Improving MRI Differentiation of Gray and White Matter in Epileptogenic Lesions Based on Nonlinear Feedback

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Introduction

Medically intractable epilepsy afflicts approximately 30% of patients experiencing seizures and may be treated by surgical resection [1]. MRI plays an especially vital role in pre-surgical planning by locating and accurately delineating the extent of epileptogenic lesions [2]. Substrates associated with epilepsy include cortical dysplasia, which is characterized by blurring of the gray-white matter interface, among other features [2]. In many cases, the associated abnormalities are frequently subtle and may show little contrast in MRI from adjacent normal brain tissue. Improved high-resolution imaging with good gray-white matter differentiation is thus essential for identification and characterization of these substrates.

A new method has recently been introduced to amplify contrast due to slight differences in MR parameters based on nonlinear feedback interactions in high-field MRI [3]. In this work, the radiation damping feedback field is shown to enhance contrast between gray and white matter in *in vitro* brain tissue excised from five patients with epileptogenic lesions, compared with conventional T_1, T_2, and proton density images. Contrast enhancement under radiation damping is demonstrated experimentally and validated through simulations based on nonlinear Bloch equations including radiation damping.

Theory and Methods

Radiation damping acts back on the spins through the induced current in the receiver coil, as dictated by Lenz's law [4]. It exerts a torque to nutate the magnetization back to the asymptotically stable +z-axis at a rate proportional to the magnitude of the net transverse magnetization. Following preparation in an unstable inverted state, the magnetization in different tissue regions are separated under radiation damping due to the differential selectivity of the feedback field for components with different resonance frequencies $\delta\omega$ [3].

All studies were conducted according to protocols approved by the UCLA institutional review board. MR microimaging experiments were performed on brain tissue samples excised from five patients with epilepsy. Images were acquired at 14.1-T using a 5-mm saddle coil optimized for ^{1}H sensitivity (radiation damping time constant τ_r = 5 ms). The pulse sequence is shown in Fig. 1. Following an initial θ flip angle pulse, the magnetization evolves for a time τ. A crusher gradient spoils the transverse magnetization, followed by a slice-selective 90° pulse and gradient echo sequence that images m_z.

Results

Radiation damping-enhanced images from 25 sections of brain tissue (5 patients total) yielded 6x better contrast-to-noise ratios (CNRs, CNR = 44.8) on average than T_1 (CNR = 7.92), T_2 (CNR = 4.20), or proton density images (CNR = 2.52). Fig. 1 shows radiation damping-enhanced images of tissue excised from the right frontal gyrus of a pediatric patient with tuberous sclerosis. The radiation damping-enhanced image exhibited marked changes in signal between gray and white matter compared to the conventional images. Mild cortical dyslamination was observed in histopathology and may have been responsible for this lack of gray-white matter differentiation. Selective excitation of the water resonance also failed to demarcate the tissue regions.

To elucidate the dynamics in different tissue regions under radiation damping, regional analysis of the signal was carried out for the radiation damping-enhanced images. Mean signal intensities were calculated for selected representative regions and plotted as a function of τ (Fig. 2). The close agreement between simulated and experimental signal intensities confirmed that radiation damping was responsible for the observed contrast.

Discussion and Conclusion

This study has shown that radiation damping can be used to highlight contrast between gray and white matter in epileptogenic lesions. The observed contrast may reflect small differences in resonance frequency due to magnetic susceptibility differences between gray and white matter arising from differential tissue iron concentrations and/or blood volume [5]. The simulations in Fig. 2 suggested that tissue components with $\delta\omega$ < 10 Hz could be distinguished under radiation damping. Such small differences in resonance frequency may be difficult to separate by selective excitation. The sensitivity of this technique to $\delta\omega$ and the magnetization in each component could provide a means of identifying different tissue regions with better specificity.

Improved hardware design may be needed to enhance radiation damping in MR spectrometers and scanners, especially at low fields. Strong radiation damping is observed in high-Q and cryogenic probes used in MR microscopy and clinical imaging. Radiation damping can also be actively reinforced or suppressed through electronic feedback to the induced current in modified circuits [6]. With the development of higher fields and more sensitive receiver coils for high-resolution imaging of epilepsy, radiation damping may aid future studies aimed at detecting epileptogenic lesions.

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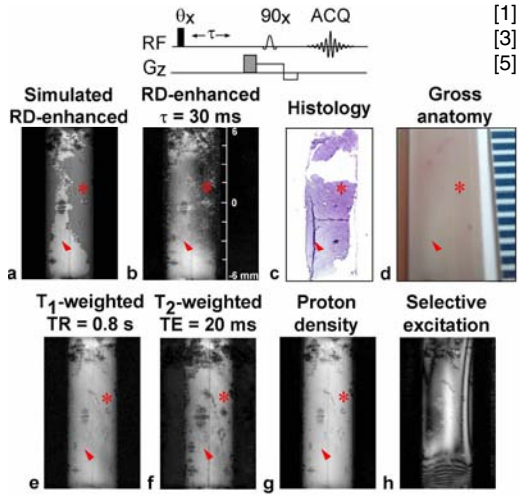

Fig. 1. (a) Simulated and **(b)** experimental radiation damping-enhanced images (θ = 179°, FOV = 1.2 cm) at 14.1 T of brain tissue, compared with **(c)** histology, **(d)** anatomy, and corresponding **(e)** T_1, **(f)** T_2, **(g)** proton density, and **(h)** selective water images (gray matter, *; white matter, ∧).

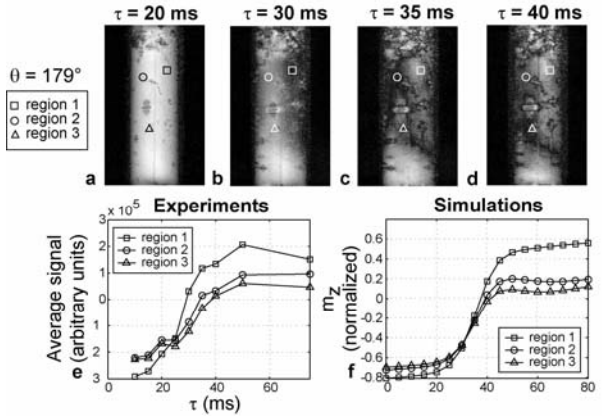

Fig. 2. Radiation damping-enhanced images following θ = 179° with variable evolution times τ: **(a)** τ = 20 ms; **(b)** τ = 30 ms; **(c)** τ = 35 ms; and **(d)** τ = 40 ms. Average signal from regions 1, 2, and 3 as a function of τ, obtained from **(e)** experimental and **(f)** simulated MR images.