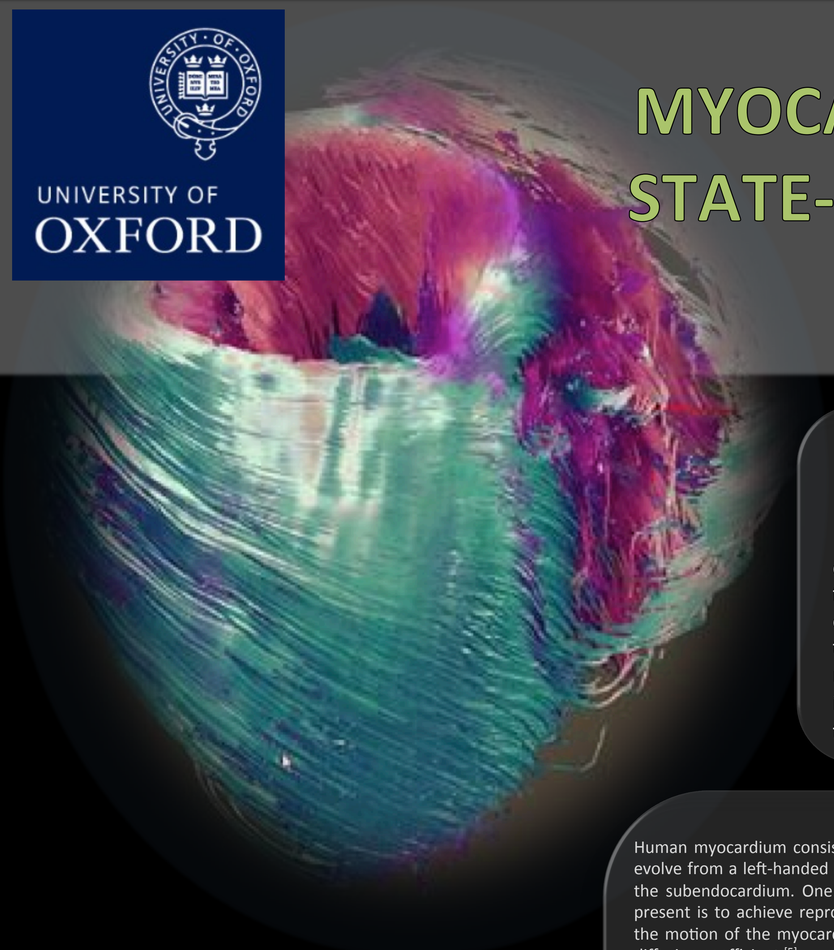
MYOCARDIAL MICROSTRUCTURE INVESTIGATION USING STATE-OF-THE-ART MAGNETIC RESONANCE TECHNIQUES

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Introduction

Abnormal myocardial wall motion is related with the most majority of the cardiac pathologies. Wall motion imaging plays a key role in the diagnosis, clinical management of the disease and prognosis of the evolution of the disease. In terms of prognosis, one important investigated feature is the viability of the cardiac tissue. Preservation of normal contractile function represents a characteristic of viable tissue. The ability to assess the viability of the myocardial tissue in an area affected by infarction can prove to be crucial in improving the clinical outcome and therefore significantly decrease the risk of sudden death caused by a second asymptomatic infarction. Imaging has advanced in the last decades from minimal invasive techniques, like using implantable radiopaque fiducial markers or ultrasonic crystals, to state of the art noninvasive MRI techniques like velocity encoding phase contrast imaging and more recently, displacement encoding imaging using stimulated echoes (DENSE). DENSE measures the tissue displacement pixel wise, encoding time using the phase of the acquired signal. DENSE is capable of better tracking the cardiac wall motion and if combined with diffusion MRI techniques can provide a valuable tool in non invasive tissue viability assessment. Computer vision techniques will be used in developing prediction tools in assessing the post-infarction myocytes recovery.

Cardiac MRI

Magnetic resonance imaging (MRI) is one of the four major clinical imaging modalities together with X-ray imaging, nuclear medicine (SPECT and PET/CT) and ultrasound imaging. Cardiac MRI (CMRI) is a versatile imaging modality in the evaluation of cardiac ischemia and hibernating myocardium[1] with distinct advantages over the conventional nuclear imaging techniques like high spatial resolution and lack of ionizing radiation exposure, substantial with computer tomography scanning and SPECT.
Cardiac motion compensation is performed by synchronising the image acquisition process with an acquired ECG signal[2] (fig 1).

