Comparison of DENSE Reference Strategies

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Introduction: Magnetic resonance imaging (MRI) offers the possibility of *in-vivo* quantitative measurement of myocardial deformation using displacement encoding with stimulated echoes (DENSE) [1]. DENSE encodes the spatial position at a reference time in the cardiac cycle, usually at the R-wave in the ECG. Readouts are then performed later during the cardiac cycle, producing images with a phase proportional to the displacement. Several aspects need to be taken into account when designing a DENSE pulse sequence; magnetic field inhomogeneities, suppression of artifact generating echoes, displacement to noise ratio and signal attenuation due to intravoxel phase dispersion. Most DENSE acquisitions use some kind of phase reference in order to correct for various artifacts. The aim of this work is to evaluate, *in-vitro* and *in-vivo*, the influence of DENSE phase reference strategy on the accuracy of the displacement measurement.

Methods: Three DENSE phase references strategies were evaluated using two phantoms and *in-vivo* using a 1.5T Philips Achieva MRI scanner. The strategies are referred to as “single”, “double” or “symmetric” reference (Table 1). Single reference consists of a single acquisition using zero displacement encoding gradient strength. Double reference adds a complementary acquisition of the non-displacement encoded reference acquisition, analogous to CSPAMM [2], to suppress the T_1 echo. In the symmetric reference encoding scheme, the reference consists of a complementary acquisition, but with a non-zero displacement encoding. Subsequent phase subtraction then compensate for magnetic field inhomogeneities. The scan parameters were: EPI-factor 7, TFE-factor 3, TE/TR 4.9/10.6 ms, phase interval 50 ms, acquisition matrix 140×121, FOV 350×350, slice thickness 8 mm, SENSE-factor 2, displacement encoding strength of 0.35 cycles per pixel. Data were reconstructed to 2.43×2.43 mm voxels. Two flip angle regimes were evaluated, fixed 20 degree and optimized for constant SNR [2]. A phantom with a homogeneous gelatin mixture was used to evaluate the accuracy of the displacement over 100×100 voxels. Another phantom consisting of the gelatin mixture and butter was used to evaluate the effects of chemical shift in ROIs of 31×11 voxels. *In-vivo* measurements were preformed on a 25 year old healthy male volunteer with no previous history of cardiac disease to visually study image quality and suppression of blood signal.

	X-encoding	Y-encoding	Z-encoding	Reference
Single	$(+E_X,0,0)$	$(0,+E_Y,0)$	$(0,0,+E_Z)$	$(0,0,0)$
Double	$(+E_X,0,0)$	$(0,+E_Y,0)$	$(0,0,+E_Z)$	$(0,0,0)$
Symmetric	$(+E_x,-E_Y,-E_Z)$	$(-E_X,+E_Y,-E_Z)$	$(-E_X,-E_Y,+E_Z)$	$(-E_X,-E_Y,-E_Z)$

Table 1: Summary of the reference encodings using encoding gradientents in X (E_X), Y (E_Y) and Z (E_Z) direction.

Results: The single reference resulted in a temporal varying offset of the displacement in all directions. A varying offset could also be seen in the double reference, but only in the through-plane component (not shown). No varying offset was seen using the symmetric reference. Measurement using symmetric reference produced a smaller standard deviation than the single and double reference, as seen in Figure 1. Figure 2 shows the difference in displacement due chemical shift. Varying difference can be seen in the single and double reference, while no severe offset can be seen with the symmetric reference. Examining the *in-vivo* anatomical magnitude images, no obvious artifact could be seen in the in-plane components (not shown). However, only the symmetric reference provided favorable black blood effect from the through-plane displacement, as shown in Figure 3.

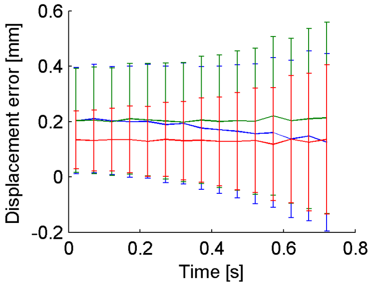

Figure 1: Displacement in readout direction for single (blue), double (green) and symmetric (red) reference.

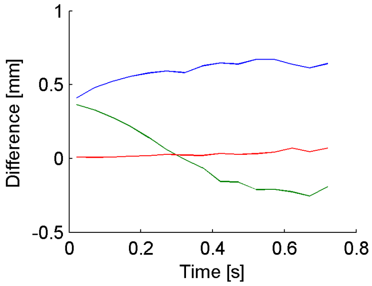

Figure 2: Difference in displacement between water and fat using single (blue), double (green) and symmetric (red) reference.

Discussion: The phase reference compensates for phase contribution due to magnetic field inhomogeneities. However, the phase images with zero displacement encoding do not separate the stimulated echo, the stimulated anti-echo and the T_1 echo. In the beginning of the cardiac cycle, when the T_1 echo is weak, the single reference produce a stimulated echo weighted result, but at the end of the cardiac cycle it mainly consists of the T_1 echo, which has a different phase. This explains the varying offset in the in-plane components for the single reference method and is not seen for double reference which suppresses the T_1 echo. This suppression might not be adequate in all cases, however, and the residual T_1 echo will manifest at the same location as the stimulated echo in *k*-space. This makes it difficult to further suppress the T_1 echo, e.g. by using *k*-space filtering [3], if the complementary acquisition is insufficient. This insufficient T_1 suppression probably explains the varying offset in the through-plane component as well as the limited black blood effect for the single and double reference. Neither of these shortcomings are seen for the symmetric reference.

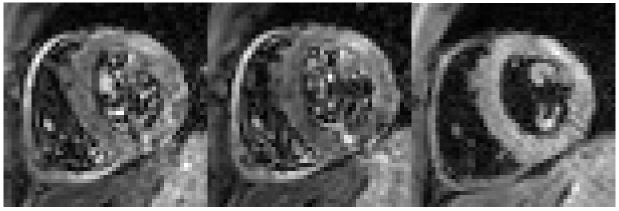

Figure 3: Magnitude images achieved for the single (left), double (center) and symmetric (right) reference acquisition. Note the suboptimal blood suppression in single and double reference acquisition.

References

[1] Aletras et al, J Magn Reson 1999;137(1):247-252 [2] Fischer et al, Magn Reson Med 1993;30(2):191-200 [3] Kim et al, Radiology 2004;230(3):862-871