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Activity Reference Number:

A20(26) 2029

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Article(s)

Systematic review of MRI safety literature in relation to radiofrequency thermal injury prevention

Speciality

MRI

Profession(s)

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Radiologist

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REVIEW ARTICLE

Systematic review of MRI safety literature in relation to radiofrequency thermal injury prevention

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Keywords

Adverse events, magnetic resonance imaging, physics, radiographer, research – systematic review

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Received: 23 January 2024; Accepted: 17 May 2024

J Med Radiat Sci **71** (2024) 445–460

doi: [10.1002/jmrs.800](https://doi.org/10.1002/jmrs.800)

Abstract

Introduction: Magnetic resonance imaging (MRI) is a rapidly evolving modality, generally considered safe due to lack of ionising radiation. While MRI technology and techniques are improving, many of the safety concerns remain the same as when first established. Patient thermal injuries are the most frequently reported adverse event, accounting for 59% of MRI incidents to the Food and Drug Administration (FDA). Surveys indicate many incidents remain unreported. Patient thermal injuries are preventable and various methods for their mitigation have been published. However, recommendations can be variable, fragmented and confusing. The aim of this systematic review was to synthesise the evidence on MRI safety and associated skin injuries and offer comprehensive recommendations for radiographers to prevent skin thermal injuries.

Methods: Four journal databases were searched for sources published January 2010–May 2023, presenting information on MRI safety and thermal injuries.

Results: Of 26,801 articles returned, after careful screening and based on the eligibility criteria, only 79 articles and an additional 19 grey literature sources were included ($n = 98$). Included studies were examined using thematic analysis to determine if holistic recommendations can be provided to assist in preventing skin burns. This resulted in three simplified recommendations:

- Remove any electrically conductive items
- Insulate the patient to prevent any conductive loops or contact with objects
- Communicate regularly

Conclusion: By implementing the above recommendations, it is estimated that 97% of skin burns could be prevented. With thermal injuries continuing to impact MRI safety, strategies to prevent skin burns and heating are essential. Assessing individual risks, rather than blanket policies, will help prevent skin thermal injuries occurring, improving patient care.

Introduction and rationale

Magnetic resonance imaging (MRI) is considered a relatively safe imaging modality, which produces excellent soft tissue

contrast, using no ionising radiation unlike X-ray or computed tomography (CT).¹ It is not without safety issues, however, with patient burns being the most frequently reported adverse event (59% of reports to the Food and

Drug Administration (FDA)² and 47% to the Medicines and Healthcare products Regulatory Agency (MHRA)³. These burns can be caused by; radiofrequency (RF) deposition, eddy currents, contact with an object (unsafe or incorrectly used electrically conductive item), contact with the individuals own skin, or even the bore wall.⁴

Published case reports of MRI burns exist from as far back as 1989.⁵ These burns are unpredictable and while some are instantaneous after MRI exposure, other significant burns may manifest even 24 h after MRI scanning.^{6,7} Severity ranges from 1st to 4th degree burns, such as small blisters⁸ up to severe burns requiring amputations.⁹ Table 1 below summarises numbers of reported thermal injuries globally over different time periods and some of the commonly assumed causes. However, Kihlberg *et al.*¹⁰ found MRI incidents are severely underreported by 1/3 and Rogg¹¹ suggests this is due to voluntary reporting, indicating potentially many more unreported incidents. Gilk and Kanal¹² analysed adverse events reported to the FDA in 2009 and 2010 and found that 97% of burns may have been prevented following ACR guidance from 2007.¹³ The ACR document is one of many published by various MRI safety advisory bodies that radiographers use to guide practice,¹⁴⁻¹⁶ however, the advice and recommendations are not required to be followed as MRI safety practise is not mandated.¹² There have been reviews of patient burns which have been reported to, and recorded by, organisations' mandatory safety reporting systems^{2,7} and there are many studies into the theoretical mechanisms of such burns.^{17,18} Tang and Yamamoto⁴ have investigated the factors associated with MRI related burns. However, to date, no comprehensive review of international safety recommendations to prevent MRI induced skin burns exists.

This article focuses on the risk of skin burns and heating associated with patient positioning causing contact with either external electrically conductive items, the patient's own skin or bore wall. It is beyond the scope of this article to address implant heating, interventional or special MRI applications (Radiation Therapy planning/or coupled with Positron Emission Tomography), field strengths over 3 T, vertical fields or core temperature changes.

Aim

The aim of this systematic review is to synthesise published information on MRI burns and safety-related guidance to develop comprehensive safety recommendations for best MRI practice to prevent burns. This article aims to guide radiographers, using published best practice documentation, to make, patient tailored, informed decisions.

