Application of a Meshfree Radial Point Interpolation Method (RPIM) for Quantifying Three-Dimensional Left-Ventricular Regional Strains with Displacement ENcoding with Stimulated Echoes (DENSE) MRI and Validation in Reference to Tagged MRI

***J. Kar[1], A.K. Knutsen[2], B.P. Cupps[1], K.M. Wallace[1] and M.K. Pasque[1]**

[1]School of Medicine, Washington University, St. Louis, MO, USA.
[2]The Center for Neuroscience and Regenerative Medicine, The Henry M. Jackson Foundation for the Advancement of Military Medicine, Bethesda, Maryland, USA.

*Corresponding author: karj@wudosis.wustl.edu

Abstract

The primary aim of this study was to develop an automated technique for rapid computation of three-dimensional (3D) left ventricular displacement and Lagrange strain (circumferential, longitudinal and radial) in a high resolution field of phase data obtained with Displacement ENcoding with Stimulated Echoes (DENSE). DENSE is an emerging Magnetic Resonance Imaging (MRI) sequence with displacement information encoded in the phases of complex images through the cardiac cycle. A rapid spatiotemporal phase unwrapping algorithm consisting of computing and averaging phase angles of a series of Fourier transforms in images was implemented for obtaining 3D displacements. The meshfree numerical analysis technique of Radial Point Interpolation Method (RPIM) with multiquadrics (MQ) basis functions was used for computing Lagrange strains. RPIM was chosen to avoid the complications of element distortion and intensive remeshing associated with conventional finite element techniques. Regional 3D LV strains computed with the DENSE-RPIM framework were validated in reference to standard tagged-MRI (TMRI) in 14 normal (healthy) subjects and in six nonischemic dilated cardiomyopathy (DCM) patients. Additional repeatability studies in 10 healthy subjects were conducted to establish intraobserver reliability and increase confidence in DENSE as a sequence for accurate displacement mapping. Bland-Altman analyses were conducted to observe the regional strain agreements between DENSE and TMRI and in DENSE repeatability studies. DENSE-TMRI differences in regional strains from Bland-Altman analyses in normal subjects were 0.01 ± 0.03 in circumferential, 0.02 ± 0.07 in longitudinal and -0.01 ± 0.10 in radial strains. Differences in regional strains from the repeatability studies were 0.0 ± 0.02 in circumferential, -0.02 ± 0.04 in longitudinal and -0.02 ± 0.08 in radial directions. DENSE-TMRI differences in regional strains in DCM patients were -0.01 ± 0.05 in circumferential, 0.02 ± 0.07 in longitudinal and -0.01 ± 0.04 in radial directions. Good regional strain agreements from

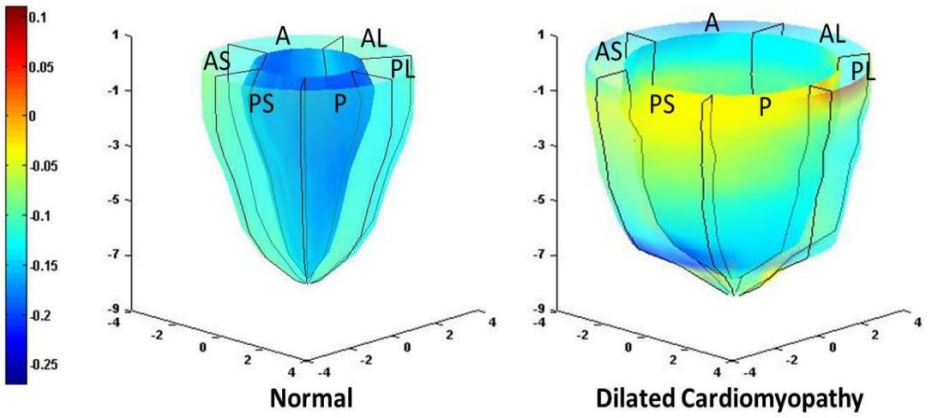

Figure 1. Left-ventricular circumferential strain contours generated with the DENSE-RPIM framework

DENSE-TMRI comparisons in normal subjects and the DENSE repeatability studies validate the accuracy of the DENSE-RPIM computational framework. Good agreements in strains from the DENSE-TMRI comparison in DCM patients demonstrate the framework's ability to quantify contractile dysfunction in the myocardium and show its potential as an efficient clinical tool for risk stratification in cardiac diseases.

Keywords: DENSE; Tagged MRI; Lagrange strain; RPIM; Multiquadrics; Bland-Altman