite images. (c).

**Conclusion**: Significant phase differences have been demonstrated in human knee and lung images acquired with a UTE sequence, which provide important information for accessing tissue characteristics. The fusion of magnitude and phase images into composite images enables easy visualization of magnitude and phase information simultaneously, which can potentially widen the usage of MR phase information in a clinical setting.

**References**: 1. Haacke et al., AJNR Am J Neuroradiol 2009, 30:19-30. 2. Lu. et al., Magn Reson Med. 2011 66:1582-9 3. Carl et al., Magn Reson Med 2012. 67:991-1003. 4. Liu et al., In: Proceedings of ISMRM 2014, p0766. 5. Lu et al.,J Magn Reson Imaging 2008. 28: 190-8. 6. Rasband WS., ImageJ, NIH, Bethesda, Maryland, USA, http://imagej.nih.gov/ij/, 1997-2012.