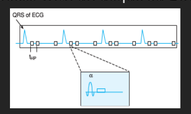


Fig. 1: From [2] "de Ross A., Higgins C., MRI and CT of the Cardiovascular System, **ISBN:** 978-1-4511-3731-6, 2013" Schematic diagram of the basic principle of a gradient echo MR sequence in relation to timing within the cardiac cycle

Why tracking myocardial motion is important

Intra-myocardial wall motion imaging plays an integrating role in the diagnosis, clinical management and prognosis of heart disease. Various methods of assessing this motion can be performed using myocardial tagging, velocity-encoded phase contrast imaging or displacement-encoded imaging using stimulated echoes (DENSE) [3]. Initially the analysis of DENSE images was performed on a frame-by-frame basis, correlating conversion of phase to tissue displacement, followed by computation of strain using finite element approaches. More recently a cinematic method of strain computation, namely cine DENSE [4] (fig.2), was developed in order to track the elements of myocardium through an entire cardiac cycle.
Diffusion MRI provides a unique capacity of analysing the microstructure of the tissues noninvasively.
Microstructural changes in the myocardium can be quantified by measuring mean diffusivity, fractional anisotropy and orientation of the fibres (helix angle).

Human myocardium consists of an array of crossing helical fibre tracts, which evolve from a left-handed helix in the subepicardium to a right-handed helix in the subendocardium. One of the major limitations of the cardiac MRI DTI at present is to achieve reproducible measurements in vivo, particularly because the motion of the myocardium is several orders of magnitude larger than the diffusion coefficient [5].

Short axis cine DENSE cardiac MR imaging

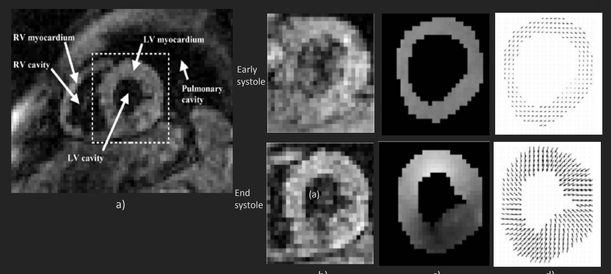


Fig. 2: From [4] "Spottiswoode B.S., et al., Tracking Myocardial Motion From Cine DENSE Images Using Spatiotemporal Phase Unwrapping and Temporal Fitting, IEEE Transactions on Medical Imaging, 26: 15-30, 2007" (a) Short axis cine DENSE image – heart anatomy, (b) DENSE images of the early systole and end systole, (c) segmented LV DENSE phase images, (d) corresponding DENSE displacements fields

Tissue tracking - In DENSE the displacement of each voxel is encoded as a phase shift that has occurred since the time that the displacement encoding was initiated (t0). The vectors in a DENSE displacement field at any time tn all reference to the material position of the myocardium at time t0 allowing an independent calculation of strain in each frame. However their use as indicators of myocardial motion is limited since they provide a net measurement of displacement from t0 and are not capable to provide measurements of frame to frame motion.

Frame to frame trajectories - considering any point of the myocardium at t1 (the difference between t0 and t1 is negligible), for each frame, the 3 vector tails closest to this starting position are identified. As showed in fig. 3 all solid vectors have heads at pixel centres and the tail of the dotted vector is the chosen starting point at t1. The darker solid vectors correspond to the 3 vectors that are closest , for this time frame, to the chosen point.

$$f_{x_1,x_2}(t) = \frac{1}{2}a_0 + \sum_{m=1}^{\infty} a_m \cos(m\omega t) + \sum_{m=1}^{\infty} b_m \sin(m\omega t) \qquad 1)$$

Temporal fitting is necessary for improving the accuracy of estimation of a point's position. This is implemented by fitting curves to each of the spatial coordinate components as a function of time (1).

