3477

# Anysotropic relaxivity measurements of solubilized multiwall carbon nanotubes suspensions reveal molecular orientation.

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**Introduction.** Magnetic Resonance Image contrast is normally obtained using Gd(III) paramagnetic complexes or superparamagnetic nanoparticles, which reduce the $T_1$ or $T_2$ values of the water molecules located in the tissues where they accumulate. Gd(III) complexes and superparamagnetic particles rotate fast in the NMR time scale averaging spherically their relaxivity values. Under these conditions, water relaxation induced by classical contrast agents occurs isotropically, becoming not possible to determine the orientation of the contrast agent probe from relaxivity measurements. In this work we aimed to investigate novel contrast agents with anisotropic relaxivity (1,2). Multi Walled Carbon Nanotubes (MWCNTs) are potentially useful systems for this purpose since they align with magnetic field and depict different magnetic properties in the longitudinal and axial directions, preserving anisotropic relaxivity in the NMR timescale (Fig1A). Here we report the first measurements to our knowledge of directional relaxivity of MWCNTs supensions fixed in agarose gels.

**Materials and Methods**. We used commercial MWCNTs (SES Research, Houston, TX, USA), <10 nm diameter, 1-5 micron average length. It was proven that the preparation of MWCNTs depicted magnetic moment since it was possible to move the preparacion along an Eppendorff tube with an external magnet. They were oxidized by sulfonitric acid (3) and, subsiquently, they were treated with 1-AminoPyrene (in dimethylformamide) to obtain soluble adducts by π-π stacking interactions. Finally, the solution (0.03mg/mL) was: mixed with melted agarose (0.5%, low melting 37°C, Sigma-Aldrich, St. Louis, Mo, USA), and cooled down (22ºC) to form a solid gel inside a 7T magnet. This protocol was able to maintain oriented the MWCNTs in the $B_0$ direction while gelling, keeping this orientation in the solid agarose matrix thereafter. The MWNTs oriented sample was placed in an Eppendorff tube accommodated to a home made PVC goniometer, allowing the rotation of the sample inside the magnet. We measured $T_1$ and $T_2$ values varying the orientation of the sample with respect to $B_o$. We used a progressive saturation or gradient echo sequences as implemented in a Bruker Pharmascan 7 Tesla scanner (Bruker Daltonics, Ettlingen, DE), employing a 38 mm volume coil.

**Results.** It was possible to demonstrate significant different values of $T_1$ and $T_2$ when measured under parallel or perpendicular orientations to $B_0$ (Figures 1B and 1C).

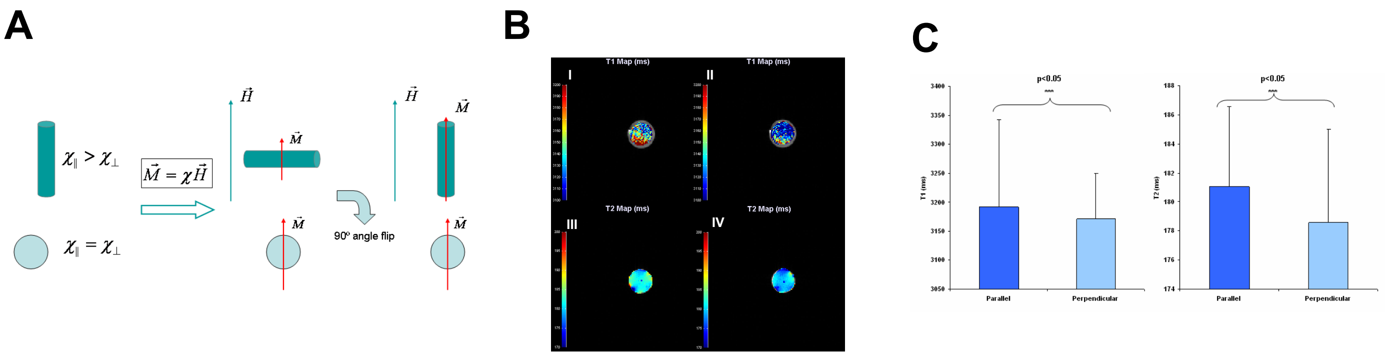


*Figure 1. A: Spherical nanoparticles depict isotropic magnetic susceptibility while MWCNTs depict larger magnetic susceptibility along the longidinal axis of the nanotube. . B: Representative $T_1$ (I - II) and $T_2$ maps (III – IV) from oriented MWCNTs in agarose.. I and III or II and IV maps, correspond to parallel or perpendicular orientations with respect to $B_0$, respectively. Note the different values in the two orientations.C: $T_1$ and $T_2$ values of water (mean ±sd) from an oriented MWCNTs suspension in solid agarose-, in the parallel and perpendicular orientations to the $B_0$ field. Both results are statistically significant ($p<0.01$).*

Fig. 1C shows the variation of $T_1$ and $T_2$ varying the orientation of the nanotubes with respect to the static magnetic field $B_0$. A significant decrease is observed when the nanotube suspension is oriented perpendicular to the magnetic field $B_0$. This response reflects a differential susceptibility effect, increasing the local magnetic field in the top and bottom extremes of the nanotube and decreasing it in the sidewalls. The variation detected is yet small probably due to the small concentration of MWCNTs and their reduced magnetic susceptibility at room temperature under the conditions of our study.

**Conclusions.** We show that oriented MWCNTs depict anisotropic relaxivity in $T_1$ and $T_2$, a property that may allow to unravel the molecular orientation of the probe from relaxivity measurements. In addition, we report a convenient method to obtain magnetically oriented MWCNTs suspensions, able to maintain the orientation within a solid agarose matrix. By changing the orientation of the agarose matrix inside the magnet with a home made, manual goniometer, we were able to prove the directional dependence of relaxivity in the MWCNTs suspension.

**Bibliography.**

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