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# Radio Frequency MRI coils and safety: how infrared thermography can support quality assurance

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## Abstract

**Background:** The safety controls in Resonance Magnetic Imaging (MRI) diagnostic site are numerous and complex. Some of these are contained in international directives and regularly conducted by medical physics expert after acceptance tests, consisting of a series of checks, measurements, evaluations called quality controls (QCs) and made to guarantee the image quality of the equipment. In this context, ensuring that the coils are in proper operating conditions is important to prevent and reduce errors in use and to preserve patient safety.

**Results:** A study by thermography was conducted to evaluate temperature changes of MRI coils during Quality Control (QC), in order to prevent any problems for the patient due to Radio Frequency waves. This experiment involves use of a thermal camera to detect temperature variations during MRI scans using head and body coils of two different tomography 1.5 T and 3.0 T static magnetic field. Thermal camera was positioned inside the MRI room to acquire images every 15 s for all the scans duration. The observations have shown a temperature increase only for body coil of 1.5 MRI tomography, whereas no significative temperature variation has occurred for the other coils under observation. This temperature increase was later related to a fault of such coil.

**Conclusions:** The authors believe this simple method useful as first approach, during routinely QCs, to verify coils functioning and so to avoid patient hazards and are preparing a methodological study about functioning of the coils with respect to their temperature variation.

**Keywords:** MRI, Radiofrequency, Coils, Thermography, Infrared, Quality assurance

## Background

A medical imaging system produces images that allow accurate and timely diagnoses and improves evaluation of such images using protocols of increasing quality and standardizing [1]. In particular, Magnetic Resonance Imaging (MRI) is a highly sophisticated imaging modality commonly used in clinical diagnoses [2]. It is a non-invasive technique which provides images of internal

tissues without applying ionizing radiations [3, 4]. MRI scanners combine three different electromagnetic fields, i.e., static magnetic field (typically symbolized by B<sub>0</sub>), radiofrequency (RF) field (B<sub>1</sub>), generated by coils, that can operate in transmit and receive mode with high signal-to-noise ratio and wide field homogeneity [5], and magnetic field gradients in the three spatial directions, to select the region of interest for spatial encoding of image. The possibility that some hazards for patient can be associated with performing MRI diagnostic images concerns, above all, B<sub>0</sub>, RF (B<sub>1</sub>) and magnetic field gradient.

It is necessary to establish regular and adequate Quality Assurance (QA) procedures to guarantee the

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maintenance of consistent image quality over the imaging equipment lifetime and to ensure safe and accurate operation of the whole process with respect to patients, workers and population.

Every QA program should include periodic tests to identify any degradation in image quality [6] reducing the ability to detect and correctly interpret abnormal findings that could imply a decrease in diagnostic accuracy.

Such tests, known as Quality Control (QC) tests, play a key role within the QA procedure because they enable a complete evaluation of system status and image quality [7, 8].

MRI QA programs for images evaluation are well established [9–13], whereas evaluation of proper operating of hardware components of scanners, such as coils, bed, is more difficult, because no specific standardized procedures and guidelines are available. In this context, every responsible person, expert in charge, shall set up his own program.

About the coils, the RF pulses generated for image production are transmitted through free space from coils to the patient.

Such pulses can induce electrical currents in conducting materials and in human body can heat tissues quite dramatically, resulting in superficial skin burning if there is a malfunction or malposition [14].

There are unquestionable evidence of MRI-related reports of patients' burns (thermal injuries or incidents) that strongly indicate the need for increased awareness, education and understanding concerning this rare, but real, MRI-related hazard [15].

Only for specific absorption rate (SAR) evaluation, the safety of RF exposure to clinical MRI is regulated by the US Food and Drug Administration and the International Electrotechnical Commission's guidelines for RF exposure adopted in Europe [16, 17]. The SAR, which describes potential heating of the patient's tissue due to RF, is automatically calculated by the system when is set a sequence to acquisition.

In all cases, coils should be periodically checked before use on patient to ensure the absence of frayed insulation, exposed wires and other hazards [18].

