Accelerated Three-Dimensional Myocardial Strain Quantification using zHARP

K. Z. Abd-Elmoniem[1], N. F. Osman[1,2], M. Stuber[1,2], and J. L. Prince[1,2]

[1]Electrical and Computer Engineering, Johns Hopkins University, Baltimore, Maryland, United States, [2]Department of Radiology, Johns Hopkins University Medical School, Baltimore, Maryland, United States

Introduction

Three-dimensional (3D) myocardial strain quantification can be used to accurately identify and characterize healthy and diseased myocardial tissue. Typical 3D strain imaging methods use short-axis (SA) slices to calculate circumferential (E_{cc}) and radial (E_{rr}) strains, and long-axis (LA) slices to calculate longitudinal shortening (E_{ll}). Unless interpolated, data for 3D strain is only available at the lines of intersection of these orthogonal slices. However, collecting images in orthogonal orientations and at multiple anatomical levels is very time consuming and susceptible to misregistration. zHARP is a recently developed tagging MRI methodology [1] that encodes both in-plane and through-plane motions in a single image plane. In this work, we developed and validated an imaging scheme for simultaneous quantification of in-plane and through-plane strain components – E_{cc}, E_{rr}, and E_{ll} – from SA slices without the need for LA data. Using this scheme, two or more SA slices are acquired and processed using zHARP. E_{cc} and E_{rr} are calculated using the in-plane displacement information while E_{ll} is calculated from the relative through-plane displacement between the SA slices. First in-vivo results show that 3D strain values measured using this two-slice zHARP approach and regular slice-following CSPAMM (SF-CSPAMM) [2] tagging were strongly correlated (R>0.92).

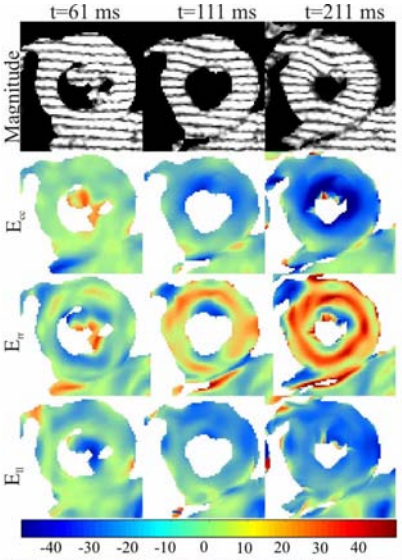

Fig.1 3D pixel-by-pixel strain mapping of an equatorial SA slice in a healthy 33-year old

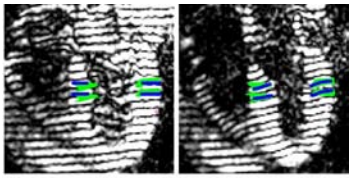

Fig.2 A 4CH SF-SPAMM slice showing the SA lines of intersection (blue) and their tracking (green)

Theory

zHARP uses standard SF CSPAMM except that during the imaging sequence a z-encoding gradient with a z-encoding frequency κ is applied immediately before the readout. An R-wave triggered tagged cardiac slice starts as a flat plane. It then undergoes both in-plane and through-plane displacements, u_x, u_y, and u_z, respectively. zHARP generates three phase maps, φ_x, φ_y, and φ_z which are directly proportional to u_x, u_y, and u_z. In-plane strain E_{cc} and E_{rr} are readily obtained from u_x and u_y [3]. To calculate longitudinal strain $E_{ll} \triangleq 1/\kappa \, \partial\varphi_z/\partial z$, at least two parallel slices SA_1 and SA_2 are required. Hence, $E_{ll} \approx 1/\kappa \, (\varphi_z^{\,1} - \varphi_z^{\,2})/\Delta z$, where, $\varphi_z^{\,1}$ and $\varphi_z^{\,2}$ are from SA_1 and SA_2, respectively, and Δz is the gap between the two slices.

