zHARP with Dumbbells (d-zHARP): Accelerated True 3-D Myocardial Regional Function Quantification and Tracking

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Introduction MRI is a leading modality for three-dimensional (3D) myocardial strain quantification, which can be used to accurately identify and characterize healthy and diseased myocardial tissue. Typical 3D strain imaging methods acquire 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}). Acquired data contain 3D strain information only at the lines of intersection of these orthogonal slices. zHARP is a recently developed tagging MRI methodology [1,2] that encodes both in-plane and through-plane motions in a single image plane. Although the proved time-efficiency of zHARP, a large amount of k-space is acquired, this is more than the needs of zHARP analysis. The hypothesis of this work is that a significant amount of acquisition time can be saved without sacrificing the quality of strain results if only the data needed for 3D strain analysis are acquired. In this work, we developed a fast pulse sequence called d-zHARP that reduces the scanning time needed for zHARP analysis from two breath-holds per slice to four cardiac cycles. First in-vivo results show that regional 3D strain values measured using d-zHARP agree with the values calculated using conventional zHARP imaging technique.

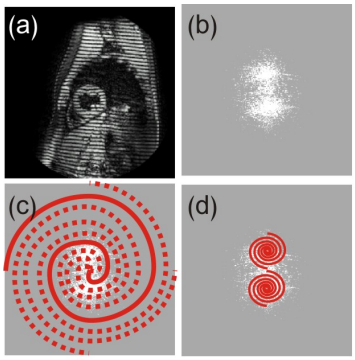

Fig.1 (a) zHARP slice. (b) zHARP k-space. (c) Regular zHARP acquisition. (d) d-zHARP acquisition.

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. In-plane strain E_{cc} and E_{rr}, and E_{ll} are readily obtained[2]. Similar to harmonic phase (HARP) analysis [3]. As shown in Fig.1(b), the k-space of zHARP image contains two harmonic peaks, which encodes all 3D motion information. Typical zHARP uses many spiral interleaves to acquire the whole k-space (Fig.1(c)). The k-space area far away from the center of the harmonic peaks are dominated by noise and interference and is filtered out before zHARP analysis. In this work, instead of using many interleaves starting from the origin, every harmonic is acquired using two short spiral interleaves originating from the peak itself in a dumbbells-shaped k-space trajectory (Fig.1(d)). In four cardiac cycles, the scanner acquires vertical-tag cosine, vertical-tag –cosine, horizontal-tag cosine, and horizontal-tag –cosine, respectively. The pulse sequence is shown in Fig.2. In every cardiac cycle, the scanner alternates between the positive and negative harmonic peaks, each of the peaks is acquired using two spirals. In addition to saving scanning time, in this strategy, harmonic peaks are more densely sampled than in the conventional DC-centered spiral acquisition and therefore, more faithful motion information is collected.

