FRAME RATE OPTIMIZATION OF ELECTROMECHANICAL WAVE IMAGING FOR THE MEASUREMENT OF ELECTROMECHANICAL ACTIVATION DURING SINUS RHYTHM

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Background: Clinical Echocardiograms prioritize high spatial resolution over temporal. This allows for better visual diagnosis, yet it restricts the use of time-shifted based techniques such as radiofrequency-based speckle-tracking, which require higher frame-rates. Electromechanical Wave Imaging (EWI) is a high frame-rate ultrasound-based technique relying on axial incremental strain estimation, successfully shown to non-invasively map the transmural electromechanical activation in all four cardiac chambers in vivo [1]. Previous studies have explored the frame rate (FR) limitations upon determining the optimal strain estimation method [2]. However, the impact of the acquisition FR on EWI mapping has not yet been investigated. Exploring EWI frame rate limitations is critical for assessing EWI future integration in the clinic.

Aims: In this study we investigate the impact of the EWI acquisition frame-rate for the assessment of electromechanical activation during sinus rhythm in healthy humans and evaluate the algorithm's susceptibility to lower frame-rate errors.

Methods: A 2.5 MHz diverging wave pulse excited at 2000 Hz PRF with a Verasonics Vantage system (Verasonics, Redmond, WA), obtained with a P4-2 phased array (ATL/Philips, Andover, MA, USA) was used to image a healthy human heart (26 year old male) in four transthoracic apical echocardiographic views, for 2 seconds per view at a depth of 20 cm. We compute the axial incremental displacement and strains with 1D RF cross-correlation with a window size of 6.2 mm and a 90% overlap followed by a 51-point gaussian window for displacement temporal filtering and a least-squares axial strain estimator of 5mm kernel size. We repeat this process by downsampling the raw RF EWI data FR from 2000 Hz to 500 Hz, 250 Hz and 125 Hz. We simultaneously adjust the RF cross-correlation axial search range and displacement temporal filtering by the equivalent down-sampling factor. We define the wavefront of the electromechanical activation as the timing of the first sign change of the incremental axial strain after the QRS onset. Multi-2D views are co-registered around the LV longitudinal median axis and corresponding activation times are interpolated around the circumference, to generate 3-D rendered activation maps [3]. Down-sampled EWI activation maps are compared in terms of qualitative and quantitative differences with the 2000 Hz maps which are used as the ground truth. A 15 ms offset from the 2000 Hz selected zero-crossing (ZC) locations is considered to be within an accepted error range for ZC detection with lower FR, whereas any difference larger than that for the same pixel are defined as false positives. Matlab (Mathworks Inc., Natick, MA, USA) was used for all processing steps and Amira 5.3.3 (Visage Imaging, Chelmsford, MA, USA) for 3-D map visualization.

Results: Of the initial pixels used for 2000 Hz EWI isochrone generation, we were able to detect ZCs in 98% of them at 500 Hz, 94% at 250 Hz and 81% at 125 Hz (Fig 1). However, only 92% for 500 Hz, 80% for 250 Hz and 41% for 125 Hz of the initial pixels' ZCs lie within the 15 ms accepted error window and hence were considered true positive ZCs. The 500 Hz map is the most consistent with the 2000 Hz baseline, showing minor differences. The 250 Hz map presents a difference mainly in the RV inferior wall, with 15% of the ZCs falsely detected. The 125 Hz map diverges significantly from the baseline, as observed particularly in the RV inferior wall and the LV lateral wall with an average of 50% of the selected ZCs considered false positives.

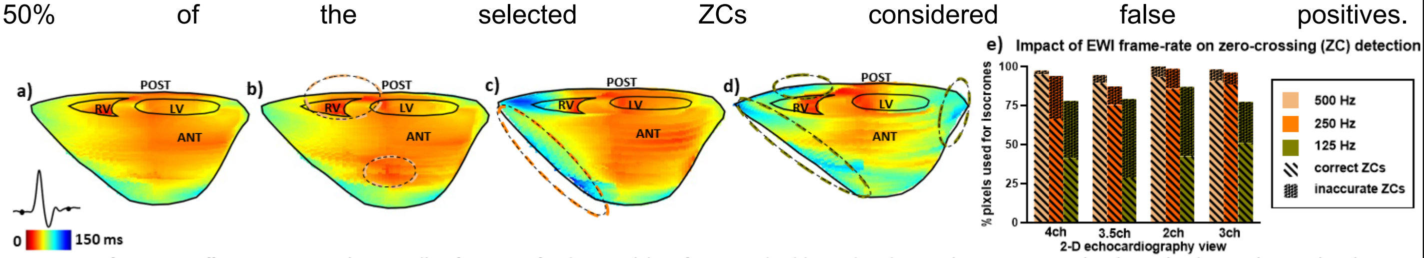

Fig. 1: EWI frame-rate effect on zero-crossing sampling frequency for the ventricles of a 26 yo. healthy male volunteer in NSR. 3-D rendered EWI isochrones in anterior view at a) 2000 Hz (baseline), b) 500 Hz, c) 250 Hz and d) 125 Hz. Red represents the earliest activation while blue the latest. e) Proportion of useable pixels at lower frame-rates compared to the 2000 Hz baseline. ZCs are considered correct when contained within a 15 ms range of the initial 2000 Hz ZC temporal locations. LV: Left Ventricle, RV: Right Ventricle, ANT: Anterior, Post: Posterior.

Conclusions: EWI mapping was shown to be quantitatively and qualitatively highly dependent on the acquisition high frame-rate, as expected. These findings indicate that EWI should not be evaluated at frame-rates lower than 500 Hz, as it can result in misleading electromechanical activation maps, which could interfere with correct diagnosis in a clinical setting.

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References: **[1]** Provost et al, Proc. Natl. Acad. Sci. 2011. **[2]** Provost et al 2012 Phys. Med. Biol. 57 1095 **[3]** Nauleau et al, Medical Physics 2017.