Absolute Beginner's Guide to Quantitative MRI

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Introduction

In standard MR imaging, local intensities and contrasts are mainly influenced by the basic MR parameters, such as the spin density and the relaxation times. However, secondary effects such as inhomogeneities of the static magnetic field B0, the transmitted radiofrequency (RF) field B1, or the receive coil sensitivities may create an additional, hardware dependent bias. This poses a problem when comparing data from different centres that are not operating the same hardware or even for longitudinal studies performed at a single site in case hardware was exchanged during the duration of the study.

The goal of quantitative MRI (qMRI) is the quantitative measurement of selected MR parameters. The results are displayed in so-called ***parameter maps***, where the local image intensity represents *exclusively* the local value of the respective parameter, without bias from other parameters. This means that parameter maps are not affected by any field inhomogeneities or variations of the receive coil sensitivity. Some of the parameters most frequently mapped that will be discussed in this presentation are the proton density (PD), the longitudinal relaxation time (T1), and the transverse relaxation times (T2 and $T2^*$).

Techniques for Parameter Mapping

T1 mapping: The time constant T1 describes the relaxation of the longitudinal component of the magnetisation. Typical T1 values in white matter and gray matter at 3 Tesla are 850 ms and 1350 ms, respectively [1]. There are several techniques for fast T1 mapping. The Look-Locker method is based on monitoring T1 relaxation after spin inversion [2, 3, 4]. This method requires a correction for the influence of the acquisition process on the relaxation [3]. The variable flip angle method [5] is based on the acquisition of in general two spoiled FLASH images [6] with different flip angles. This method requires a correction for B1 inhomogeneities [7] and incomplete spoiling [8].

T2 and $T2^*$ mapping: The time constant T2 describes the decay of the transverse component of the magnetisation. Typical T2 values in white matter and gray matter at 3 Tesla are 80 ms and 110 ms, respectively [1]. In the presence of magnetic field inhomogeneities, transverse relaxation is accelerated due to spin dephasing, and can be described by the time constant $T2^*$ (about 50 ms in white matter and gray matter at 3 Tesla, [1]). Techniques for mapping T2 or $T2^*$ are usually based on the acquisition of spin echo or gradient echo images, respectively, at different echo times TE, followed by exponential fitting. In $T2^*$ mapping, macroscopic inhomogeneities of the static magnetic field may yield systematic errors, requiring corrections, such as the application of compensatory magnetic field gradients (z-shimming, [9]) or corrections based on field maps [10].

PD Mapping: Most techniques are based on the acquisition of a series of gradient echoes with different TE, followed by exponential fitting of the signal amplitudes and extrapolation to the value at TE=0. Several additional correction factors are required, in particular for T1 dependent saturation effects, B1 field inhomogeneities, variations of the receive coil sensitivity, and temperature changes [11]. Macroscopic inhomogeneities of the static magnetic field may result in non-exponential signal behaviour, giving rise to erroneous values. This can be resolved by polynomial fitting [12] or adaptation of slice profiles [13].

Applications of qMRI: Clinical

Various applications of qMRI for clinical diagnosis have been reported. In this presentation, some representative examples will be given for each MR parameter for illustration.

T1 mapping: It has been shown that the T1 values in normal appearing white matter of patients suffering from Multiple Sclerosis are significantly prolonged [14]. Other researchers reported significant T1 changes in various brain areas induced by Parkinson's Disease and Multiple System Atrophy [15].

T2 and T2* mapping: Both T2* and T2' (given by 1/T2'=1/T2*-1/T2) can be used as markers for brain iron content, which is altered in patients suffering from Parkinson's Disease [9, 16]. Thus, T2 and T2* mapping can be used for investigation of this disease.

PD mapping: In a study on a patient suffering from an oligodendroglioma, regional water content (as determined from PD maps) was significantly increased in distant white matter of the same hemisphere. The absolute water content decreased across the corpus callosum, revealing changes brought about by water diffusion from the affected side into the other hemisphere [12].

Applications of qMRI: Anatomical Imaging

Since parameter maps obtained with qMRI do not suffer from inhomogeneities of B0, B1 or the receive coil sensitivity, it is possible to use them for the creation of unbiased anatomical images, facilitating the comparison of data acquired with different hardware configurations. A further advantage is the fact that anatomical images calculated from parameter maps may allow for the visualization of structures that are not visible in standard anatomical scans, such as the brain nuclei [17].

Applications of qMRI: Teaching

Quantitative parameter maps allow for the calculation of weighted images with virtually any contrast. Thus, students can simulate the influence of imaging parameters (such as the repetition time TR and the echo time TE) on image contrast for a variety of sequences, without the need of having access to an MR scanner.

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