Specialty area: Emerging Cardiovascular Imaging Techniques

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Highlights:

Clinical cardiac MRI techniques are increasingly being developed to quantify MRI relaxation parameters (relaxometry) as a means to characterize healthy myocardium and cardiovascular disease**.**

This presentation aims to provide an overview of these methods, how they work, and what the current state of optimization and application of these methods are in order to investigate myocardial pathology in the clinical research setting.

Talk title: Myocardial Tissue Characterization (T1, T2, T2*, quantitative T1-mapping)

- **Target Audience**
  The target audience for this presentation includes basic scientists and clinicians who are interested in learning about myocardial tissue classification using MRI relaxometry and current applications in the clinical setting.

- **Outcome/objectives**
  The objective of this presentation is to provide an overview of MRI relaxometry as applied specifically to the myocardium.
  - Clinician attendees will gain a better understanding of the basic physics underlying commonly used techniques. T1, T2, and T2* relaxation will be described, with particular reference to calculation in the myocardium in the clinical setting, and limitations of commonly used techniques and data analysis.
  - Basic scientist attendees will gain a better understanding of the current methods of optimizing MRI relaxometry techniques for use in the myocardium and their application and utility in the clinical setting.

- **Purpose**
  The clinical mainstay of myocardial MRI classification was previously the use of heavily 'weighted' images for classification of myocardial tissue and associated pathological processes (inflammation, oedema, infarct, persistent myocardial obstruction etc.). This involved the use of a range of strongly T2-weighted, and T1-weighted acquisitions in order to qualitatively discern myocardial tissue status. The use of magnetization preparation schemes have been well established to 'weight' the resulting MRI acquisition image contrast towards specific pathologies. For example, inversion-recovery acquisitions implemented after the administration of standard gadolinium-based contrast agents (commonly referred to as "late gadolinium enhancement' acquisitions) are a T1-weighted MRI clinically accepted standard approach to characterization of a wide range of ischemic and nonischemic cardiomyopathies (Kellman and Arai 2012). T2-weighted preparation schemes have also been well established, primarily to characterize edema in myocardial disease (Amano Y et al 2012). However, due to the fact that these techniques rely on image contrast differences between 'healthy' and pathological myocardial tissue, these methods perform poorly in the classification of diffuse myocardial disease, such as diffuse myocardial fibrosis (Kellman et al 2012). Additionally, because these methods are qualitative in nature, they are prone to local contrast-to-noise image artifacts cause by relative proximity to the surface coils used in cardiac MRI and also variability in B1 field

that may obscure myocardial pathology (particularly problematic at higher magnetic field strengths). The recent development of breath-held, ECG-gated relaxometry techniques optimized for use in cardiac MRI attempts to address some of these (and other) limitations and provide a quantitative method of characterizing myocardial tissue.

- **Methods and Results**

  Historically, MRI relaxometry methods used to quantify relaxation times required long acquisitions in order to measure MRI relaxation times, and were therefore unsuitable for use in cardiac imaging. In the 2000's, continual development and optimization of more rapid, truncated methods of MRI relaxometry for use in the heart has occurred. The first relaxometry method to gain prominence in cardiac application was estimation of myocardial T2* values. The paramagnetic nature of hemosiderin produces localized perturbations in the static magnetic field, primarily affecting spin-spin (T2*) relaxation times (Storey et al 2007). Acquisition of multiple gradient echoes in the myocardium (that are inherently sensitive to T2* effects) in a breath-held acquisition, gated to the cardiac cycle, allows 'quantification' of iron overload in the myocardium. As such, MRI T2* 'mapping' of the myocardium has been very successfully applied to conditions such as thalassemia major (Anderson et al 2001). To minimize time spent by clinicians to calculate T2* values from the resulting gradient echo images, automated calculation of T2* on a voxel-by-voxel basis is desirable. However, localized static field inhomogeneities (such as those surrounding cardiac veins), 'noisy' image data and artifacts caused by motion or ECG gating inconsistencies may all contribute towards noise in the characteristic T2* signal decay curve used to estimate T2*. Therefore, care must be taken in the accurate estimation of T2* values for each voxel (He et al 2013, Mavrogeni S et al 2013). **This presentation will describe some of the problems, pitfalls and potentials solutions that have been proposed for accurate calculation of T2* (and R2*) in the myocardium**.

