ELECTRIC CURRENTS INCREASE THE DIFFUSION OF WATER MOLECULES

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ABSTRACT

We observed the phenomenon in which electrical currents enhanced the diffusion of water molecules. The Apparent Diffusion Coefficient (ADC) of water molecules in a phantom study experienced a 20-fold increase after electrical currents of 0.6 mA/cm^2 were applied. In an in vivo study using rats, the intensity of the diffusion weighted images of the rat brains decreased when electrical currents were applied through subcutaneously implanted electrodes in the skull and neck. This effect has great clinical potential in the diagnosis of brain pathologies, particularly in the early detection of small lesions or acute infarctions, and direct neuronal electrical activation.

INTRODUCTION

Diffusion weighted imaging is a widely used method to detect brain pathologies at an early stage by analyzing water movement within the brain tissue at the molecular level. Until now, there has not been a known method to drastically alter the diffusion characteristics of water molecules in either water solutions or living tissues. Here we report on a new method to obtain diffusion weighted images of living tissues by applying electrical currents, which significantly increases the ADC of water molecules. An increase of the ADC of water molecules permits earlier and clearer imaging.

METHODS

All experiments were conducted using a 7.05 T, 18.3 cm bore MRI system and a quadrature radiofrequency coil operated at 300 MHz for 1H resonance. The ADC was measured using an acrylic column model (26 mm inner diameter, 45 mm long) filled with 0.9% NaCl solution. The current density in the phantom was constant in any cross section. Diffusion weighted images were obtained using a plastic spherical model with a small current dipole and filled with 0.9% NaCl solution, which was an equivalent model of an activated neuron in the brain. Direct electrical currents were generated from a tightly twisted-pair copper cable, which was isolated from the solution except for the tip. Male Wistar rats, 180 to 250 g, 10 to 14 weeks old, were orally anesthetized with 1.5% halothane. Graphite square planar electrodes (20 × 20 mm) were subcutaneously implanted in the rat heads and necks. Transversal diffusion weighted images were obtained with 3, 7 and 10 mA and without electrical currents.

RESULTS and DISCUSSION

The ADCs with electrical currents were much greater than those without currents. Fig 1 shows the relationship between the ADC of water molecules in mm^2/s and the electrical current density in mA/cm^2. The ADCs parallel to the column with electrical currents of $0.6 mA/cm^2$ was 20 times greater than the ADC without electric currents. The ADCs perpendicular to the column were less than the ADCs parallel to the column. In other words, the ADCs were affected by the direction of the electrical current. Fig. 2 shows the relationship between the ratio of signal intensities classified with b factors and electrical currents. The intensities decreased stepwise as the currents increased over 0.2 mA. The results show that the signal intensities decreased as electrical currents and MPGs increased. The dipole model showed that the signal intensities in close proximity to the electrodes decreased as the electrical currents increased (Fig 3). Thus, electrical currents promoted the diffusion of water molecules between the dipoles. In the in vivo study, signal intensities decreased when electric currents were applied (Fig. 4-b). Weak electrical currents can significantly increase the ADCs of water molecules. The mechanisms of this phenomenon are essentially attributed to the behavior of water molecules. Our results indicate that electrical dipoles of water molecules in the phantom and in living tissues experience either an attractive or repulsive force, and react to external fields. We showed that this effect of water molecules occurs in both phantoms and living animals. This effect has great clinical potential in the diagnosis of brain pathologies, particularly in the early detection of small lesions or acute infarctions.

