**MRI of Cardiac Microstructure**

**The Route Forward: Clinical Needs, Technical Challenges**

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Histological studies have shown that the myocardium consists of an array of crossing helical fiber tracts (1). Changes in myocardial fiber architecture occur in ischemic heart disease and heart failure, and can be imaged non-destructively with diffusion-encoded MR. Diffusion MRI tractography (DTI) provides a discrete measure of fiber orientation (2). This has been performed in humans *in vivo* and has shown a reduction in right handed (endocardial) fibers in the infarct zone (3). Numerous *ex vivo* studies have shown that the scalar indices of diffusion (mean diffusivity (MD) and fractional anisotropy (FA)) change in acute infarction. Cell rupture leads to an increase in diffusion and a local increase in MD. The loss of structure also leads to a corresponding reduction in FA. In a recent study in patients with acute myocardial infarction, similar changes were documented *in vivo* (4). Therefore, MD and FA have the potential to provide important information on the degree of cellular integrity and structural organization within the myocardium.

*In vivo* DTI techniques have been used successfully to demonstrate the myocardial fibre architecture in the normal beating heart and to depict zone dependant alterations in the presence of disease both in small animals and in humans (2,5). *In vivo* DTI could therefore prove to be a powerful tool to characterise the structural remodelling and fibre disarray patterns of diseases such as myocardial infarction and cardiomyopathies, improving the capability of cardiac MRI for diagnosis and therapy follow-up.

However, many challenges remain to be overcome before this technique is ready for routine clinical application. Aside from all the difficulties connected to DTI in general (6,7), *in vivo* cardiac DTI has a number of particular pitfalls:

1. **Motion**

   Probably the biggest challenge for cardiac *in vivo* DTI is motion correction. While water diffusion is in the order of micrometers, cardiac motion and respiratory motion are in the order of centimeters. Techniques to monitor and correct for cardiac and respiratory motion are therefore indispensable to guarantee the successful acquisition of diffusion information.

   To correct for respiratory motion several techniques, such as breath-holding, synchronised breathing, prospective navigators, and retrospective navigators based on cross-correlation have been used (8-12). Although these techniques have been shown to accurately monitor and correct for respiratory motion, they all decrease scanning efficiency and / or patient comfort and compliance.

   To correct for cardiac motion, not only is ECG gating necessary, but also arrhythmia rejection algorithms. Moreover, special DTI acquisition techniques have been developed to time the diffusion encoding and data acquisition to specific time-points in the cardiac cycle, thereby minimizing cardiac motion effects on the diffusion data (8,9,12).
2. EPI Artifacts

Owing to the high sensitivity to motion, the image readout method of choice in cardiac diffusion MRI is single shot EPI, which could suffer from susceptibility artifacts, eddy currents, chemical shift artifacts and ghosting (6). Parallel imaging strategies and zonal excitation have been implemented to minimize these issues.

3. Low signal to noise ratio (SNR) technique

Diffusion MRI is inherently a low SNR technique because it looks at signal loss. Several averages are needed to have enough SNR in the cardiac diffusion weighted (DW) images. This leads to potential registration issues, long acquisition times and/or small coverage of the heart. With limited gradient hardware capacity (most clinical systems have gradient systems capable of delivering maximum gradient amplitudes of 40-80 mT/m), increasing the b-value implies increasing the echo time (TE) to play out the diffusion-encoding gradients, which, in turn, leads to increased T₂-related signal losses and therefore a reduction in SNR. For in vivo cardiac diffusion MRI in clinical scanners, b-values of about 350 s/mm² are generally used, leading to TE = 60-65 ms for spin echo (SE) approaches (12) and TE = 20-25 ms for stimulated echo (STEAM) approaches (9).

Higher magnetic fields can contribute to increase SNR, while potentially decreasing EPI image quality, requiring more accurate shimming algorithms. Stronger and faster gradients would allow shorter diffusion encoding gradients and EPI readouts, which in turn would minimize echo times, leading to acquisitions more robust against motion and higher SNR.

References


