Introduction

It is well-known that $T_1$ contrast varies with the magnetic field strength. These variations are closely linked to molecular dynamics via random spin-spin interactions (Fig. 2). Hence the shape of the $T_1$ dispersion curves, also named the NMR Dispersion profiles (NMRDp), is a unique source of information about water dynamics and material structures [1]. Here we introduce Fast Field-Cycling (FFC) MRI, a new technology able to exploit $T_1$ NMRDp for medical applications [2].

Theory

The shape of the $T_1$ NMRDp can be predicted by combining the type of spin interaction with the probability of motion associated with a particular material structure (see Fig. 2). The association of quantum mechanics and statistical physics generally gives difficult problems but some general structures have been resolved such as free rotational and translational motions (such as liquids or gases), diffusion of polymer chains or diffusion in porous media [3]. Paramagnetism and super paramagnetism also exhibit typical profiles due to electron spin interactions [4].

Figure 2

$T_1$ originates from random but resonant spin-spin interactions that randomly affects the spin orientation, and compete with the remagnetisation due to the external magnetic field (see "Theory").

Figure 3

$T_1$ images from healthy breast in (a) taken at different fields give the $T_1$ NMRDp of tissues (b), which compares with similar results from samples (c). In (b), the yellow line is typical from polymer chains (fatty tissues) while the blue one corresponds with one-dimensional diffusion (fibrous tissues).

Methods

Our group has successfully commissioned a new type of whole-body scanner (see image at centre) that can exploit $T_1$ dispersion contrast by varying its main magnetic field $B_0$ from Earth field to 0.2 T (see presentation S20.02).

Biological tissues contain a large variety of sources of $T_1$ relaxation (see Fig. 1) and a model-based analysis of the shape of NMRDp can inform on the tissue structure. We use field-cycled spin echo acquisitions to provide images with $T_1$ at different fields, then NMRDp-based images are obtained from the raw images after corrections [5], automated segmentation and $T_1$ fitting. When automated, this procedure takes between 15 and 30 min depending on the image size.

Results

$T_1$ was measured with 10% accuracy between 1 and 200 mT, giving access to the NMRDp of biological tissues in vivo (Fig. 3). A 5-points dispersion curve was obtained within 40 min that compared well with sample-based analysis using a commercial non-imaging FFC relaxomètre (see Fig. 3). Experiments on healthy breast showed good agreement with previous measurements on excised tissues: the differences between fibrous and breast tissues readily appear in the shape of their respective NMRDp, which can be used to provide specific contrast (see Fig. 4).

Conclusion

FFC-MRI opens new horizons for quantitative molecular imaging and may be able to determine tissue structures based on the NMRDp information alone. Pilot clinical trials are currently running to find applications in breast cancer, stroke and brain glioma.


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