Many different techniques have been proposed for coil efficiency estimation [19, 20].

Some of these use methods that produce images directly whereas probe techniques generate B1 map from different points in the space. The perturbing sphere method has recently been applied to map the RF fields from MRI coils but it can provide accurate efficiency measurements only when the electric and magnetic field components are well separated in space [21, 22].

In this paper, a simple method that use non-contact Infra-Red (IR) thermography is presented in order to evaluate the proper operating of coils.

This method involves the use of an IR Camera to detect if a temperature variation occurs during MRI scans.

It is well known that all objects with temperature above the absolute zero emit electromagnetic radiation known as thermal radiation [23–25].

The wavelength range of this radiation is (0.7–350)  $\mu\text{m}$  [26]; this range can be subdivided in three bands: near infrared (NIR), medium infrared (MIR) and far infrared (FIR). According to thermal radiation theory, blackbody is considered as a hypothetical object that absorbs all incident radiations and radiates a continuous spectrum according to Plank's law [25]. The total emissive power of a blackbody is described by Stefan–Boltzmann's law (Eq. 1):

$$E = \sigma T^4 \quad (1)$$

where  $E$  is the total emissive power,  $\sigma$  is the Stefan–Boltzmann's constant and  $T$  represents the absolute temperature in kelvin.

For real bodies, Eq. (1) is modified in the following Eq. (2):

$$E = \varepsilon \sigma T^4 \quad (2)$$

where  $\varepsilon$  represents the emissivity of the emitting surface.

In this experiment, thermography is used during MRI phantom tests, to evaluate the heat delivered by coils during scans, to inspect, without interference non-destructive manner, eventual surface crack in materials and to individuate superficial abnormal behavior. The local temperature increase, besides, can be correlated to electric field around the coil [27].

The thermal camera detected the infrared (IR) energy emitted by the investigated coils and created electronic images based on information about the temperature differences [28]. In fact, due to thermal conductivity and specific heat, each object or its region has its own temperature; a thermal camera can detect all the field of view, and the objects appear as distinct in a thermal image, although less detailed [29–31].

## Methods

The thermography measurements were conducted on two different MRI scanners of the same Institute, 3.0 T Philips Achieva and 1.5 T Philips Intera. In both cases, the in use body and head coils were tested. All the investigated RF coils were loaded with the phantom used during image QC procedures. Two different probes were used for temperature measurements:

- (a) The FLUKE 62 mini IR Thermometer.

(b) The FLIR T440 Camera.

The Fluke 62 mini IR thermometer works in the temperature range  $-20\text{ }^{\circ}\text{C}$  to  $+500\text{ }^{\circ}\text{C}$  with an accuracy of  $\pm 1.5\text{ }^{\circ}\text{C}$  and an emissivity from 0.10 to 1. It allows us to measure single spot temperature in a contactless manner. The FLIR T440 camera allows us to display images in both the IR range (7.5–13)  $\mu\text{m}$  and in the visible (0.4–0.7)  $\mu\text{m}$  one. Thermal images are normally grayscale in nature: black corresponds to cold objects surface and white to hot; gray shades indicate intermediate temperatures. The FLIR T440 camera, however, processes images in false colors so that users better identify objects at different temperatures [30]. The FLIR T440 camera was positioned inside the MRI room, because it is a MRI conditional device, and the distance between the RF coil and the thermal camera was  $(1.00 \pm 0.01)\text{ m}$ .

IR radiations emitted by a surface strictly depends on the micro-climatic conditions such as humidity, airflow, and surrounding temperature. For this reason, it is necessary to conduct measurements in controlled environments.

The temperature and humidity conditions inside the MRI room were constantly monitored using the thermohygrometric probes installed by manufacturer inside the MRI room, while the ventilation was measured using an anemometer probe. In Table 1, the measured micro-climatic values are reported.

To measure temperatures accurately, the emissivity represents the most important parameter to correctly set.

