Measuring Myocardial Motion using HARP Imaging

S Masood1, PD Gatehouse2, F Deligianni1, DN Firmin2, GZ Yang1
1 Visual Information Processing Group, Dept of Computing
2 Cardiovascular Magnetic Resonance Unit, Royal Brompton Hospital

Introduction
Cardiovascular magnetic resonance (CMR) allows accurate and reproducible imaging of anatomical and functional information. One important functional index which can be measured using CMR is myocardial contractility. CMR tagging and myocardial velocity mapping have become the standard techniques for assessing contractile abnormalities of the heart. Recent advances in MR tagging include improved HARPimaging based on Complementary Spatial Modulation of Magnetisation (CSPAMM) tagging to obtain more accurate strain distributions of the heart [1]. Existing techniques are, however, still limited to 2D slices because of the acquisition time involved. Three-dimensional coverage of the left ventricle (LV) can only be achieved using multiple breath-holds to limit the effect of respiratory motion. This limits the acquisition time available and hence the spatial resolution of the images.

In cardiac imaging, the effect of respiration on cardiac motion has been well-documented. Respiration superimposes a large motion on top of the complex contraction, relaxation and torsion of the heart. Extensive research has been carried out in 3D coronary imaging to address the effect of respiratory motion on the accuracy of the acquired images. The purpose of this study was to assess the applicability of prospective respiratory gating with real-time navigator echoes for 3D HARP imaging. The effect of free-breathing at different respiratory positions on the strain distribution was examined.

Method
HARP imaging exploits the information content of CMR tagging and allows the estimation of myocardial motion in near real-time. It makes use of a simple CSPAMM tagging sequence for assessment of myocardial motion and processing is done in frequency space (k-space) with spectral filtering and reconstruction. The technique has shown promise in application to different clinical settings particularly for the on-line assessment of stress induced contractility changes. In our studies, the data is acquired on a Siemens Sonata 1.5T system with a peak slew rate of 200mT/m/s and peak amplitude of 40mT/m. A segmented FLASH sequence was used to acquire the data with a segment size of 8 k-line recordings. A TR of 52ms, flip angle of 20°, image matrix of 64x256, field-of-view of 300x300 mm² and a slice thickness of 8mm were used to obtain a cine sequence of 12 image frames. The phase encode direction was switched according to the tag direction.

Five normal subjects were recruited for this study with informed consent. The same mid-ventricular short axis slice was imaged three times for each subject, using a single breath-hold at end-expiration, free-breathing with respiratory gating at end-inspiration and end-expiration, respectively. A complete CSPAMM data set was acquired with +90°, +90° and -90° vertical and horizontal tagging pulses. A 90-180° navigator echo pulse with a column size of 10 mm was used to sample the movement of the dome of the diaphragm. A gating window of ±4mm and ±2.5mm was used for the expiratory and inspiratory gating respectively. By using the breath-hold data as the baseline measurement, the percentage changes in strain due to respiratory motion were measured. HARP processing was carried out, based on the framework developed by Kuijer et al. [1]. The strain maps were then analysed by dividing the LV into quadrants: septal, posterior, lateral and anterior. Figure 1 is a flow diagram illustrating the HARP imaging method used to obtain myocardial strain from the CSPAMM tagged images.

Results
Figure 2 illustrates SPAMM tagged short axis images of the heart. Consistent with our previous findings in coronary imaging, respiratory gating at end-inspiration involves significant respiratory jitter [2], and therefore the quality of the image is slightly deteriorated. In this figure, the top row shows just one set of tags while the bottom row shows the corresponding subtracted CSPAMM images. The first column, (a) and (d), show images obtained using breath-holding which is used as the baseline measurement. The second column, (b) and (e), shows images obtained with free breathing gated at end-expiration, whereas the corresponding result for end-inspiration is illustrated in (c) and (f). It can be seen from the figure that the tag deformation in each of the three imaging protocols is noticeably different even though the same short axis slice has been acquired each time. Figure 2 illustrates the minimum principal strain over the cardiac cycle for 5 normal subjects obtained using the breath-hold data.

Figure 3 shows the percentage change in strain distribution for the five normal volunteers studied. The y-axis scale ranges from -15% to +50% and the light grey represents free-breathing at expiration and black at inspiration. The calculations were carried out for four separate regions of the heart, (a) septal, (b) posterior, (c) lateral and (d) anterior segments. The mean and standard deviation, represented in percentile strain changes, for the four segments are 5.2±16.5, -1.1±14.2, 4.6±6.1 and 7.0±5.7 at end expiration, and 1.4±5.7, 5.1±7.7, 5.9±6.1, and 19.5±14.0 at end inspiration, respectively.

Conclusions
It is evident that respiration can have a significant effect on the absolute strain values derived. For the five subjects studied, the changes in strain ranges from -17.4% to 40.0% compared with data calculated from breath-holding. This highlights the importance of using real-time navigator echoes for performing 3D HARP imaging so that physiologically correct strain distributions can be calculated. The existing study also indicates that the effect of respiration on different segments of the myocardium is not uniform, which can potentially interfere with assessment of regional contractile abnormalities if respiratory motion is not consistently monitored.

The respiratory-gated CSPAMM sequence potentially offers a much higher spatial and temporal resolution enabling detailed study into regional contractile motion of the normal heart. Volunteer and animal studies could be used to elucidate the relationships between physiological factors such as coronary blood flow, electrical excitation and regional contractility. The tag spacing could be reduced while increasing the resolution, allowing a greater number of tags to cover the myocardium hence improving the strain measurement. Studies of the complete 3D volume of the LV could be carried out with detailed analysis of regional contractility. The higher spatial resolution would also allow study of right ventricular (RV) contraction which is not possible robustly using any other modality. A full 3D model of heart function could be built incorporating RV and LV electrical excitation, coronary blood flow and contraction. A truly integrated MR system with online HARP MRI would have the added advantage of standard CMR tools, such as being able to measure ejection fraction, LV mass and volume, and perfusion. This would enable the technique to become an integral part of the MR heart function clinic, allowing near real-time assessment of contractility.

References

Contact:
Email: Dr Sharmeen Masood
Internal Extension: sm1@doc.ic.ac.uk

Image Processing Centre
Imaging Sciences Centre