# MR and CT compatible electrical heating system for mouse imaging

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## Introduction

Active heating is required to avoid hypothermia in anaesthetised animals. Small resistive MR-compatible heaters are useful where space limitations prevent the use of circulating fluids but computerised tomography (CT) imaging is severely compromised by these, due to the presence of high atomic number elements. Positron-emission tomography (PET) and Single-photon emission computerised tomography (SPECT) imaging are unaffected by these heaters unless a corrupted CT scan is used for attenuation correction. We describe a carbon-fibre sheet heater element, used with 100 kHz alternating current (AC) that is demonstrated to be MR, CT, SPECT and PET-compatible.

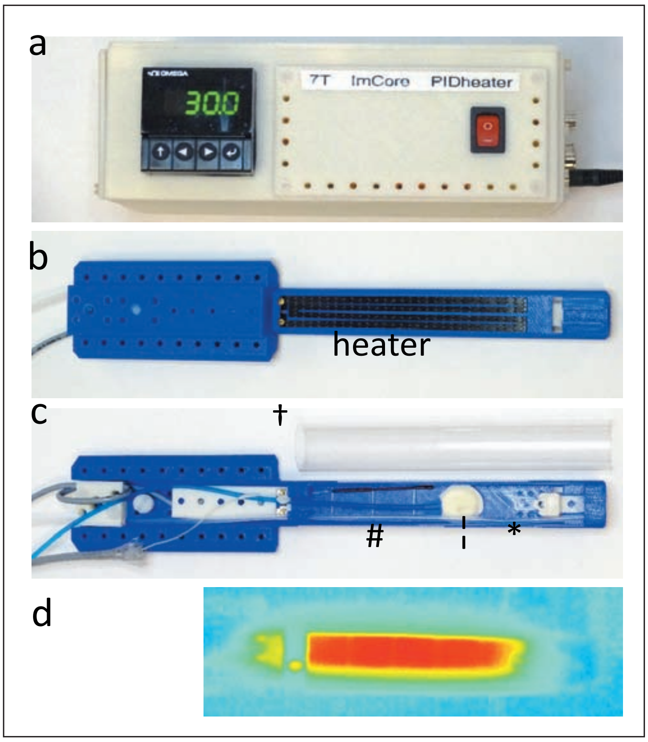



**Figure 1.** Carbon-fibre sheet resistive heater embedded in a 3D-printed, flat-base multimodal imaging cradle.

(a) Proportional-Integral-Derivative Controller (PID), (b) Bottom view of the cradle containing the heater element, (c) Top view of the cradle containing an adjustable mouthpiece (*) and physiological monitoring apparatus (¦, respiration; #, optical thermometer) and ( ) a cover sheet to contain anaesthetic gas, (d) thermal image of the cradle surface. The current wires and metal couplings to the carbon fibre are located beyond the imaging FOV so do not present image distortions.

The assembly is shown in Figure 1. A 250 Ω resistive heater element formed from 0.75 mm thick carbon-fibre sheet (RS, 764-8700) cut into 4 x 3 mm wide legs, each 120 mm long and spaced by 1 mm, which was glued to the underside of the cradles as shown in (Figure 1b).

A PID-controlled gain setting amplified a 100 kHz sine wave generated using a Pierce oscillator to maximum power of ca. 2 W (Figure 1a). The input to the PID was derived from a fibre optic rectal temperature system (Opsens, Accusens).

**Thermal stability** was validated in vivo in CBA mice.

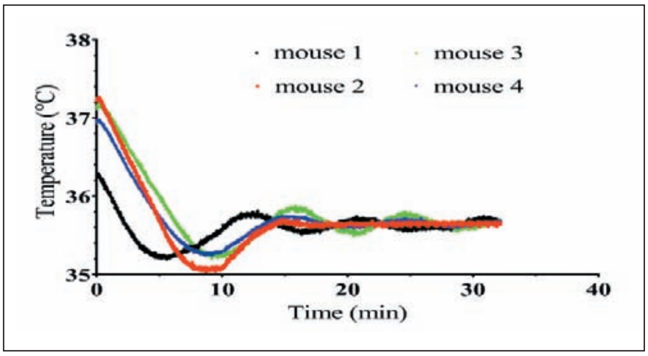
**Magnetic resonance (MR)-compatibility** of the heater element was tested using MR-compatibility of the heater element was tested in a water gel phantom using single shot PRESS spectroscopy and 2D fast low angle shot (FLASH) imaging, and in vivo in the mouse using respiratory-gated 2D FLASH and cardio-respiratory-gated 3D FLASH imaging. In all cases the same acquisition was repeated for the heater turned on and off. (7T, Varian Inc, VNMR).