The emissivity is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature. According to Watmough [32], the emissivity of a surface of a wavelength  $\lambda$  and a view angle  $\beta$  is given by Eq. 3:

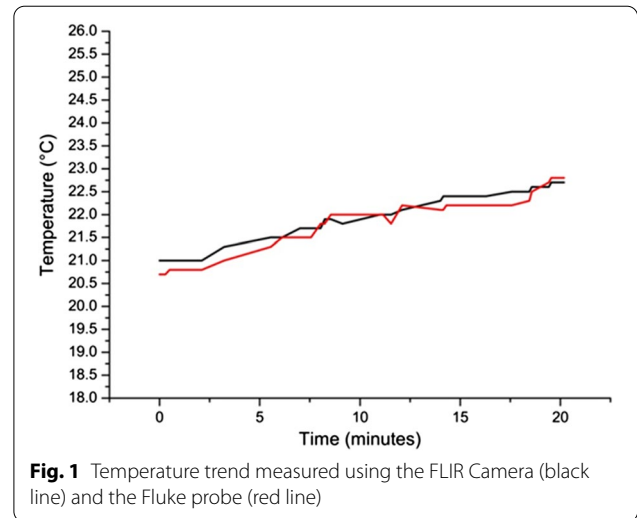
$$\varepsilon_{\phi,\lambda} = 1 - \left[ \frac{1}{2} \left( \frac{\beta - \cos(\phi)}{\beta + \cos(\phi)} \right)^2 \right] \left[ 1 + \left( \frac{\beta \cos(\phi) - \sin^2(\phi)}{\beta \cos(\phi) + \sin^2(\phi)} \right)^2 \right] \quad (3)$$

where  $\beta$  is defined as:

$$\beta = \sqrt{n_{\lambda}^2 - \sin^2(\phi)} \quad (4)$$

**Table 1** Micro-climatic values stored inside the MRI rooms

	3.0 T	1.5 T
Temperature ( $^{\circ}\text{C}$ )	$20.0 \pm 0.5$	$20.5 \pm 0.5$
Humidity (%)	$48 \pm 2$	$51 \pm 2$
Air flow (m/s)	$2.5 \pm 0.5$	$2.2 \pm 0.5$



**Fig. 1** Temperature trend measured using the FLIR Camera (black line) and the Fluke probe (red line)

where  $n_{\lambda}$  = refractive index. The emissivity value was set by using the database reported in [33]. The acquisition of thermal images was performed during MRI scans. The camera acquired one image every 15 s. Total acquisition time was about 20 and 27 min for head and body scans, respectively. The FLIR T440 resolution was equal to  $\pm 0.1\text{ }^{\circ}\text{C}$  and the accuracy  $\pm 2\%$  of the reading [33]. All the acquired images were stored in.TIFF format for later post-processing and the analysis of the raw data was performed by using the FLIR tools available on the dedicated software. The post-processing analysis was conducted to evaluate temperature variations. For each acquired image, three regions of interest (ROI) were selected and tracked over time. The segmentation of ROI intends to separate the main part from the rest of the image [34]. Using Area Tool of the software, the three circular ROIs were located on different coils positions in the images; in particular ROIs 1, 2 and 3 were located on the left, medium and right region, respectively, of each coil image. The average temperature profile of each ROI versus time was then evaluated.

**Results**

To assess the compatibility of the two different probes, 3.0 T Philips Achieva MRI head coil temperature was measured, during a routinely scan, by placing both probes simultaneously in the same position, consistently with their physical dimensions. The results of the measurements are presented in Fig. 1. The Wilcoxon test was used to evaluate the consistency of the experimental data presented in Fig. 1 and the resulting confidence level of  $p=0.59$  made it possible to conclude that there were no significant differences between the

measurements obtained from the two different instruments. Having assessed the consistence of the probes, for practical reasons, the remaining measurements were conducted using only the FLIR T440 Camera in order to obtain data on a large image and not only from a single spot. Thermal images were acquired throughout MRI routinely scans, carried out during periodic QCs.

Visible and IR images of both head and body coils of the 3.0 T Philips Achieva MRI are depicted in Fig. 2. In the same figure, the ROIs used for evaluating temperature profile are also highlighted.

