Technical Advances in Cardiovascular Imaging

New & Emerging Techniques: Myocardial diffusion

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Highlights

- The fibre structure of the myocardium contributes to ventricular function and is subject to remodelling and disarray in the presence of disease.
- Cardiac Diffusion Tensor Imaging (cDTI) is a non-invasive approach that provides information on mean intravoxel myocyte orientation and potentially myocardial disarray.
- cDTI could 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.

Target Audience

Scientists and clinicians interested in the field of clinical cardiac diffusion MRI and clinical cardiac diffusion tensor imaging (cDTI).

Objectives

This presentation will focus on clinical cardiac DTI.

At the conclusion of this presentation, participants will be better able to:

- Understand the clinical potential of cardiac DTI in terms of diagnosis and therapy follow-up.
- Understand the basics of cardiac Diffusion MRI and cardiac DTI.
- Understand the main technical issues concerning clinical cardiac DTI.
- Have an overview of the clinical cardiac DTI techniques and studies published to date.

Purpose

Histological studies have suggested that the myocardium consists of an array of crossing helical fibers [1]. Changes in myocardial fiber architecture are expected to occur in ischemic heart disease and heart failure. In addition, post-mortem studies, following sudden caridac death have shown myocardial disarray in hypertrophic

cardiomyopathy (HCM), aortic stenosis and hypertensive heart disease (ref). The *in vivo* prevalence and extent of myocardial disarray is unknown, as well as its role in the genesis of malignant ventricular arrhythmias and myocardial contractile dysfunction.

Cardiac DTI is a non-invasive approach that provides information on mean intravoxel myocyte orientation and potentially myocardial disarray [2]. This presentation will describe the *in vivo* cardiac MRI acquisition techniques developed so far and review the clinical cardiac DTI studies performed to date.

Methods

Many challenges remain to be overcome before cardiac DTI is ready for routine clinical application. Aside from all the difficulties associated with DTI in general [3, 4], *in vivo* cardiac DTI has a number of particular pitfalls:

1. Motion

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

   To correct for respiratory motion several techniques, such as breath-holding, synchronized breathing, prospective navigators, and retrospective navigators based on cross-correlation have been used [5-17]. 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. A stimulated-echo technique over two heartbeats [5-7], either with monopolar or bipolar diffusion encoding, a spin echo technique with bipolar diffusion encoding gradients [16] and, more recently, diffusion-prepared bSSFP techniques have been described[18].

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 [4]. Although parallel imaging strategies and zonal excitation have been implemented to minimize these issues, it is still necessary to keep the spatial resolution of these acquisitions is low.

3. Low signal to noise ratio (SNR) technique

   Diffusion MRI is inherently a low SNR technique because it measures signal loss. Several averages are required to provide enough SNR in the cardiac diffusion weighted (DW) images. This leads to potential registration issues, long acquisition times and limited spatial coverage. 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 (particularly for spin echo and bipolar STEAM sequences), which, in turn, leads to increased T_2 -related signal losses and therefore a reduction in SNR. For *in vivo* cardiac diffusion MRI in clinical scanners, b-values of about 350 s/mm^2 are generally used, leading to TE = 60-65 ms for spin echo (SE) approaches [16] and TE = 20-25 ms for stimulated echo (STEAM) approaches [6, 17].

Higher magnetic fields can contribute to increased SNR, while potentially decreasing EPI image quality, requiring more accurate shimming algorithms and lengthening T1. 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.

Results

In vivo cardiac DTI techniques have been used successfully to demonstrate the myocardial architecture in the normal beating heart and to depict zone dependent alterations in the presence of disease, both in small animals and in humans [2, 10, 14, 15, 19]. The reproducibility of *in vivo* cardiac DTI both in healthy subjects [17] and in patients with HCM [20] has been presented.

In vivo cardiac DTI performed in MI patients revealed a significant increase in diffusivity and a decrease in anisotropy in the infarct area, indicating altered tissue integrity. The redistribution of myocyte orientation suggested by the changes in helical angle (HA) maps correlated with infarct size and left ventricular function [15]. In patients with acute myocardial infarction, changes in the scalar indices of diffusion (mean diffusivity (MD) and fractional anisotropy (FA)) were observed [14]. Cell rupture should lead to an increase in diffusion and, therefore, a local increase in MD. The loss of structure should also lead to a corresponding reduction in FA. Therefore, HA, MD and FA have the potential to provide important information on the degree of cellular integrity and structural organization within the myocardium.

Results from in vivo cardiac DTI performed in HCM patients have suggested regionally disordered myocyte orientations and reduced fractional anisotropy (FA), believed to originate from myocyte disarray, which correlated with abnormalities in myocardial function [10].

Discussion and Conclusion

In vivo cardiac DTI is still in the developmental phase and currently a very active area of research. A lot of questions in terms of technological development, technique validation and diagnostic utility remain to be answered. Nevertheless, *in vivo* cardiac DTI has the potential to become a powerful tool to characterise the structural remodelling and disarray in diseases such as myocardial infarction and cardiomyopathie, improving the capability of cardiac MRI for diagnosis and therapy follow-up.

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