**CT-compatibility** (MILabs, Vector$^4$CT) was tested in the absence of any heater, and in the presence of either copper wire or carbon-fibre sheet heater elements.

**Multimodal MR-CT-PET-SPECT imaging** of kidneys was performed using $^{111}$Indium Citrate ($^{111}$In, SPECT), $^{18}$F-fluorodeoxyglucose (FDG, PET), anatomical CT, respiratory-gated bSSFP and DCE-MRI.

## Results: thermal stability

The power dissipation of the carbon-fibre sheet heater resulted in homoeothermic maintenance of the animals. The PID based controller allowed automated temperature maintenance with a fluctuation of 0.1˚C at approximately 0.5˚C below the target temperature.



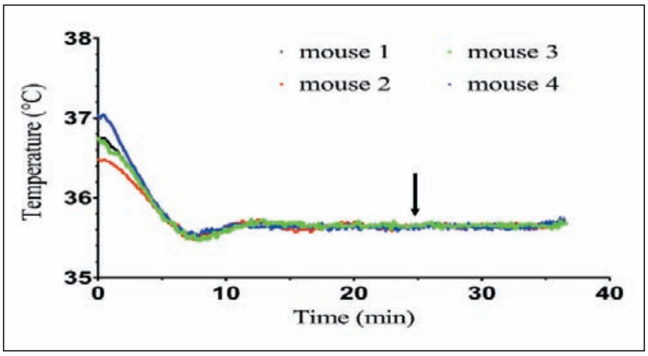




**Figure 2.** (A) core temperature of 4 mice placed into the SPECT/PET/CT scanner. (B) Core temperature of 4 mice placed into the MRI scanner.

The arrow indicates when respiratory-gated bssfp imaging was initiated to replicate the additional heat load of high duty cycle MRI scanning.

## Conclusion

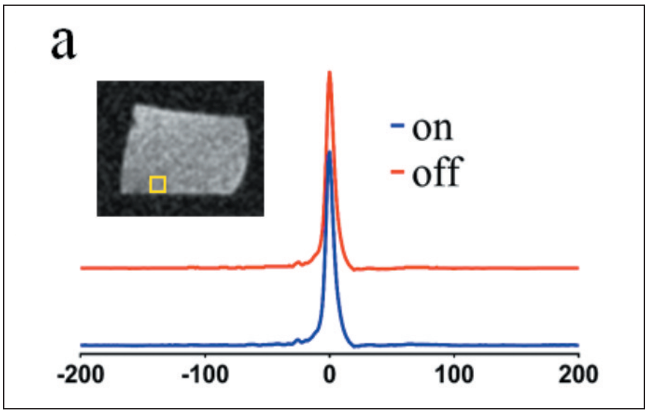
Carbon-fibre sheet resistors powered with high frequency AC under PID control:

- allow homoeothermic maintenance
- allow automated temperature control with 0.1°C fluctuation
- are compatible with multimodality imaging using MR, CT, PET and SPECT
- are small heaters
- are easy to produce
- are easy to integrate into cradles for multi-modal imaging

## Results

### *MRI compatibility*

The equivalence of spectra and images acquired in the presence and absence of AC heating demonstrates that the heater element delivers heat in a manner that does not corrupt the imaging process and the carbon fibre material does not lead to any marked image distortions.



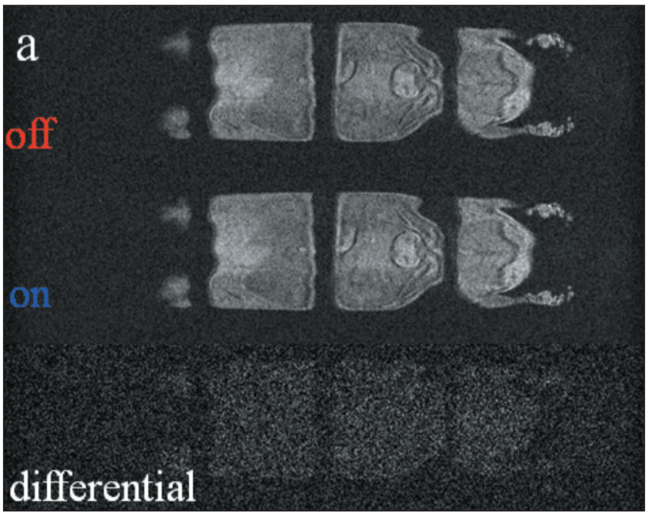




**Figure 3.** Impact of current flow through the carbon-fibre sheet heater element on *in vivo* MRI of the mouse. An area close to the heater was chosen to achieve this data (yellow square) as image distortions originate from current flow in the MR. (a) T1 weighted *in vivo* whole-body respiration gated 2D FLASH MRI with the heater turned off (top) and on (middle). The bottom image displays the difference between both images.

