New MR thermometry approach to follow small temperature variation: in-vivo validation on the anesthetized baboon's brain at 7T

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Introduction: Measuring small temperature rises (< 1 °C) in the brain and in-vivo using MR thermometry[1] is a challenging task given the required stability of the whole transmission-reception chain as well as the physiological noise easily spoiling the desired signal. The proton resonance frequency shift method is the most sensitive MR thermometry (MRT) technique whereby phase-difference images can quickly be acquired and converted into temperature rises via the coefficient[1] $\alpha \approx -0.01$ ppm/°C. Breathing alone however is known to induce changes in the resonance frequency[2] comparable or larger than the shifts one can expect for a temperature rise on the order of 1 °C. It is thus crucial to correct for this effect when studying small heating such as the one induced by an MRI RF coil. Several techniques have been proposed to tackle this problem including reference phase library[3] or background phase substraction[4] methods, which either rely on breathing reproducibility or on localized heating. We here report an experiment performed in-vivo on a baboon's head and at 7T, where a (non-local) RF-heat generating system was separate from the MR scanner to provide higher stability than the MRI coil/scanner itself, and where navigator free induction decays (FID) were used to correct for the 2D ΔB_0 variations induced by breathing and for the drift of the external field.

Materials and methods: Experiments were performed on an anesthetized (Sevofluorane 2%) baboon using a 7T Magnetom (Siemens Healthcare, Erlangen, Germany) scanner and a birdcage coil for measuring the image phase. The animal was covered with a blanket. A separate system (Fig. 1.a) was used to expose the baboon's back of the head to an RF field coming from a loop coil tuned and matched at 125 MHz in order not to couple with the birdcage imaging coil resonating at 297 MHz. The frequency generator provided a -6.5 dBm signal which was then amplified by 50 dB. A circulator placed at the output of the amplifier then allowed to route the signal to the coil, to protect the amplifier from spurious reflections and to monitor the stability of the heating coil via a spectrum analyzer. With this power and set-up, the global and peak 10-g SAR were roughly estimated at 2.7 and 23 W/kg respectively by performing MRT on a spherical (15.8 cm diameter) water-gel agar phantom ($\sigma = 0.78$, $\varepsilon_r = 74.3$) doped with salt (4g/l). The overall experiment consisted of 3 stages. First, before heating, about 300 2D GRE central axial acquisitions (matrix = $64 \times 64 \times 1$, re s= $2.8 \times 2.8 \times 5$ mm^3, FA = 12°, TE = 25 ms, TR = 33 ms) were performed for 10 minutes where each echo was preceded by a recorded FID. The unwrapped phase of the FID was fit with a linear function whose slope then characterized the average ΔB_0 induced by breathing every 33 ms, as well as the linear drift of the main magnetic field. In addition, this allowed to reconstruct images and test our correction scheme since negligible temperature variations are expected during this stage. Second, a series of 12 1-min long heating periods (no gradients played) were interleaved with 3 identical and consecutive GRE 2D acquisitions to achieve steady state and include a full breathing cycle. Likewise each echo was preceded by a FID to locate its position in the breathing cycle and make the corresponding phase correction. It was therefore crucial to measure and characterize these changes over axial slices as the shift due to breathing to first order is spatially constant in the X-Y plane[2]. Finally, a series of 300 similar 2D acquisitions as in the first stage was performed after RF heating was stopped. The phase images acquired in the second and third stages were subtracted from the phase obtained in the first stage. These differences were then divided by $\alpha\omega_0$TE to determine the temperature rise. At 7T, the magnetic field generated by the baboon itself was such that no phase signal could be reliably measured at this echo time in an external probe made of oil or water.

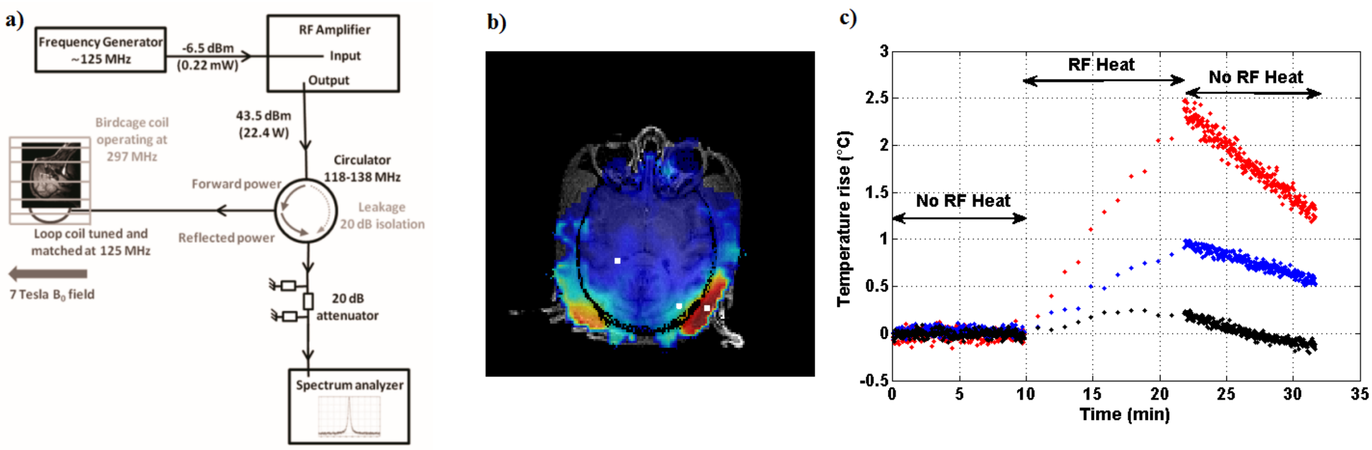

Fig. 1: **a**) Experimental set-up. **b**) Temperature rise map superimposed on a T1-weigthed image. **c**) Temperature rise at the three locations indicated in b) by white squares.

Results: A superimposed temperature rise map on top of a T1-weigthed image is shown in Fig. 1.b. The peak temperature over the measured slice was around 2.5 °C. Breathing was stable and measured to induce throughout its cycle a peak to peak variation over the slice of ~2.5 Hz, equivalent to 0.8 °C. Fig. 1.c provides the temperature evolution at the three locations indicated by white squares in Fig. 1.b after corrections (linear drift + breathing) were made. The reconstructed temperature rise in the preheating period is nearly constant and roughly suggests a ± 0.1 °C accuracy with a time resolution in 2D of 2 s, at least over the length of this experiment. Not correcting for breathing on the other hand resulted in a temperature uncertainty of ± 0.25 °C. The low temperature results in Fig. 1.c. did not return strictly to 0 indicating a loss of linearity in the drift or a cooling of the animal. The RF powers used to induce this temperature rise were sufficient to affect the tuning/matching of the loop coil so that adjusting the frequency manually and progressively seemed a necessity to maintain a constant power deposited in the head, again justifying the use of a dedicated set-up for RF heating.

Conclusion: A new method for MR thermometry was reported, where the temperature rise in a baboon's head could be obtained with ~0.1 °C accuracy at 7T despite breathing. This set-up and method can be useful to investigate bioheat models[3] non-invasively. The robustness of the method must now be assessed on freely breathing human volunteers.

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