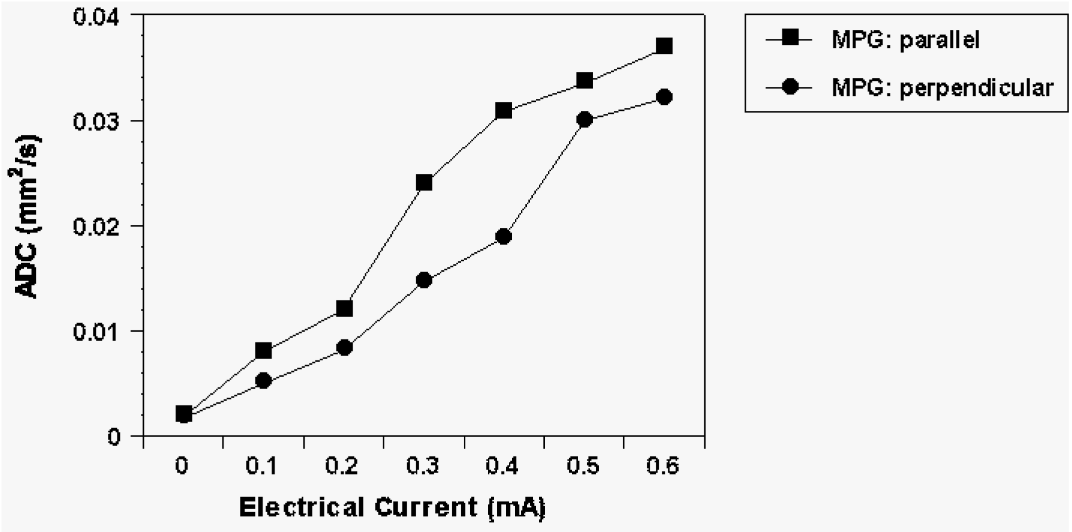

Fig. 1

ADCs were measured by a spin echo sequence with MPG pulses. This figure shows the relationship between the ADC of water molecules in mm^2/s and the electrical current density in mA/cm^2 in the phantom. [TR/TE = 15,000/26 ms, G = 3.575 G/cm, δ/Δ = 4/15 ms, b = 20.0 s/mm^2]

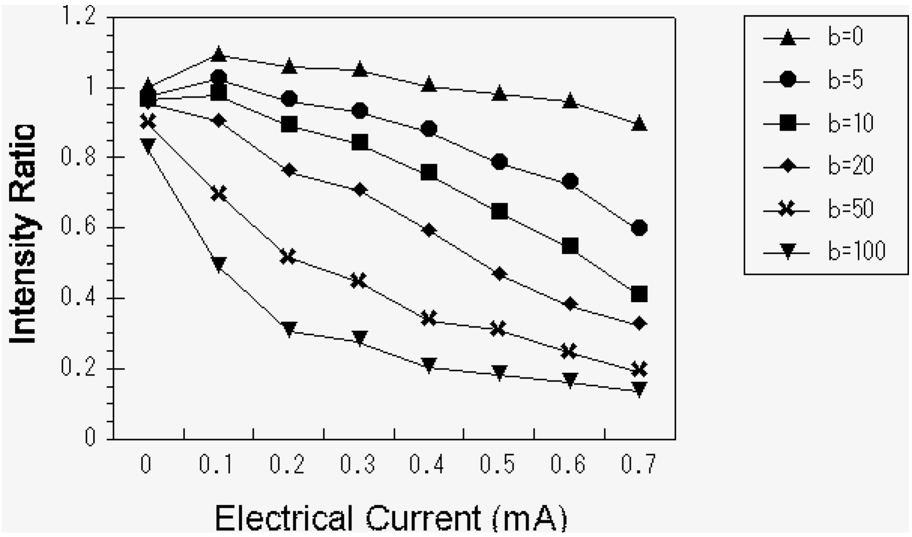

Fig. 2

The graph shows the relationship between the ratio of signal intensities classified with b factors and electrical currents. These intensities were normalized by the intensity without electrical currents and MPGs

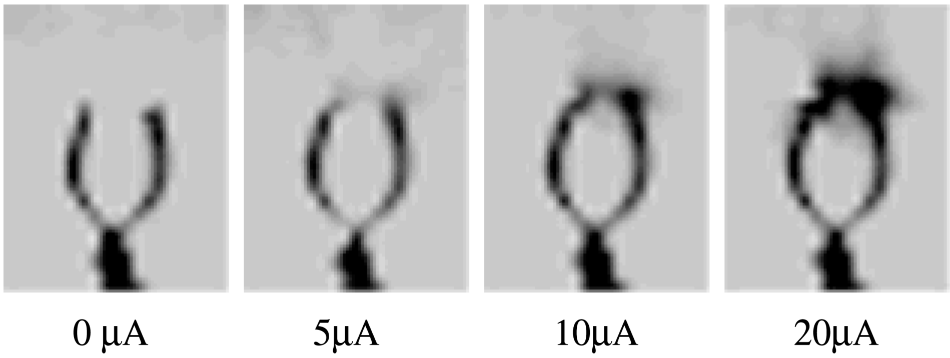

Fig. 3

The dipole model shows that the signal intensities in close proximity to the electrodes decreased as the electrical currents increased. [TR/TE = 1,000/50ms, G = 4.0G/cm, δ/Δ = 10/30 ms, b = 305 s/mm^2]

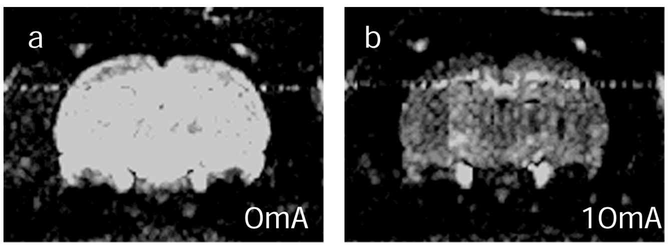

Fig. 4

Fig. 4-a shows the Diffusion-Weighted transversal image without electrical currents. Fig. 4-b shows that electrical currents of 10mA significantly decreased signal intensities in the normal brain. [TR/TE = 3000/65 ms, G = 6.0 G/cm, δ/Δ = 20/35 ms, b = 2920s/mm^2]