The average temperature profile versus time of each ROI pointed out on the 3.0 T MRI head coil is shown in Fig. 3a, whereas Fig. 3b reports the average temperature versus time trend of the ROIs. In particular, in Fig. 3a and b black, red and blue lines are referred to ROIs enumerate 1, 2 and 3, respectively, depicted in Figs. 2a and c.

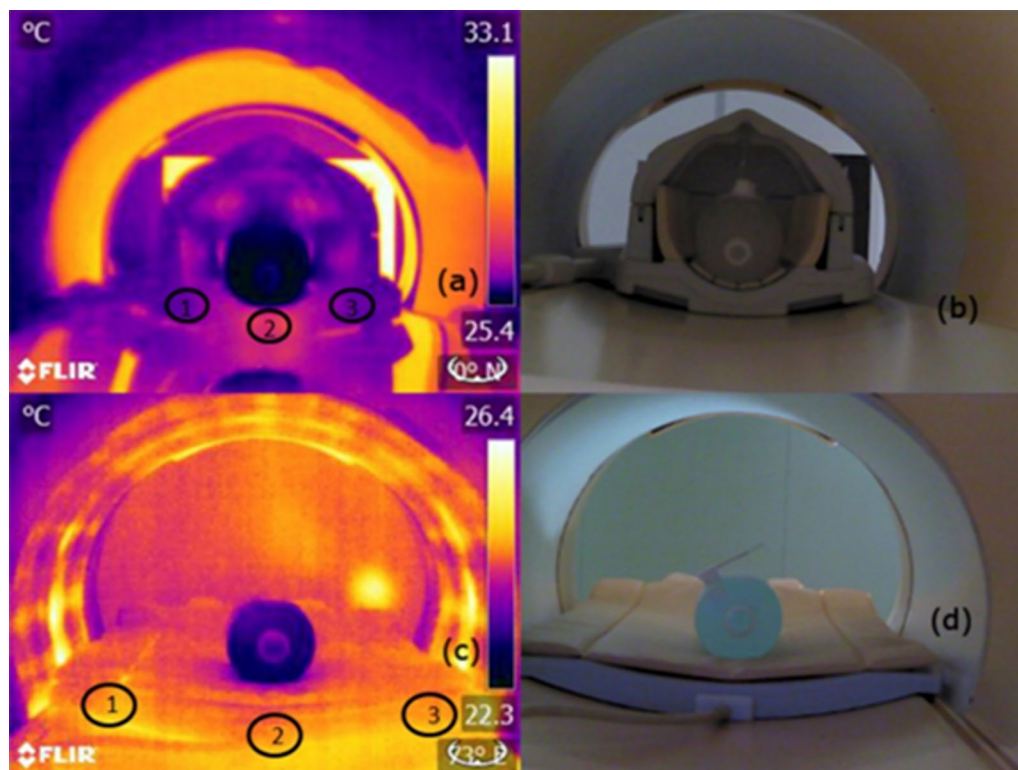
Figure 4 shows visible and infrared images of the 1.5 T MRI body coil. In this case, a hot spot was noticed during QCs in the left region of the body coil. Figure 5a reports the average temperature versus time trend of the ROIs located in different positions of the 1.5 T MRI body coil.

In particular, the black line indicates the average temperature over time trend of the ROI located on the hot spot. The hot spot trend was also compared with the ROI 2 (red line) and the ROI 3 (blue line). In this case, the ROI 2 was positioned on the coil amplifier (following the manufacturer technicians' indications) and the ROI 3 on the right side of the body coil.

In Fig. 5b, the curve trend of the temperature over time of the ROIs depicted on the head coil, always used on the same scanner, is reported; black, blue and red lines are referred to ROI 1, 2 and 3, respectively.

