Evaluation of Myocardial Eulerian Strain Using Bandpass Optical Flow. Comparison to Harmonic Phase Imaging

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INTRODUCTION: MRI provides a unique tool for comprehensive evaluation of the heart function. Specifically, MRI tagging has been established as a valuable technique for quantifying regional heart function, which is usually affected before changes in global measures [1]. Different techniques have been developed for tagline tracking. Specifically, harmonic phase (HARP) [2] presented a big advancement in tag analysis in terms of the processing time and level of automation, as it is based on k-space analysis compared to conventional image-based analysis techniques. Nevertheless, the drawback of HARP is that tracking the material points fails near the myocardial boundaries [3], which prohibits quantifying strain in these areas. Band-Pass Optical Flow (BPOF) is a motion analysis technique that has been developed and implemented in different applications [4]. BPOF uses Fourier domain filtering of the spectral peaks to generate multiple views of the same underlying motion. The inclusion of optical flow constraints in BPOF could be a remedy to the HARP limitation in tracking taglines at the myocardial boundaries. The purpose of this work is to implement BPOF for calculating strain from numerical phantom and in vivo tagged images, and compare the results to HARP at different myocardial regions.

METHODS: A numerical phantom was generated to evaluate both HARP and BPOF. The phantom consists of 25 timeframes of spatial modulation of magnetization (SPAMM)-tagged images of size 256×256 pixels and FOV = 145×145 mm^2 to represent different cardiac phases. Each image contains an annular object representing a SAX view of a basal LV slice with endo- and epicardial radii of 30 and 40 mm, respectively, at end-diastole. Tag fading and noise were added to the images for realistic implementation. The generated images were used as the ground truth for quantifying errors in strain estimation. Further, tag analysis was performed on SPAMM-tagged images from five human subjects scanned on a 3T MRI scanner.

HARP works by extracting the first harmonic peaks in the k-space of the tagged image. The phase image of the inverse Fourier transformation of the modified k-space is then calculated and called the HARP image. As phase is a tissue property, then a certain material point can be tracked during the cardiac cycle by identifying the points in a small neighborhood of this point that have the same phase in consecutive timeframes [2]. Optical flow (OF) is a commonly used motion tracking technique, which assumes constant brightness of the material points with time. BPOF is an OF technique that estimates velocity by representing the tagged image as 2D sinusoidal pattern multiplying the underlying brightness field. Thus, in the frequency domain, the image consists of various sub-bands located at frequencies related to multiples of the fundamental sinusoidal frequency [4]. To extract these sub-bands, band-pass filters are applied at the locations of the first harmonic peaks in the horizontal, vertical, diagonal, and back diagonal directions. Tissue velocity is calculated from all the extracted sub-bands to provide a robust solution without the need for regularization parameters or iterations. BPOF has the advantages of providing reliable results by solving a system of over-determined linear equations, and that the checkered texture in the processed tagged images is no longer present, indicating a spatially homogeneous conditioning of the system of equations.

RESULTS AND DISCUSSION: Figure 1 shows Eulerian strain at different regions in the heart calculated in the numerical phantom using both HARP (Diagnosoft VIRTUE software) and BPOF (in-house software developed with Matlab). The processing time was comparable for both techniques. The results show close agreement between the strain measurements by BPOF and actual strain. HARP showed differences in the estimated strain, especially during diastole and at the anterior and anteroseptal regions, where the tracked points were close to the myocardium boundaries. The minimum root square (MRS) strain errors for BPOF/HARP were 0.32/1.15 (anterior), 0.58/8.2 (anteroseptal), 2.8/2.4 (inferoseptal), 1.17/2.7 (inferior), 0.39/0.62 (inferolateral), and 1.09/2.34 (anterolateral). Figure 2 shows Eulerian strain maps of the numerical phantom generated with HARP and BPOF. Although BPOF resulted in homogeneous circumferential strain and gradual change in radial strain in accordance with the actual phantom deformation, HARP resulted in abrupt changes in the strain measurements at the endo- and epicardial boundaries. Figure 3 shows an example of Eulerian strain measured for the in vivo images using both HARP and BPOF. Differences in the estimated strains can be observed at different myocardial locations, especially during diastole, where tag fading contributes to the challenging task of tagline tracking. The RMS error of the difference in strain measurements by BPOF and HARP for all 16 segments was 10.1, which was a significant difference ($P < 0.001$).