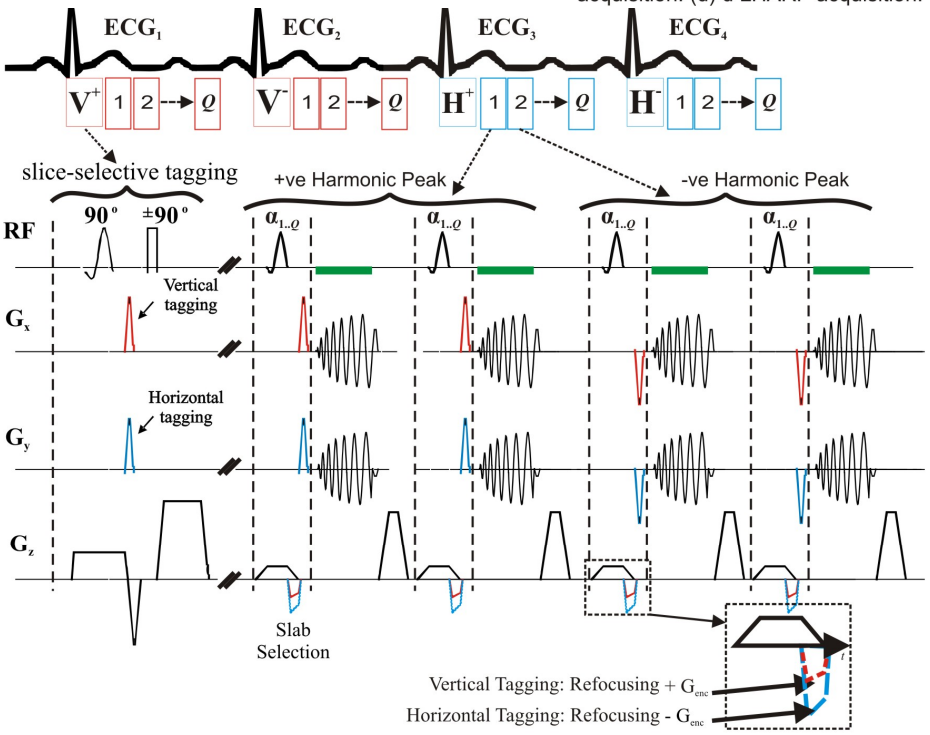

Fig.2 (a) d-zHARP pulse sequence. The vertical and horizontal tagging data sets are acquired in the first and the second two heart cycles, respectively. At every cardiac phase, the positive and negative harmonic peaks are acquired sequentially. Each peak is acquired using two short spiral interleaves.

Methods ***Imaging:*** The zHARP and d-zHARP pulse sequences were implemented on a commercial Philips 3T-Achieva whole body system. Image processing was performed off-line on a personal computer. A healthy 29 year old male volunteer were scanned using VECG triggered spiral imaging. zHARP data were acquired with a 10 ms acq. window, 10 spiral readouts, FOV =300mm, slice thick.=8mm, TR=35 ms, and tag spacing=7 mm. d-zHARP data were acquired with 8 ms. acq. Window per interleaf, TR=15 ms. sequence is shown in Fig.2. Mid-ventricular SA slices were acquired using z-encoding frequency $\kappa = 2\pi/33$ rad/mm. In zHARP, breath-holding was used to suppress respiratory motion artifacts, and vertical and horizontal tagging were applied in separate breath-holds.

Analysis: The endo- and epicardial contours were segmented manually and the myocardium was divided into six segments as shown in Fig.3. 3D displacements, E_{cc} and E_{rr} were calculated[1]. The average strains in each segment was calculated with d-zHARP and zHARP.

Results Fig.3 shows E_{cc} at different cardiac phases using the proposed scheme and conventional zHARP. Fig.4 shows the time-profile of E_{cc} in three segments using both techniques. Notice the agreement between strain maps and strain time profiles using conventional zHARP, acquired in two breath-holds, and d-zHARP, acquired in four cardiac cycles.

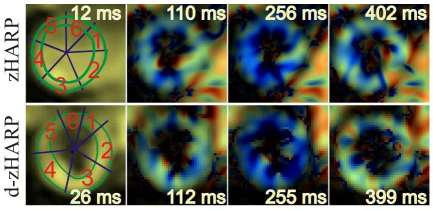

Fig.3 Ecc calculated using zHARP (top) and using d-zHARP (bottom) at different cardiac phases.

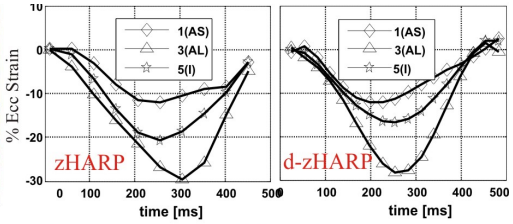

Fig.4 The Regional Ecc % strain during the cardiac cycle using zHARP (left) and d-zHARP (right) at three heart segments 1, 3, and 5.

Discussion A fast zHARP imaging scheme was proposed for 3D strain quantification and tracking using only four cardiac cycles slices with the result being pixel-by-pixel 3D strain maps. The scheme was compared to conventional zHARP approach in-vivo. In addition to free-breathing 3D motion tracking, the d-zHARP sequence is potentially useful for whole heart 3D functional quantification and tracking in as few as two breath-holds.

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References: 1) Abd-Elmoniem, et. al., *MRM* ,2007, 92-102. 2) Abd-Elmoniem, et. al., *IPMI* 2007, pp. 62-73. 3) Osman, et. al., *MRM 1999*; 1048–1060.