Methods ***Imaging:*** The zHARP pulse sequence was implemented on a commercial Philips 3T-Achieva whole body system. Image processing was performed off-line on a personal computer. Three healthy 26-33 year old male volunteers were scanned using VECG triggered spiral imaging with a 9 ms acq. window, 10 spiral readouts, FOV =300mm, slice thick.=8mm, TR=25 ms, and tag spacing=6 mm. In each study, two mid-ventricular SA slices were acquired using zHARP with an 8 mm center-to-center gap and $\kappa = 2\pi/33$ rad/mm. For validation, the same SA slices and four LA slices were acquired using SF-CSPAMM tagging. Breath-holding was used to suppress respiratory motion artifacts. For all the acquired slices, vertical and horizontal tagging were applied in separate breath-holds.

Analysis: The endo- and epicardial contours were segmented manually. SF-HARP processing[4] was applied on the HARP phases extracted from zHARP to get E_{cc} and E_{rr} . The myocardium was then divided into 16 segments and the regional strains were computed over multiple cardiac phases. The same processing was applied to SF-CSPAMM data for comparison. Longitudinal shortening E_{ll} was estimated using the equation above. The lines of intersection between the SA and LA slices were used for E_{ll} validations. The average E_{ll} on the line segments calculated in the SA slice was compared against the corresponding average in-plane shortening on the same line segments in the LA slices. Precision and relative accuracy were evaluated using linear regression and Bland-Altman analyses on all strain components.

Results: Figure 1 shows an example dataset using the proposed scheme at 61 ms, 111 ms, and 211 ms after the R-wave of the ECG. Note the transmural variation of E_{cc} while E_{ll} is homogeneous about the circumference. Figure 2 shows a 4CH SF-CSPAMM image at two different times showing the lines of intersection between the 4CH and the two SA slices. The in-plane longitudinal shortening of the intersection lines are shown in green. As shown in Figure 3, the strain components measurements using the proposed scheme and SF-CSPAMM are strongly correlated (R>0.91, 1>= slope >0.85, |intercept| < 0.025). According to the Bland-Altman analysis, more than 95% of the measurements were within the 95% limits of agreement.

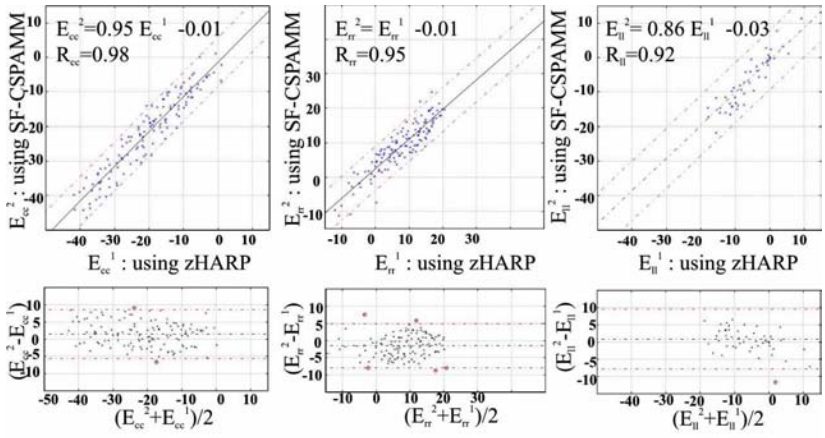

Fig.3 Linear regression and Bland-Altman analyses results for the 3D strain components.

Conclusion: An imaging scheme was proposed for 3D strain quantification using only SA slices with the result being pixel-by-pixel 3D strain maps. The scheme was validated against typical SF-CSPAMM approach. Since no LA slices are required, the scheme has the potential to significantly abbreviate a 3D cardiac strain imaging as compared to more conventional approaches.

References: 1) Abd-Elmoniem: IPMI'05, 2.)Fischer: MRM'94. 3) Osman: MRM'99. 4) Sampath: ISMRM'04