Imaging 2-D myocardial motion and chamber blood flow simultaneously with EGGS SPAMM & SPAMM (Encoded Gradients for Gauging Speed in sinusoidal SPAMM and co-sinusoidal SPAMM acquisitions)

S. Sampath[1], E. R. McVeigh[1]

[1]Laboratory of Cardiac Energetics, Division of Intramural Research, NHLBI, NIH, DHHS, Bethesda, MD, United States

Introduction: It has been shown that myocardial motion quantification using HARP or DENSE in conjunction with CSPAMM techniques reduce artifacts in the strain maps due to the suppression of interference from the recovering dc peak [1,2]. To obtain 2-D in-plane motions, four tagged image sequences are typically acquired—horizontal SPAMM (A_h), horizontal complimentary SPAMM (B_h), vertical SPAMM (A_v) and vertical complimentary SPAMM (B_v). In this abstract, we present a new method—Encoded Gradients for Gauging Speed in sinusoidal SPAMM and co-sinusoidal SPAMM acquisitions (EGGS SPAMM & SPAMM)— that encodes 2-D blood velocities simultaneously during these four acquisitions, providing multi-phase measurements of chamber blood flow velocity patterns in addition to myocardial displacements. Data obtained from a normal volunteer is presented.

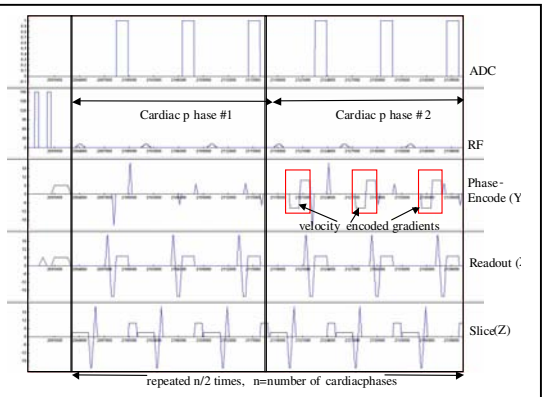

Fig. 1. Timing diagram of the velocity encoded tagging sequence. The red boxes highlight the bipolar gradient pulses played out during the even cardiac phases.

Theory: EGGS SPAMM & SPAMM is similar to the standard CSPAMM acquisitions; with the exception that a bipolar gradient pulse with sensitivity to blood velocities in a given direction is played out every even cardiac phase just before the phase encode gradient (See sequence timing diagram). This adds a velocity-encoded phase to these images, which can be extracted using simple algebraic manipulations of the acquired images. Now, let us consider the acquisition of vertical 1-1 SPAMM tagged image sequences A_v and B_v, both acquired with a bipolar gradient pulse along the Y-direction during the even cardiac phases. The FT of these images comprises three spectral peaks—one dc peak and two harmonic peaks. Eqns. 1 & 2 mathematically express the even cardiac phase images, and Eqns. 3 & 4 express the odd cardiac phase images as a summation of the individually reconstructed harmonic images (term1) and the dc images (term2). The 2-D in-plane position vector is $\mathbf{p}$ (x,y) , and the time at which the cardiac phase is acquired is denoted by t. Similar to standard HARP and DENSE methods, the tag preparation pulse sequence modulates and stores the magnetization along the longitudinal axis for a certain period of time, which is later tipped back repeatedly into the transverse plane during image acquisitions to produce the harmonic peaks. Hence, the harmonic images (term1) in Eqns. 1—4 contain the motion encoded phase terms (denoted by $\phi_x(\mathbf{p},t)$). Similar to phase-contrast methods, the bipolar gradients are applied just before every readout gradient causing the velocity encoded phase terms (denoted by $\phi_{vy}(\mathbf{p},t)$) to appear in both the dc (term2) as well as the harmonic images (term1). The time-invariant background phase terms, denoted by $\phi_0(\mathbf{p})$, are also found in both the harmonic and the dc images.

$$A_v(\mathbf{p},t;n_{even}) = c_1(\alpha,t)I_0(\mathbf{p},t)\cos(\omega_x x+\phi_x(\mathbf{p},t))e^{j\phi_0(\mathbf{p})}e^{j\phi_{vy}(\mathbf{p},t)} + c_2(\alpha,t)I_0(\mathbf{p},t)e^{j\phi_0(\mathbf{p})}e^{j\phi_{vy}(\mathbf{p},t)} \quad (1)$$

$$B_v(\mathbf{p},t;n_{even}) = -c_1(\alpha,t)I_0(\mathbf{p},t)\cos(\omega_x x+\phi_x(\mathbf{p},t))e^{j\phi_0(\mathbf{p})}e^{j\phi_{vy}(\mathbf{p},t)} + c_2(\alpha,t)I_0(\mathbf{p},t)e^{j\phi_0(\mathbf{p})}e^{j\phi_{vy}(\mathbf{p},t)} \quad (2)$$