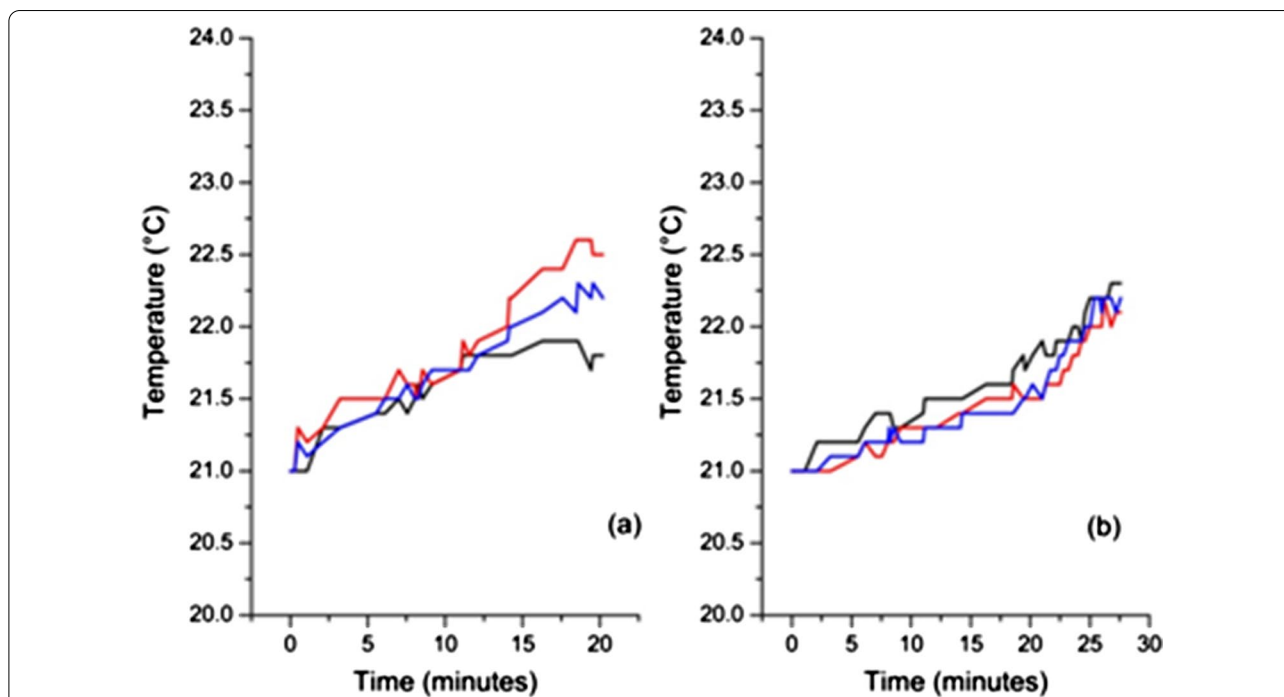
**Discussion**

The obtained results highlighted that no differences in temperature were noticed when both the head and body coils available on the 3.0 T Philips Achieva scanner were monitored. In particular, the maximum temperature rise was equal to 1.5 °C when the head coil was monitored and 1.0 °C when the body coil was tested. The scenario changed when the body coil in use on the 1.5 T Philips Intera scanner was analyzed using the thermal camera. The IR camera revealed an unusual behavior and, during QCs, a high-temperature