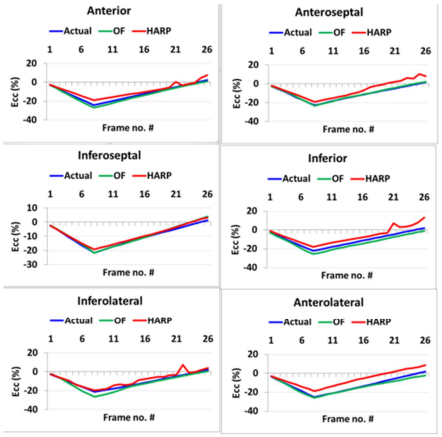

Fig 1. Eulerian strain (Ecc) in numerical phantom calculated at different regions in the heart using HARP, BPOF, as well as actual strain.

CONCLUSIONS: BPOF provides accurate estimates of myocardial strain that are in agreement with HARP at points inside the ventricular wall. However, BPPOF provides more reliable results than HARP, with no tracking errors, at the myocardial boundaries.

REFERENCES:[1]JCMR 2011,13:36; [2]IEEE-TMI 19:186; [3]IEEE-EMBC 2005:4289; [4]Med Physic 27:108

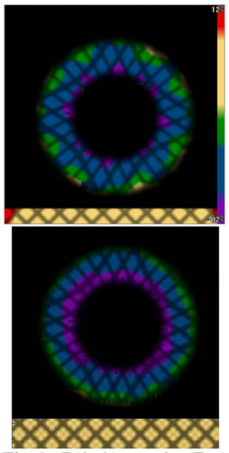

Fig 2. Eulerian strain (Ecc) maps in the numerical phantom using HARP (top) and BPOF (bottom).

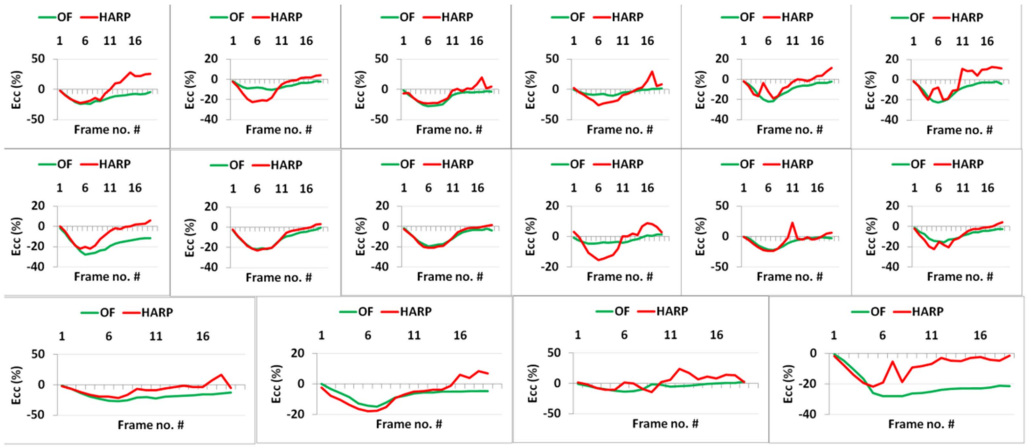

Fig 3. Eulerian strain (Ecc) in human subject at basal (top), mid (middle) and apical (bottom) SAX slices. The slices were divided into 16 segments: base and mid (left to right): anterior, anteroseptal, inferoseptal, inferior, inferolateral, and anterolateral; apex (left to right): anterior, septal, inferior, lateral.