

Carbon-13 Imaging in the Heart

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Dynamic nuclear polarization (DNP) and dissolution is a recently developed method for creating a new class of contrast agents for MRI [1, 2, 3]. The technique results in an intravenous contrast agent that is "hyperpolarized", having a degree of spin alignment that is up to 5 orders of magnitude higher than thermal equilibrium. DNP-dissolution offers the exciting possibility of imaging biochemical reactions *in vivo*, including some of the key enzymatic reactions involved in cellular metabolism. This holds many possibilities for the management of patients with cardiovascular disease. In this presentation, the key considerations surrounding ¹³C cardiac imaging will be discussed, as well as the disease processes that may be interrogated with these methods.

To meet its task of continually circulating blood throughout the body, the heart consumes more energy in the form of ATP than any other organ. The healthy heart derives 60-90% of its energy from the oxidation of fatty acids, with the remainder primarily from pyruvate oxidation, derived from glucose (via glycolysis) and lactate. However, under certain conditions, the relative contributions of lipids, carbohydrates, etc., to cardiac ATP production can vary substantially. The driving idea here is that hyperpolarized carbon-13 substrates can be used to image these changes to give useful information to the clinician.

In the failing heart, changes in metabolic substrate utilization and depleted myocardial energetics increasingly are considered as causes, rather than symptoms, of disease. Abnormal myocardial energy metabolism has been identified by studies performed in heart failure patients using ³¹P magnetic resonance spectroscopy (MRS) [4, 5, 6] and positron emission tomography (PET) [7, 8, 9]. Substrate utilization in the failing heart is associated with a "fetal" pattern of metabolic gene expression [10] that results in the preferential use of carbohydrates over free fatty acids (FFA) to form ATP. It is not so simple though, as the relative utilization of fatty acids and glucose shifts depending on the etiology and stage of disease [11].

To acquire metabolic information from the heart using hyperpolarized substrates, specialized pulse-sequences and data acquisition strategies have been developed. At one extreme, simple pulse-acquire spectroscopic acquisitions are useful, where spatial localization is mainly performed by the sensitivity pattern of a surface coil placed over the heart. This strategy is useful for measurement of the net signal from the entire heart, particularly for low-SNR metabolite signals (e.g. the [5-¹³C]glutamate signal that results from [2-¹³C]pyruvate injection). Alternatively, for larger signals such as the [1-¹³C]lactate that persists in the myocardium after ischemic injury to the muscle, imaging can be performed using rapid k-space trajectories such as spirals. These different pulse sequences and their design will be discussed in the presentation.

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