# Feasibility of fast MR-thermometry during cardiac RF ablation

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## Introduction

On-line MR-temperature monitoring during radio-frequency (RF) ablation of cardiac arrhythmias may improve the efficacy and safety of the treatment [1]. The efficiency of the ablation is directly related to the delivered thermal dose, which is a function of temperature increase and exposure time. Magnetic Resonance Imaging (MRI) can provide rapid and quantitative thermometric measurements in addition to a detailed anatomical information. Recent results showed that MR thermometry on the heart was feasible with ECG and respiratory triggering but at the cost of a limited temporal resolution, making precise dosimetry of the deposited energy difficult to assess [2]. To overcome this limitation, we propose in the present study a method for monitoring the temperature evolution in the heart at each cardiac cycle. For this purpose, cardiac triggering and dynamic navigator-based slice tracking were combined with image registration and compensation of susceptibility changes with respiration, in order to investigate the precision of PRF thermometry during a RF ablation (RFA) in-vivo on a sheep heart.

## Materials and Methods

***MR compatible RFA device:*** A 7 FR MR compatible non perfused steerable catheter (Bard SA) was specially designed for the study, equipped with a single electrode tip for RF ablation. The return electrode was positioned on the posterior leg of the animal after removing the hairs to ensure good electrical coupling. The catheter and return electrodes were connected to a RF generator (AG 1006, Germany) located outside the Faraday cage. The electrical output signal (500kHz in frequency) of the generator was filtered by inserting a series of 4 notch passive filters (one at the output of the RF generator, one on each side of the Faraday cage and one close to the electrical plug of the catheter) tuned to the MR resonant frequency (64MHz) in order to suppress the electromagnetic interferences that may alter the quality of the MR images. The MRI compatible RF ablation catheter was advanced into the left ventricle with a retro aortic approach.

***MR-acquisition protocol:*** MRI guided RF-heating was performed in-vivo in the left ventricle of a sheep under general anaesthesia. Real-time MR thermometry was performed during RFA by acquiring 400 dynamic images in the short axis orientation (5 slices, TR/TE=32/16ms, bandwidth in readout direction=2085Hz, flip angle=35°, FOV=320×140mm$^2$, slice thickness=6mm, matrix=128×56). The acquisition was ECG triggered and respiratory compensated in the slice encoding direction using a navigator based slice tracking technique.

***Image processing:*** Despite both cardiac and respiratory motion were compensated during the acquisition, variations in the cardiac cycle duration over the examination period may occur. In addition, slice tracking was performed only in the slice encoding direction, without in plane repositioning of the FOV. Therefore, combination of both effects required additional in plane image registration. Moreover, phase variations induced by local susceptibility changes related to lung volume modifications and organ displacements need to be compensated for prior to temperature calculation. To account for these effects, the following corrections were applied:

*In plane image registration:* In plane motion compensation was performed by analyzing the magnitude images. For this purpose, the first image in the time series was selected as the reference in position. A gradient driven descent algorithm maximizing the inter-correlation coefficient between the reference and the current image was initially performed on each image of the time series, assuming a global translational displacement. The estimated displacement was then used for preconditioning of a more complex optical flow algorithm for image registration on a pixel-by-pixel basis [3].

*Correction of susceptibility related phase changes with motion:* The first images in the time series (50 dynamics) were stored in a multi-baseline collection of reference data set, including registered phase images and the corresponding magnitude image. The following dynamics were corrected with this reference data set. For this purpose, the current magnitude image was compared to each magnitude images of the collection by computing the list of inter-correlation coefficients. The phase image associated to the magnitude of the collection with the maximal inter-correlation value was selected and subtracted to retrieve the susceptibility corrected temperature map.

***Implementation:*** The image processing pipeline has been implemented in C++ and required approximatively 100ms of total computation time for one image of resolution 128×128 on a dual processor dual core AMD Opteron 2.4GHz with 8Gb of RAM, demonstrating that it is compatible for real-time processing.

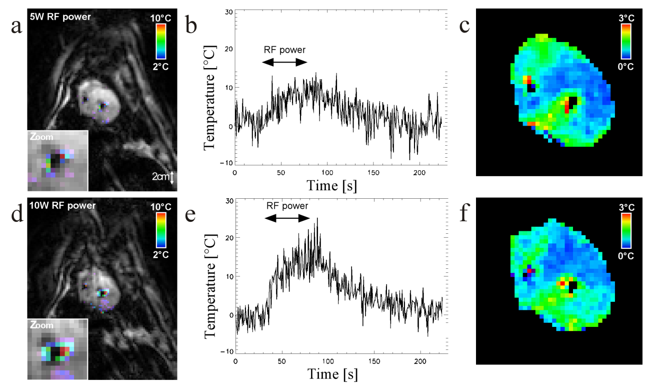


**Figure 1.** MR-Thermometry results obtained on the left ventricle of a sheep heart during RF-heating. **a:** the temperature distribution obtained after one minute of 5W RF heating overlayed on the anatomical image, **b:** corresponding temporal evolution of the temperature at the extremity of the catheter (up to 8°C of temperature evolution were measured), **c:** corresponding TSD map obtained before hyperthermia, **d:** the temperature distribution obtained after one minute of 10W power heating overlayed on the anatomical image, **e:** corresponding temporal evolution of the temperature at the extremity of the catheter (up to 16°C of temperature evolution were measured), **f:** corresponding TSD map obtained before hyperthermia.

## Results and Discussion

The cardiac cycle duration was approximately 650 ms. The SNR on the magnitude images was 20 and a temperature standard deviation (TSD) (evaluated on the 50 dynamics acquired prior to RF ablation) of 1°C was measured on the whole myocardium. This value rose to 2°C at the tissue electrode interface (Fig 1c and 1f). MR-guided RFA of the left myocardium showed consistent evolution of the tissue temperature, with a progressive increase near the catheter tip during the 60 sec of energy delivery, followed by spontaneous tissue cooling caused by heat conduction and perfusion. Temperature images acquired at the end of the RF energy delivery showed a larger heated area for a heating performed at 10W RF power than for a heating performed at 5 W (Fig 1a and 1d). The maximum increase of temperature in the pixel at the contact with the catheter tip for 5 W/10 W RF power were 9°C (Fig 1b) and 16°C (Fig 1e), respectively. No heating was observed in the adjacent slices. Temperature elevation higher than 5°C were achieved in ellipsoidal regions of dimension 7×17 mm² (5 W RF) and 10×20 mm² (10 W RF).

## Conclusions

Obtained results demonstrates the feasibility of real-time tissue temperature monitoring during RF delivery. Combination of slice tracking, cardiac triggering, efficient image registration and compensation of susceptibility changes related to motion allowed for significant improvements of the precision of the thermometry in the heart, with a temporal resolution given by the cardiac period (~1 second). The resulting temperature precision was acceptable in view of typical temperature increase achieved during cardiac catheter ablation.

## References

[1] Jais P et al, Arch Mal Coeur Vaiss 1995. [2] Kolandaivelu A et al.Circulation: Arr and Elec. 2010;3:521-529 . [3] Roujol et al. MRM 2010;63:1080–1087.