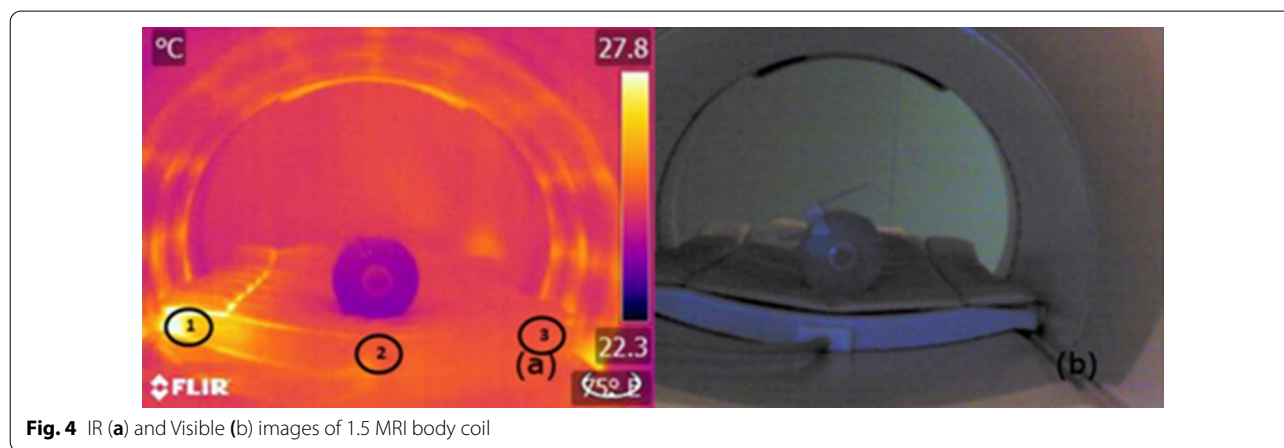


**Fig. 2** Visible and IR images of MRI coils: **a** IR image of 3.0 T MRI head coil, in which are highlighted the three ROIs used in temperature trend evaluation. **b** Visible image of 3.0 T MRI head coil. **c** IR image of 3.0 T MRI body coil and the three ROIs for temperature assessment. **d** Visible image of 3.0 T MRI body coil





**Fig. 3** The temperature over time trend of 3.0 T MRI head and body coils: **a** head coil: the temperature trend of the three ROIs (ROI 1 black, 2 blue, 3 red) depicted in Fig. 2a. **b** Body coil: the temperature trend of the three ROIs (ROI 1 black, 2 blue, 3 red) depicted in Fig. 2c

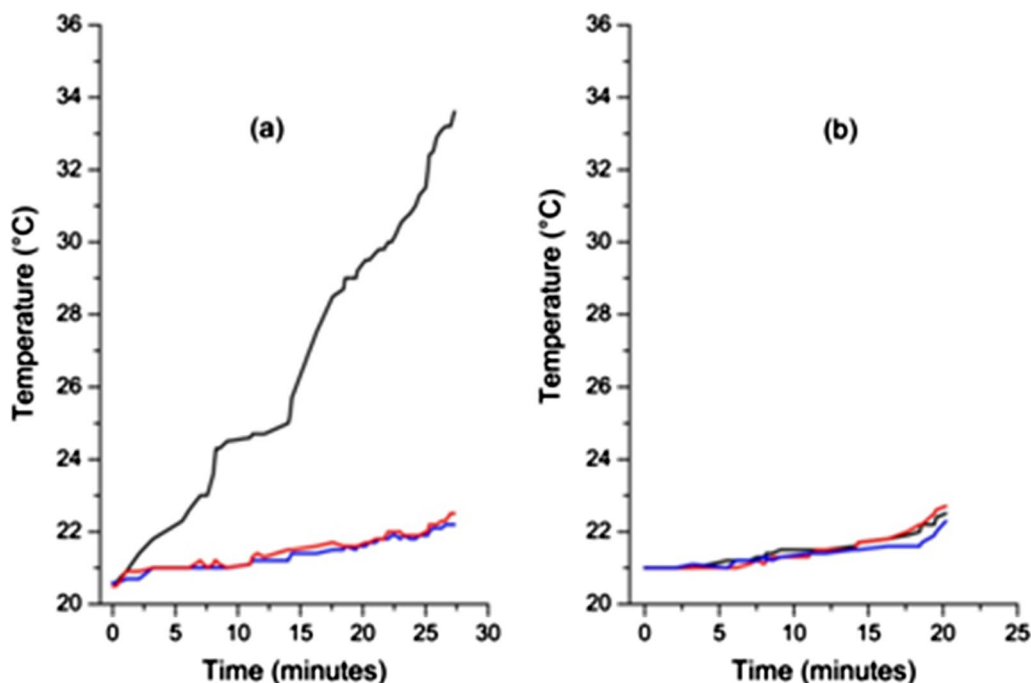


**Fig. 4** IR (a) and Visible (b) images of 1.5 MRI body coil

spot appeared in the IR images, far from coil amplifier. The temperature rise of the hot spot is equal to 12 °C, whereas the ROIs located on the coil amplifier and on the right side of the coil showed a temperature increase of 1.5 °C. The high-temperature spot appeared only on the body coil, which subsequently inspected, showed a failure. In fact, a maximum temperature increase of only 1.5 °C was observed, when the head coil has been mounted on the MRI scanner and analyzed by using the thermal camera.

