Extending the capabilities of quantitative MRI

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A technique based on highly undersampled radial MRI yields data with excellent spatiotemporal resolution for quantitative parameter mapping without increasing scan time.

MRI technology is widely used in the clinic because of its excellent spatial resolution and soft tissue contrast, and the fact that it does not expose patients to ionizing radiation. In current clinical practice, diagnosis based on MRI relies on the qualitative assessment of images by a radiologist, which in turn relies on changes in contrast within tissues. Consequently, there is great interest in measuring the parameter(s) underlying various MRI contrast mechanisms. Such a quantitative approach should help to improve diagnostic accuracy, particularly in early disease.

One obstacle to the adoption of quantitative MRI (qMRI) in lieu of the qualitative approach used in the clinic is the extra time needed to acquire data for parameter estimation. Extending the scan time in MRI examinations increases cost and reduces patient comfort. Moreover, for areas of the body affected by respiratory motion, qMRI is challenging because data collection is typically limited to a breath hold.

Fast imaging techniques reduce scan time in qMRI, but imaging speed should not be at the expense of spatial or temporal resolution. Spatial resolution is critical for obtaining information on small structures (e.g., small tumors). Temporal resolution is needed for accurate parameter estimation, particularly for contrast mechanisms described by nonlinear models. Collecting data that is undersampled (i.e., at rates lower than the so-called Nyquist criterion) is one approach to save imaging time. A variety of techniques known as parallel imaging have been developed to preserve spatial resolution in undersampled data through simultaneous acquisition of information from multiple receiver coils that are spatially distributed. Although parallel imaging is widely used, for many clinical applications current acceleration rates do not meet the demand of spatiotemporal resolution for accurate parameter mapping within practical acquisition times.

Our approach to parametric imaging combines a radial acquisition strategy with a novel reconstruction algorithm to obtain parameter maps from highly undersampled data. We demonstrated this strategy for the quantification of spin-spin relaxation time (T2), a parameter that underlies contrast in a form of weighted imaging used to diagnose a wide variety of pathologies. For T2 mapping, several images at different echo time (TE) points need to be collected and fitted to a function modeling the signal evolution. T2 signal models vary from exponential decays to models that account for complex spin dynamics due to system imperfections.

For data acquisition, we use a radial fast spin-echo technique that collects data for several (16–32) TE points with a temporal resolution of 6–8ms. To reduce the total acquisition time, we highly undersample the data per TE point in the azimuthal direction (4–8% sampling relative to Nyquist) while maintaining high spatial resolution in the radial direction (e.g., 1.2–1.5mm). For reconstruction of T2 maps, we developed a model-based algorithm that uses the T2 signal evolution as prior information. By constraining the solution to follow the known signal model, the feasible solution space is significantly reduced, and

Figure 1. Spin-spin relaxation time (T2) maps of (left) brain, (middle) liver, and (right, color map) the left-ventricular heart wall obtained from highly undersampled MRI data acquired with a radial fast spin-echo sequence and reconstructed using a model-based algorithm. The combined radial acquisition and reconstruction strategies allow acquisition of data with high spatiotemporal resolution within a short scan time.

Continued on next page
reconstruction of accurate T2 maps from highly undersampled data becomes possible. An important component of our approach is careful design of the spatiotemporal sampling patterns, which enable maximum spatial and temporal information to be acquired within the short imaging time. Reconstructions involving nonlinear models suffer from fitting instability and are computationally expensive. Our approach, relative to other model-based reconstruction techniques,\(^3\),\(^4\) is to approximate the T2 signal model using a linear combination of principal components. In this way, we obtain accurate T2 maps even for complex signal models, such as those that incorporate the effects of radio-frequency imperfections or the presence of multiple components.\(^5\)

Figure 1 shows examples of T2 maps obtained using our method for the brain, abdomen, and heart. The maps have high spatial resolution, and, thus they capture small structural details. The scan times are short and in the range of the conventional imaging methods used for the qualitative assessment of pathology. Note that high-quality T2 maps can be obtained even from data acquired in a breath hold, a great advantage for abdominal and cardiothoracic applications.

In conclusion, the use of quantitative MRI as a clinical diagnostic tool is constrained by the extra time required for collecting sufficient data for parameter estimation. The use of highly undersampled data reduces scan time, but the challenge is to maintain the information present in well-sampled data. In this work, we present an approach to T2 mapping that combines the acquisition of highly undersampled radial data with a model-based reconstruction algorithm to preserve the spatiotemporal information required for accurate parameter estimation. The new fast parametric imaging method, demonstrated here in the brain, abdomen, and heart, can easily be incorporated within a routine clinical scan. The approach can also be extended to other contrast mechanisms. Work in our laboratory is now focused on extending the method to other contrast mechanisms.

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References