3D temperature mapping with MPI and MRI

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Introduction: Temperature mapping in 3D is of utmost importance in different contexts, including hyperthermia therapies where heat is delivered to malign tissues and temperature should be controlled in space and time. MRI and MPI offer a great opportunity to obtain such measurements with complementary strengths in terms of temperature, space and time resolutions. In MRI, the intrinsic temperature variation of parameters such as T1, T2 and resonance frequency have been explored together with contrast-based approaches where a contrast agent increases temperature sensitivity. In MPI, the temperature variation of superparamagnetic nanoparticles such as magnetite has also been explored. However, in the temperature window of hyperthermia therapies this variation is small and hard to tune since is governed by the ratio between magnetic and thermal energy, which changes dramatically at cryogenic temperatures but much less around room temperature. Here we present a strategy to map temperature around room temperature based on magnetic nanoparticles with a magnetic phase transition tunable around room temperature, that provide variations of the MRI signal of about 10%/ºC and impressive variations of MPI signal of about 50%/ºC.

Methods: Magnetic Nanoparticles are synthesized by thermal decomposition and sol-gel methods (please see details here [1,2]). MRI images were obtained in a 0.5 T MRI using gradient-echo sequences and in a traveling-wave MPI, both from PureDevices GmbH.

Results and discussion: The magnetic nanoparticles are dispersible and stable in aqueous media, being able to provide temperature-dependent contrast, both in MRI and MPI. The relative variation of this temperature-contrast is tunable by the doping level of the nanoparticles. In particular, when the maximum contrast variation is tuned for ~42 ºC, we are able to produce 3D temperature maps in the context of near-infrared thermal treatment in 3D cellular assembles that mimic tissues, as shown in Fig. 1

Conclusion: Contrast agents with a controlled magnetic phase transition can be explored to generate 3D temperature maps both in MPI and MRI. This can find application in temperature monitoring during laser hyperthermia, for instance.

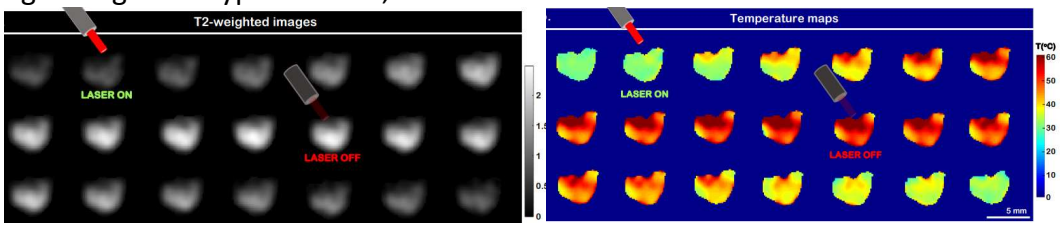

Fig. 1: T2-weighted and temperature images obtained with a cell sample before, under NIR irradiation for 82 s at 0.67W cm^{-2}, and after that irradiation (8 s integration time per image, pixel size of 0.16 mm).(From[1])

References: [1] Soeiro et al., Small Structures (2025). [2] Soeiro et al., ChemRxiv (2024).