

3-D Electromechanical activation mapping of the heart in canines and humans in vivo

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Electromechanical wave imaging (EWI) is an ultrasound-based methodology that can transmurally map the electromechanical activation of the heart at high temporal resolution. Previous reports have shown strong correlation between EWI-based and electrical activation times. However, EWI has only been performed with 2D echocardiography, which cannot map the full cardiac volume in a single heartbeat. In this study, we show the feasibility of 3D EWI in silico and in vivo.

A 32x32 elements array, with 3 MHz center frequency was simulated using Field II. The right and left ventricular geometry and displacement were obtained from a computational electromechanical model based on real human heart anatomy and benchmarked as the “ground truth”. Ultrasound radiofrequency (RF) channel data were acquired at 1000 Hz using diverging wave imaging and inter-volume axial displacements and strains were estimated as well as electromechanical activation times. Estimated axial displacements, strains and activation times from ultrasound simulations were compared against the benchmark. In vivo RF signal acquisition was performed transthoracically in a normal subject and in an open chest canine using the same 2-D array connected to two synchronized Verasonics scanners with a full volume imaging rate of 500 Hz. The inter-volume axial displacements and strains as well as the 3D transmural electromechanical activation of the heart were estimated from diverging wave acquisitions.

Estimated and true axial displacements in silico were found to be strongly correlated ($R^2=0.97$) in both the right and left ventricles. Good agreement ($R^2=0.86$) was found between estimated electromechanical activation times and true electrical activation times. The electromechanical wave was imaged in vivo with 3D ultrasound and the electromechanical activation sequence of the full heart was mapped during a single heartbeat. This study shows that 3-D EWI is feasible and opens new avenues for non-invasive cardiac arrhythmia characterization.