### *CT compatibility*

The absence of attenuation-derived streak artefacts when using the carbon-fibre sheet heater provides good image quality that enables quantitative analysis of image intensities. This was not the case where the copper wire heater was used.

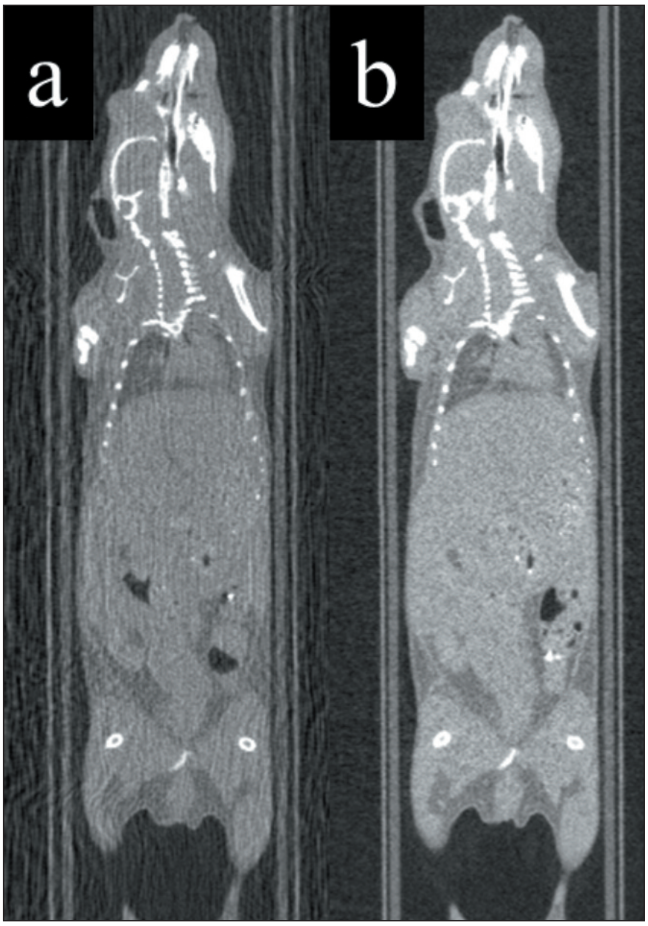



**Figure 4.** Impact of the heater material on CT image quality. CT imaging using (a) the 150 mm diameter copper wire heater or (b) carbon-fibre sheet heater. Streak artefacts due to the presence of the heater are absent when using the carbon fibre heater and image intensities remain intact.

### *Multimodal MR-CT-PET-SPECT imaging*

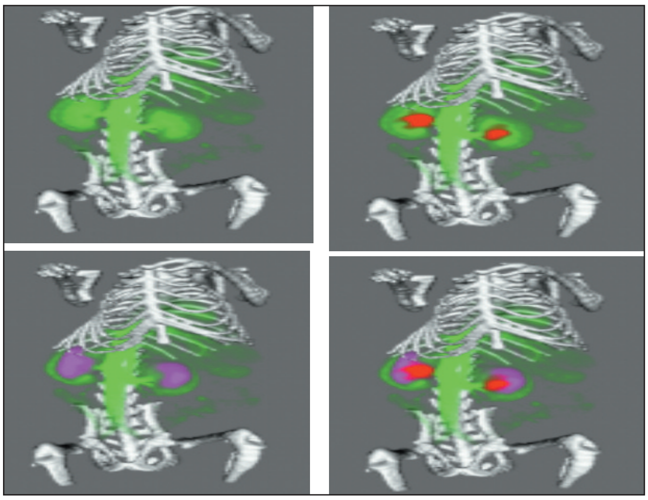


**Figure 5.** Multimodal imaging of a mouse using the carbon-fibre sheet resistive heater embedded in a 3D-printed, flat-base multimodal imaging cradle. The skeleton, kidneys, major vessels to the kidneys (*) are marked up. The **skeleton (white)** was imaged by CT, whilst **$^{111}$In-citrate (red)**, **$^{18}$F-fluorodeoxyglucose (purple)** and **Gadodiamide (green)** were used for SPECT, (PET)SPECT and DCE-MRI of the kidneys, respectively. Each panel shows an additional layer of the co-registered, segmented image: (a) CT + MRI, (b) CT + MRI + SPECT, (c) CT + MRI + (PET)SPECT, (d) CT + MRI + (PET)SPECT + SPECT.