Hybrid nanoparticles as theranostic agents: thermoplasmonic effects and proton relaxation

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Superparamagnetic nanoparticles are used in magnetic resonance imaging (MRI) to enhance the contrast of the images. By adding a gold shell to these nanoparticles, it is possible to transform them into nanoparticles exhibiting plasmonic excitation. This plasmonic excitation results in a collective oscillation of electrons within the nanoparticle, which generates heat through the Joule effect [1]. When the temperature increase reaches approximately 5 degrees, it can kill cancer cells; this method is called phototherapy [2]. Hybrid nanoparticles composed of a magnetite core and a gold shell can therefore be used in a theranostic approach: combining the diagnostic and treatment phases by performing MRI and phototherapy simultaneously. The concurrent use of both techniques will allow tracking the position of the nanoparticles targeted by the laser while monitoring the heating through MRI.

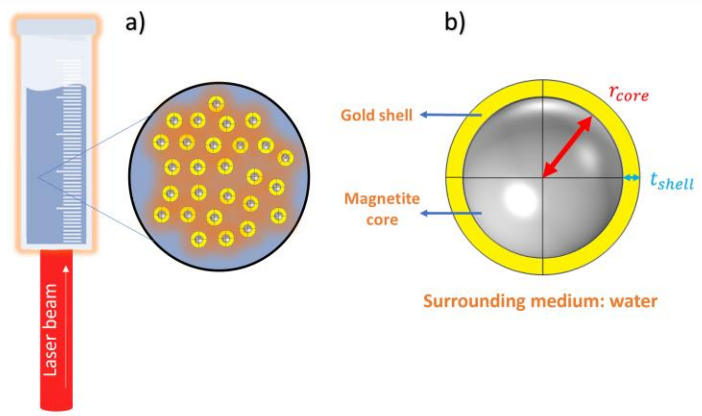

Figure 1: ***a) Simulated experimental setup:*** *a nanoshell solution illuminated by a continuous wave laser.* ***b) Diagram of a hybrid nanoparticle:*** *magnetite core with a gold shell*

Our research aims at studying the interactions between MRI and phototherapy when used together to optimize these hybrid nanoparticles for both applications. To achieve this, we have developed a method to calculate the changes in transverse relaxation rate (R_2), a fundamental parameter in MRI contrast, within a solution containing hybrid nanoshells (NS) under laser illumination. This method consists of two steps: the first one, based on optical simulations and the theory of collective thermal effects for nanoparticles in solution [3], allows us to determine the temperature gradient generated by laser illumination. The second step uses the theory of relaxation induced by superparamagnetic particles to predict the relaxation time in the temperature map obtained after the first step [4].

Fig. 2 displays the results obtained for three different geometries of NSs. For the smallest NSs in Fig. 2a, the diminution of R_2 due to laser illumination can reach 20 % in an area extending up to 5 mm in the sample. Figures 2b and c reveal that for larger NSs, two regimes coexist. One regime where heating has a negligible influence on the transverse relaxation (fairly constant value, Fig. 2b), and another where, contrary to small NSs, heating increases the transverse relaxation at the hottest focal point (Fig. 2c, note the small R_2 on average due to the larger NS). The transition from one relaxation regime to another is due to the modification of the water diffusion coefficient caused by the heating.

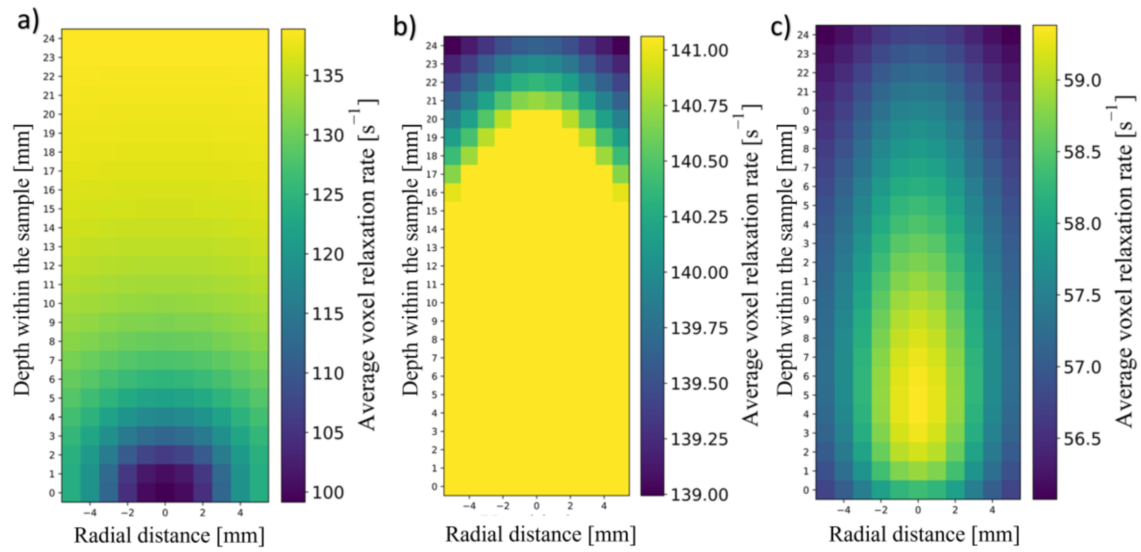

*Figure 2: **MRI relaxation rate depends on the geometry (r_{core} and t_{shell}) of the nanoparticles under laser illumination.** Maps of the transverse relaxation (R_2) within the sample for an incident laser power of 0.33 W/cm^2. The radius of the magnetite core and the thickness of the shell are: (a) 20/10 nm, (b) 95/10nm, (c) 150/10nm.*

Our results highlight that it could be possible to monitor the heating effect using MRI, thanks to the modification of R_2 by laser illumination. To do this it is necessary to select a NS geometry that allows reaching a relaxation regime where the relaxation rate depends on temperature, but also a geometry that allows achieving the temperature increase required for phototherapy. This study sets the stage for inventive and comprehensive biomedical interventions.

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