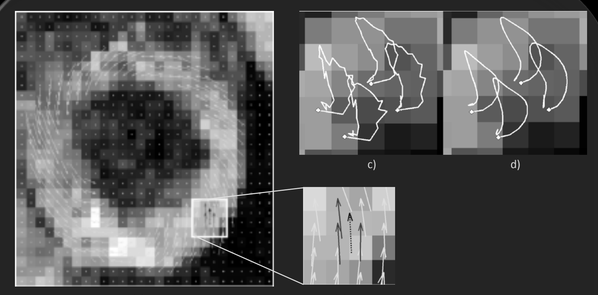


Fig. 3: From [4] "Spottiswoode B.S., et al., Tracking Myocardial Motion From Cine DENSE Images Using Spatiotemporal Phase Unwrapping and Temporal Fitting, IEEE Transactions on Medical Imaging, 26: 15-30, 2007", (a) overview image , (b) magnified image showing a 2D displacement vectors corresponding to each voxel using linear interpolation to estimate the displacement of a chosen starting point at an arbitrary frame, (c) Raw displacement motion and (d) Temporal fitted trajectories

Fifth order Fourier basis function is used to fit curves to each of the spatial coordinate components as a function of time. Since not all the cardiac cycle is imaged the position of each point is linearly interpolated from the end point back to the starting point for the fit.

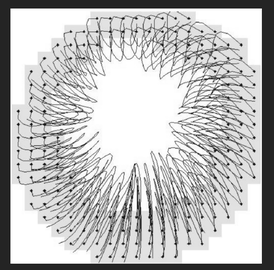


Fig. 4: From [4] "Spottiswoode B.S., et al., Tracking Myocardial Motion From Cine DENSE Images Using Spatiotemporal Phase Unwrapping and Temporal Fitting, IEEE Transactions on Medical Imaging, 26: 15-30, 2007", Trajectories of a healthy volunteer, traversing 75% of the cardiac cycle with the septum centred at 9 o'clock

$$\boldsymbol{F} = \begin{bmatrix} \Delta x_1^1 & \Delta x_1^2 \\ \Delta x_2^1 & \Delta x_2^2 \end{bmatrix} \qquad 2)$$

A conventional method of calculating strain-time curves is based on circumferential cardiac segments that are geometrically fixed with respect of a frame of reference. Cardiac asymmetrical contraction causes portions of myocardial to move into adjacent segments.

The 2D Lagrangian finite strain tensor E is calculated using $E=1/2(F^{T}F-I)$

Infarcted area identification

In fig. 5(b) can be observed that temporal fitting, using fifth order Fourier basis function, reduces artefacts related to errors introduced by wrong estimation of a point's position, in comparison with 4(a) where temporal fitting was not used.

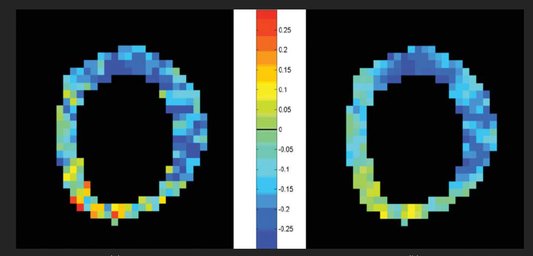


Fig. 5: From [4] "Spottiswoode B.S., et al., Tracking Myocardial Motion From Cine DENSE Images Using Spatiotemporal Phase Unwrapping and Temporal Fitting, IEEE Transactions on Medical Imaging, 26: 15-30, 2007", (a) end systolic circumferential for a patient with an infarct centered at seven o'clock, overview, (b) end systolic circumferential at end systole for a patient with an infarcted centered at seven o'clock before fitting, (c) end systolic circumferential at end systole for a patient with an infarcted centered at seven o'clock after fitting

Computer vision in myocardial microstructure investigation

It is believed that diffusion in tissues and tissue viability are highly interconnected. Extensive research has been made in brain tissue viability investigating the degree of diffusion. In heart one of the major limitation at presence in using diffusion in investigating the tissues viability is the myocardial motion, several orders of magnitude higher that the diffusion process.
Combining diffusion MRI technique with cineDENSE might significantly improve the capacity of structurally and functionally investigating the myocardial wall.

One of the biggest killers in myocardial infarction is the second infarction, often asymptomatic and lethal second infarction can be prevented if the way the damaged myocytes evolve post-infarction. Computer vision techniques will be used in developing prediction tools in assessing the post-infarction myocytes recovery.

References

Top left image: http://www.leonidzhukov.net/research/visualization/dt-mri-heart
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