Optimal z-Encoding Frequency for zHARP: In-vivo Validation and Comparison with SF-CSPAMM

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Introduction: Quantitative functional cardiac imaging can be used to characterize healthy and diseased myocardial tissues. Imaging protocols that measure 3D motion of the heart can lead to more accurate characterization than 2D approaches. However, 3D protocols are often too time-consuming for clinical feasibility. zHARP[1] is a fast imaging technique that can quantify 3D myocardial motion from a single slice. The technique is based on slice-following CSPAMM[2] tagging, adding a z-gradient to encode the through-plane displacement of the tagged CINE images. Although zHARP has demonstrated promising 3D displacement results, no research has been done on either the optimality of the z-encoding frequency for through-plane displacement measurement or its effect on the measurement of in-plane displacements.
The purpose of this work is to establish the mathematical framework for studying the intravoxel dephasing effect of the z-encoding on zHARP 3D displacement and in-plane strain measures. The optimal z-gradient strength is determined from this work by experimental comparison of the in-plane and through-plane displacement and strain maps.

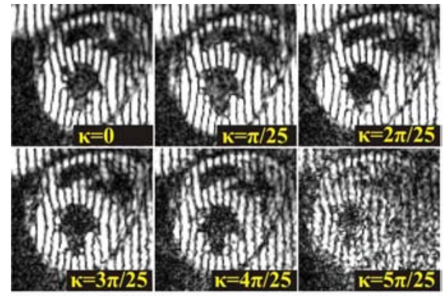

Fig.1 A zHARP SA equatorial slice acquired with different **κ** values (151 ms after R-wave).

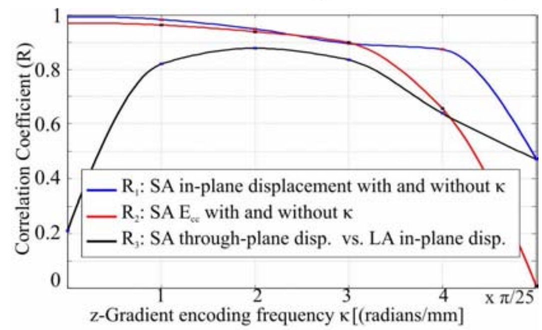

Fig.2 Correlation between in-plane/in-plane displacements, E_{cc}, and in-plane/through-plane displacements with different κ.

Methods: *Theory:* zHARP is a recently developed tagged MRI methodology for direct imaging and automatic tracking of the 3-D myocardial displacement of all points in an image plane[1]. The z-encoding gradient can be described by its z-encoding frequency **κ** [radians/mm]. The zHARP complex image signal I is,
$I \propto \rho \times TAG \times e^{j\varphi_e} \times e^{j\kappa\delta_z} \times \mathrm{sinc}\left(\boldsymbol{\kappa}\frac{\tau}{2}\right)$, where δ_z is the through-plane displacement and τ is the slice thickness. Thus, the z-gradient encodes through-plane displacement in the phase of the complex data but also causes intravoxel dephasing in the slice-select direction. This dephasing reduces the magnitude of the tagged image and the overall SNR, which potentially affects the accuracy of the measured quantities.
Implementation: A normal 33-year old adult was imaged in a 3T MRI system (Achieve, Philips) using a cardiac phased-array coil and zHARP pulse sequence with six different z-gradient encoding frequencies (0, π/25, 2π/25, 3π/25, 4π/25, 5π/25 rad/mm). Basal, equatorial, and apical SA slices were acquired. Four LA slices were acquired using SF-CSPAMM. All data had FOV=300 mm, 12 spirals, TR=20 ms, flip angle=20, and 8 mm slice thickness. The lines of intersection between the LA and the SA planes were tracked in both planes. The through-plane displacement in the SA slices, were compared against the equivalent in-plane displacement in the LA slices. Each SA slice was segmented into 16 segments and the average circumferential strain (E_{cc}) in each segment was computed over 15 cardiac cycles. In addition, SA in-plane tracking was done for 2000 points per slice evenly distributed throughout the myocardium. E_{cc} and displacements were calculated in each dataset and compared to the corresponding quantities measured from SF-CSPAMM data and the correlation coefficients were calculated.

Results: Fig. 1 shows an example SA slice acquired with different **κ** values**.** Notice the reduction in SNR with the increasing **κ**. Fig.2 shows the SA in-plane/in-plane displacement correlation coefficient (R_1) and E_{cc} correlation coefficient (R_2) as functions of **κ**. Even with **κ** as high as 2π/25, R_1 and R_2 are still above 0.95. In addition, the SA through-plane/LA in-plane correlation coefficient (R_2) shows a peak value above 0.87 for **κ** around 2π/25 suggesting an optimal **κ** from 2π/33 to 2π/20 rad/mm which keeps R_1 and R_2 above 0.95 and R_3 around its maximum. We considered in that range the typical variations of the above-mentioned imaging parameters for normal adult scans. The zHARP 3D tracked pathlines of an equatorial slice with **κ** = 2π/25 is shown in Fig.3 together with E_{cc} at end-diastole and end-systole and in-between. Notice the in-plane thickening and the smooth downward shortening.

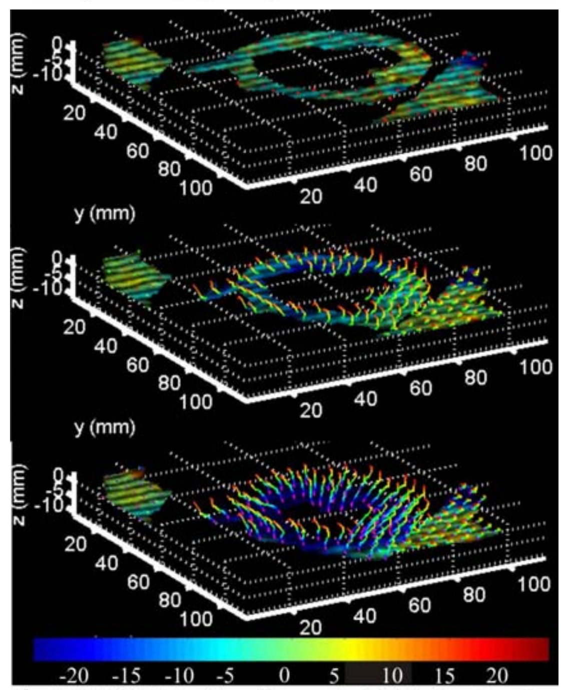

Fig. 3 zHARP 3D tracking of an equatorial SA slice at end-diastole (top) at end-systole (bottom) and in-between (middle)with 3D zHARP tracking pathlines and E_{cc} superimposed.

Conclusion: The effect of intravoxel dephasing due to z-encoding in zHARP was evaluated. Preliminary in-vivo results show that in-plane displacement and strain are highly correlated (R=0.92) with SF-CSPAMM results with optimal z-encode selection. As well, through-plane displacement can be calculated reliably (R> 0.87) with the same z-encode. We conclude that zHARP can be used to acquire 3-D displacements comparable to conventional tagging without the need for the time-consuming, 3D tagging acquisitions.

References:
1-Abd-Elmoniem, et. al: "ZHARP: Three-Dimensional Motion Tracking From a Single Image Plane",IPMI'05
2-Fischer, et. al: "True myocardial motion tracking",MRM'94