$$A_v(\mathbf{p},t;n_{odd}) = c_1(\alpha,t)I_0(\mathbf{p},t)\cos(\omega_x x+\phi_x(\mathbf{p},t))e^{j\phi_0(\mathbf{p})} + c_2(\alpha,t)I_0(\mathbf{p},t)e^{j\phi_0(\mathbf{p})} \quad (3)$$

$$B_v(\mathbf{p},t;n_{odd}) = -c_1(\alpha,t)I_0(\mathbf{p},t)\cos(\omega_x x+\phi_x(\mathbf{p},t))e^{j\phi_0(\mathbf{p})} + c_2(\alpha,t)I_0(\mathbf{p},t)e^{j\phi_0(\mathbf{p})} \quad (4)$$

Now, for every subsequent odd and even cardiac phase, performing the operation $\angle\{[A_v(\mathbf{p},t;n_{odd})+B_v(\mathbf{p},t;n_{odd})]^*[A_v(\mathbf{p},t;n_{even})+B_v(\mathbf{p},t;n_{even})]\}$ gives us the velocity encoded phase images (see Fig. 2c) along the Y-direction. Regular vertical SPAMM tagged magnitude images can be obtained by simply taking the magnitude of the images in Eqns. (1&3) (See Fig. 2d). To obtain strain images with no dc interference using HARP, the MICSR reconstruction formula [3] $|A_v(\mathbf{p},t)|^2-|B_v(\mathbf{p},t)|^2$ can be employed to suppress the dc peak. The same process is repeated during the horizontally tagged image acquisitions, but now the velocity encoding gradient is applied in the orthogonal X direction (See Fig. 2a &b).

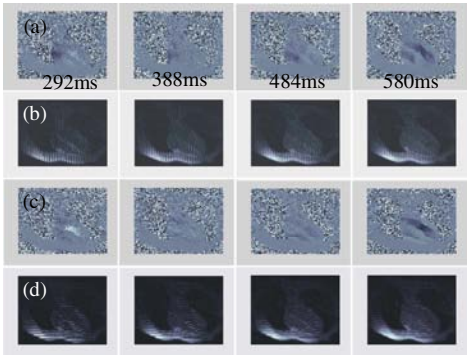

Fig. 2. Images acquired using the velocity-encoded CSPAMM sequence at four representative time frames. Velocity encoded phase images along the horizontal (a), and vertical (c) directions. Vertical (b), and horizontal (d) SPAMM tagged magnitude images.

Imaging Technique: Experiments were conducted on a 1.5 T Siemens Sonata scanner. The timing diagram of the pulse sequence for a vertically SPAMM tagged image with velocity encoding along the phase-encode (Y) axis is shown in Fig.1. During each heartbeat, an R-wave triggered 1-1 SPAMM tag preparation module is played out. This mainly comprises two non-selective 90° rectangular pulses separated by a tagging gradient along the readout (X) axis followed by crusher gradients along the X and Y-axes. The tagging preparation is then followed by a gradient-echo based multi-segmented, multi-phase acquisiton module. During even cardiac phases, a bipolar velocity encoded gradient pulse is played out along the Y axis just prior to the phase encode gradient pulse itself. The zeroth moment of the readout and the slice selective gradients were nulled at the center of the echo to provide flow compensation along these axes. The phase encode gradients were rewound and a z-crusher gradient was played out at the end of every readout acquisition. The key imaging parameters used were: imaging matrix: 128X96, resolution: 2.3mmX2.3mm, slice thickness: 10mm, tag separation:8mm, VENC:80cm/s, RBW:700Hz/pixel, TE=5.1ms, TR=8ms, 3 views per cardiac phase, imaging flip angle=8°. The image sequences (A_h, B_h, A_v and B_v) were acquired in four separate breath-held acquisitions, with temporal resolution of 24ms. Note however that one velocity encoded image is obtained every 48ms.

Results and Discussion: Figs. 2(a) and (c) show the reconstructed velocity images along the horizontal and vertical directions respectively obtained using the method described above at four representative time frames. Figs. 2(b) and (d) show the reconstructed magnitude SPAMM images along the vertical and horizontal directions respectively for the corresponding time frames. Note the left-ventricular outflow during the first early systolic time frame and the left ventricular inflow during the last early diastolic time frame. We note that the SNR of the velocity encoded phase images improve with time, while the tagged signal decays with time. Achieving an optimal compromise by adjusting the timing parameters and flip angles in the sequence remains to be investigated.

Conclusion: We have demonstrated the simultaneous acquisitions of 2-D in-plane myocardial motions and 2-D in-plane chamber blood flows using a velocity encoded CSPAMM acquisition.

References:**1.** Kuijer et. al. MRM 2001 46(5)
2. Epstein et. al. MRM 2004 52(4)
3. NessAiver et. al. MRM 2003 50(2)