2D and 3D imaging of axial and lateral cardiac strain with coherent compounding of diverging waves in silico

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Cardiac imaging at high frame rates is of key interest for the characterization of heart contraction abnormalities. Current methods being developed for high frame rate cardiac imaging include multi-line transmit, ECG-gated acquisitions and single diverging wave imaging. However, these techniques suffer from cross-talk, motion matching artifacts or poor lateral resolution, which affects the image quality. Coherent compounding of diverging waves in the heart has been shown to improve SNR and tissue velocity images in 2D as well as contrast and lateral resolution in 3D while maintaining a high frame rate. The objective of this study is to investigate the performance of coherent compounding of diverging waves for 2D and 3D imaging of cardiac strain in simulations.

For 2D imaging, the left ventricular cross-section was modeled as a 50 mm diameter and 10 mm thickness annulus and a 64-element, 2.5 MHz center frequency transducer (ATL, P4-2) was simulated with Field II. For 3D imaging, the left ventricle was modeled as a 50 mm diameter, 10 mm thickness and 50 mm long tube and a 32x32-element, 3 MHz center frequency transducer was simulated. Left-ventricular contraction was modeled as radial thickening of the annulus or the tube with 0.25% strain, which can be obtained at a frame rate of 500 Hz. Coherent compounding of N = {1; 3; 5; 9; 15; 21; 51} for 2D and of N = {1; 5; 9; 25; 81} for 3D diverging waves were used to simulate pre- and post-contraction radiofrequency channel data. Axial and lateral interframe displacements and strains as well as radial strains were estimated in each case and compared to their true value. The interframe cross-correlation coefficient was also calculated.

The radial strain mean error decreased by a factor of 2.8 between 1 and 9 compounded waves for 2D imaging and by a factor of 1.7 for 3D imaging (see Table I). In both the 2-D and 3-D configuration, the mean error of axial, lateral, radial strain estimation decreased with the number of compounded waves while the correlation coefficient increased. These results show improvement of axial, lateral and radial strain estimation with a number of transmitted beams that allows for high frame rate acquisition. Implementation of this technique in vivo has the potential to significantly improve the detection and characterization of contraction abnormalities in the heart.

Table I. Mean error of axial, lateral and radial strain as well as correlation coefficient with the number N of compounded waves for 2D and 3D imaging.

2D imaging	Axial strain error (%)	Lateral strain error (%)	Radial strain error (%)	Correlation coefficient
N = 1	0.052	0.27	0.14	0.994
N = 9	0.019	0.082	0.051	0.999
N = 51	0.018	0.057	0.046	0.999
3D imaging	Axial strain error (%)	Lateral strain error (%)	Radial strain error (%)	Correlation coefficient
N = 1	0.17	0.85	0.51	0.983
N = 9	0.082	0.40	0.29	0.996

N = 81	0.054	0.29	0.17	0.997