Always using the images acquired by using the thermal camera, it was possible to observe that on the surface of the phantom, there were no variations in temperature and therefore it was possible to conclude that no thermal variation was due to the SAR.

In addition, in order to evaluate the performance of the MR system, the SNR was evaluated on the images acquired by using MR scanner and the obtained results were compared with those found during previous QCs measurements. It was possible to observe a slight



**Fig. 5** Temperature over time trend of body and head coil of the 1.5 T MRI equipment. **a** Black line represents the hot spot temperature trend, red and blue lines are related to ROIs centered on the coil amplifier and on the right area of the coil image, respectively. **b** Temperature trend of the ROIs depicted on the head coil image

decrease in the SNR, such as not to invalidate the diagnosis, and not attributable to a malfunction of the coil; in fact, it can suffer from systematic errors due to scanner instabilities [35].

### Conclusions

The aim of this experiment is to propose a non-contact thermography modality in order to evaluate the MRI coils proper functioning as a simple approach could be added to a QA program. To the knowledge of the authors, this is the first study where a thermal camera is used to conduct QCs on MR coils. Such procedure does not affect image quality, but it examines coils functionality and, consequently, patient wellness during MR scans. Besides it is possible to identify the source of eventual equipment malfunction, pointing to preventive or immediate maintenance requirements in order to manage QCs and the identification of image degradation. IR non-destructive tests are used to reveal surface defects of manufactured products, and thermal camera is used by coil manufacturers during the final testing phase to identify hot spots. This study implies the use of a thermal camera inside a MRI room during routinely QCs, when no patient is inside

the gantry. Thermal camera represents a non-contact and non-invasive technique and the interpretation of pseudo-colors thermal images is fast and easy without further elaborations. This is a real-time technique which enables monitoring of dynamical variations of surface temperature and it is suitable for repeated use. In this experiment, the feasibility and the relevance of thermography, during routinely QCs, have been demonstrated. A coil malfunctioning was in fact found and also the manufacturer's tests revealed a non-proper operating of the RF body coil under investigation. In this context, the temperature increase could be a significant risk to produce severe discomfort in patients.

The MRI is considered by the research and medical community to be safe for workers when compared to other more invasive image modalities [36]. Various hazards nevertheless can be associated with the use of MRI diagnostic for patients that are exposed to a combination of static, gradient and RF fields and their consequence [37]. Besides, if magnet is superconductive, presence of cryogenic gas is also dangerous.

The authors believe that any initiative for patient safety is useful and can be included in a program of MRI Quality Assurance.

**Abbreviations**

MRI: Magnetic resonance Imaging; RF: Radiofrequency; QA: Quality assurance; QC: Quality control; SAR: Specific absorption rate; IR: Infrared; NIR: Near infrared; MIR: Medium infrared; FIR: Far infrared; ROI: Region of interest.

**Acknowledgments**

Not applicable

**Authors' contributions**

GA contributed to conceptualization; GA, BT, CS contributed to design of the work; FMS, LD, SG contributed to analysis; GA, ER contributed to acquisition; GA, BT drafted the work; ER revised the manuscript. All authors have read and approved the submitted version of the manuscript and have agreed both to be personally accountable for the author's own contributions and ensure that questions related to the accuracy or integrity of any part of the work. All authors read and approved the final manuscript.

**Funding**

This research received no external funding.

**Availability of data and materials**

Not applicable.

**Declarations****Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare that they have no competing interests.

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Received: 31 May 2021 Accepted: 11 November 2021

Published online: 16 November 2021

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