Air Susceptibility Effects on Proton Resonance Frequency Temperature Mapping

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Introduction:
MR thermometry is usually based on the temperature dependence of the proton resonance frequency (PRF), therefore any magnetic field changes might be misinterpreted as temperature changes [1]. Possible reasons for field changes are changes in susceptibility of the tissue [2] or movement of paramagnetic matter close or inside the object [3]. Here we report on the effects of the change of susceptibility with temperature of the surrounding air on the magnetic field inside an object.

Methods:
A spherical 1% agar gel phantom (0.9% NaCl, diameter 10cm) was mounted inside a polystyrene foam box connected by long pipes to a hair dryer outside the scanner room (figure 1). Phase images were acquired at a 7T scanner to measure field perturbations. Additionally, a fibre-optic thermometer (Lumasense) was placed inside the phantom to monitor the temperature of the phantom and outside the phantom to measure the air temperature. Phase images were acquired every 40 seconds using a spoiled GRE sequence (TR/TE = 200/20 ms; bw = 100 Hz/pixel; voxel size: 2×2×2 mm^3), for a period of 160 minutes. The first 10 scans (no heating) were taken as a reference. Then the hair dryer was switched on for 20 minutes to heat the phantom, followed by a non heating period of 20 minutes and another heating period until the end of the experiment. Images were phase unwrapped using the PhUN package [5]. The so-called phase temperature change was then calculated using $\Delta T = \Delta\varphi(T)/(2\pi f_0 \alpha TE)$, where T is the Temperature, φ the phase difference, f_0 the resonance frequency and α = −0.01 ppm/°C [1]. The magnetic field change in the spherical phantom due to the susceptibility change of the surrounding air was calculated using the forward simulation described by Marques [6] and Salomir [7].

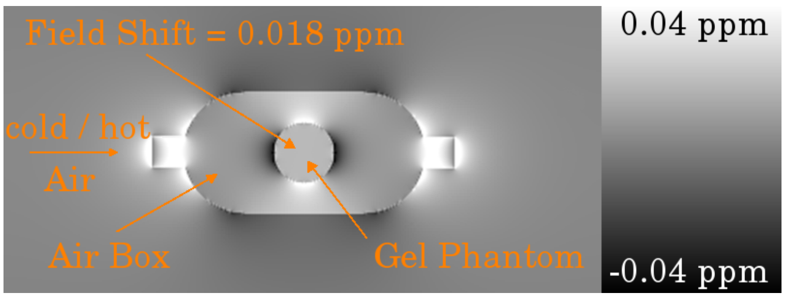

***Figure 1:** Calculated field shift map of the experimental setup due to a susceptibility change of the air inside the box.*

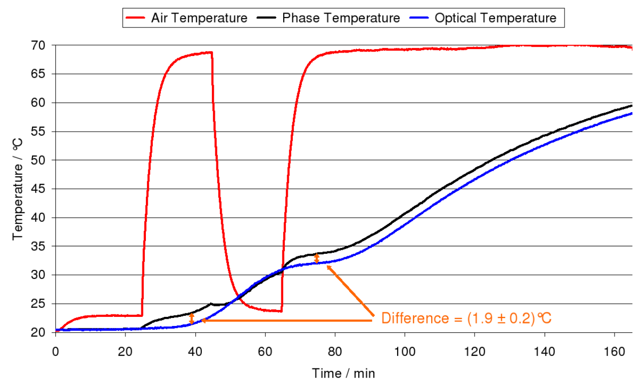

***Figure 2:** Measured phase and actual temperatures during the experiment. As the surrounding air temperature increases (red line), the phase temperature (black line) deviates from the actual temperature (blue line) at the same point.*

Results:
Figure 2 shows the measured temperature curves. The black line describes the temperature measured using the MR phase and the blue line the thermometer reading at the same point in the centre of the phantom. Once the air temperature (red line) increases, the phase temperature clearly deviates from the actual temperature, and this deviation disappears as the air temperature returns to the initial air temperature. During the rest of the experiment, phase temperature and actual temperature increase in parallel due to the surrounding hot air. The air temperature of 69°C yields a difference of 1.9°C at the position of the optical sensor inside the phantom between the measured temperature using the optical sensor and the temperature using phase imaging. The forward simulation for a volume susceptibility change of the surrounding air from $\chi_{air}(23°C) = 3.6\times10^{-7}$ to $\chi_{air}(69°C) = 2.7\times10^{-7}$ [4] gives a magnetic field shift of 0.018 ppm (figure 1), translating into an apparent temperature change of 1.8°C [6,7], in excellent agreement with our measurement. To determine the field shift dependence on the radius and length of the air box, we simulated a simplified model, consisting of a spherical phantom in a tube of variable length and radius. The results of this simulation are visualized in figure 3, assuming the same air temperature change and therefore same change of volume susceptibility.

Discussion:
The phase temperature deviation from the actual temperature of 1.9°C (figure 2) is explained by the change in susceptibility of the surrounding air (figure 1). This change in magnetic field is strongly dependent on the geometry of the setup, as seen in figure 3. Here the field shift due to a susceptibility change of surrounding tissue was simulated. For the approximation of a long cylinder the field shift approaches 0.03 ppm, equivalent to 3°C. Interestingly, for some configurations a field shift of zero can be expected. In addition, the field shift is approximately linearly dependent on the air temperature change. Therefore, as a worst case scenario for in-vivo MR Thermometry, an air temperature change of 10°C could result in a phase temperature error of 0.75°C.

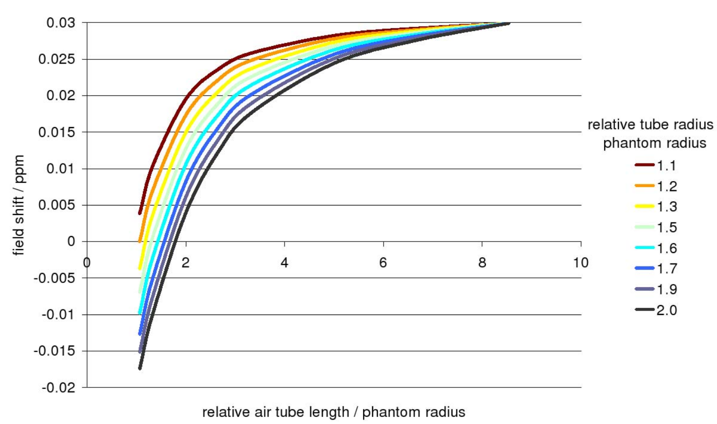

***Figure 3:** Field shift simulation for different simplified geometries of a spherical phantom inside a cylinder of different radii and lengths. A volume susceptibility change from 0.36 ppm to 0.27 ppm outside the phantom was considered.*

References:
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