  Although T2-weighted imaging has been extensively used to detect edema using a range of magnetization preparation methods such as double or triple inversion spin-echo schemes (Schulz-Menger, 2011), image artifacts and relative variations in myocardial signal contrast due to proximity to receiver coils make this method susceptible to variability in specificity/sensitivity. Several groups have recently developed methods of T2-prepared acquisitions that instead allow estimation of myocardial T2 relaxation values on a voxel-by-voxel basis, such as the T2-prepared steady-state free precession technique (Giri et al 2009). Recent data has demonstrated that T2-mapping of the myocardium may be more useful and reliable in identifying myocardial edema in the infarcted myocardium than T2-weighted imaging, and is less prone to coil proximity/contrast artifact (Park et al 2013). **This presentation will describe common cardiac T2-mapping techniques and their merits and applications.**

  Because T1 relaxation times are inherently much longer than T2 or T2* relaxation times, accurate estimation of T1 in a short enough time to be acquired within a single breath-hold duration, and gated to cardiac motion proved difficult. The modified Look-Locker inversion recovery (MOLLI) technique introduced by Messroghli et al in 2004 currently remains the most widely implemented breath-held cardiac gated method of estimating myocardial T1 (Rogers et al 2013). This method performs a series of interleaved inversion recovery experiments over several heart-beats, within a single breath-hold, to calculate myocardial T1 values. Several groups have suggested that the MOLLI technique may systematically underestimate longer T1 values, with a particular dependence on heart rate and variability. Several variations of the MOLLI technique have been introduced in order to iteratively improve the technique, including a range of magnetization preparation 'start-up schemes', an 'optimized' MOLLI acquisition

(Messroghli et al 2007), and a 'shortened' MOLLI technique (ShMOLLI) able to be acquired in shorter breath-holds (Piechnik et al 2010). These have been used in an attempt to improve accuracy of T1 estimation and reduce the somewhat long breath-hold times required by the original MOLLI technique. As with T2, and T2* estimation, careful fitting of the exponential T1 decay from the resulting MOLLI data is required. **This presentation will describe the common myocardial T1 mapping techniques, current use and problems/pitfalls and solutions to T1-fitting.**

- **Discussion**

  Due to the relatively recent development of several of these relaxometry acquisitions designed for use in the heart during ECG-gated breath-hold acquisition, there is a great deal of research currently being performed in order to determine the clinical utility and versatility of myocardial relaxometry. For example, recent work has demonstrated the potential utility for T1 and T2 mapping for use in myocardial iron overload assessment, avoiding some of the field inhomogeneity artifacts that T2* mapping is prone to (Feng et al 2013). Non-contrast T1 mapping in particular demonstrates very positive results in application in cardiomyopathy (Puntmann et al 2013) and specific disorders such as Anderson Fabry disease (Sado et al 2013). The current development of relaxometry (particularly the implementation of T1-mapping) will be briefly discussed in this presentation, although a thorough review of current development is out-with the scope and duration of this introductory lecture. Due to the current range of 1.5 and 3.0 T MRI systems used for clinical cardiac imaging, care must be taken in the specific application and analysis of these techniques at different field strengths due to the differences in relaxation rates at different field strengths and image artifacts that tend to be present at the differing field strengths commonly used. **This presentation will briefly discuss the topic of magnetic field strength with reference to calculation of myocardial relaxation rates.**

- **Conclusion**

  Myocardial relaxometry mapping represents an active area of research and development in clinical cardiac MRI. Almost continual development of cardiac-gated breath-held relaxometry techniques over the last ten years have resulted in a constantly evolving field. The fundamental physical mechanisms behind the most common techniques will be discussed in a manner accessible to basic scientists and clinicians, as well as an overview of the current applications, their limitations and clinical applicability.

- **References**

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