Methodology

A systematic review was performed across multiple databases and grey literature sources to obtain all literature associated with MRI safety and burns. This included the physical principles and explanations for burns caused by MRI, and general guidance, policy statements, original research, protocols, recommendations, reviews and case reports.

Protocol

This systematic review was conducted with guidance from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.²⁴ The review was registered with PROSPERO.²³ The database search was initially run on 9th March 2022 and repeated on 17th May 2023. Two reviewers performed title and abstract screening using Covidence²⁵ with 100% agreement (0 conflicts). The second reviewer suggested expanding the inclusion criteria to include case reports as these are often used by the radiographer community as a reference source. After first reviewer completed full-text review, the second reviewer repeated this on a selected sample of 32% of the data with 0 conflicts. Data extraction was completed by the first reviewer only.

Sources of Information

The selected databases were PubMed, Scopus, CINAHL and Science Direct. Guidelines and manuals were further sourced in grey literature, related textbooks and online sources. These databases were selected for their strong medical and scientific content.

Eligibility criteria

Eligibility criteria applied to the search were limited to English language and publication date from 01 January 2010 until 17th May 2023. This start date was selected as a 'neat' date and then final date was just prior to final data analysis. Full inclusion and exclusion criteria are shown below in Table 2.

Search strategy

The search strategy concepts were 'MRI' and 'safety' or 'burns'. The key concepts were expanded to include search terms shown in Table 3 and combined with Boolean operators with relevant truncation and adjustments for each databases's thesaurus (MeSH terms vs. subject headings). The words 'best practice', 'guideline', policy, 'protocol' and 'white paper' were not used as the inclusion of these could have excluded

Table 1. Reported burn and thermal injury adverse events reported in US, UK, Japan, Australia and Denmark over different time periods referenced to total MRI exams over the same period. This data is sourced and synthesised from.^{2,3,4,7,19,20,21,22}

Country year (reference)	United States 1997–2009 ⁷	United States 2008–2017 ²	United Kingdom 1993–2014 ¹⁹	United Kingdom 2012–2021 ³	Japan < –2010 ⁴	Australia 2010–2022	Denmark 2015–2017 ²⁰
Contact with an object	58	257	53	11	79	7	-
Skin-to-skin contact	46	147	39	31	49	7	-
Bore contact	105	97	-	-	12	1	-
Unclear	150	348	39	55	9	14	5
Total events	419	849	131	97	149	29	5
Total MRI exams this period (reference)	278 million ²¹	335 million ²¹	26 million from 1995 to 2014 ²²	28 million in NHS England ²²	14 million in 2014 alone ²¹	10 million ²¹	1.4 million ²¹

Table 2. Full inclusion and exclusion criteria used for screening.

	Inclusion	Exclusion
Study type	• Original research • Commentaries • Review documents • Editorials • Systematic Review	• Conference abstracts • Randomised control trials – disease/treatment associated • Published book reviews – original book sought for grey literature • Where no full-text available
Type of MRI	• Clinical-human/animal • Research-human/animal/phantom • Virtual/simulations	• Ultra-high field (e.g., 7 T) • Interventional/intraoperative • Radiation Therapy • Nuclear Medicine/PET • MR guided High Intensity Focused Ultrasound (HIFU) • Functional MRI • Vertical field
Primary Theme	• MRI safety • MRI burn prevention	• MRI contrast agents • Sedation techniques in MRI • Active implants • Passive internal implants • Occupational exposure (static field, RF, noise) • Exposure limits (static field, RF) • Sequence developments • Coil developments • Disease, condition or pathological process – treatments, diagnosis, prognosis etc • Drug or clinical trials for above • MRI of clinical burns (diagnosis of) • MRI in pregnancy
Population demographics	• Humans (all ages) • Animals • Virtual human simulations	
Types of outcomes	• Document/paper/article that addresses safety in MRI	• Developing/quality of training programs
Language	• English	• All others
Dates	• 1 January 2010–17 May 2023	

Table 3. Search strategy used for Pubmed with each row using OR and Concept 1 and 2 combined with AND.

	Concept 1 all OR	AND	Concept 2 all OR
Concept	MRI		Burns
Keywords used	MR imaging		Burn
[Title/Abstract]	Magnetic resonance imaging		Safety
	Magnetic resonance MRI		Adverse event
			Adverse incident
			Thermal effect*
			Thermal injur*
			Rf burn
			EMF burn
MESH terms	Magnetic Resonance		Burns
[MeSH]	Imaging		Patient safety
Limiters	("2010/01/01"[Date – Publication]: "2023/05/17"[Date - Publication]) AND (English[Language])		

physics and reference material not containing these phrases. Full electronic search strategy for PubMed is available on request. The search was open to include case studies, qualitative papers and the preferred results would include white papers. Further refinement was applied during screening using the inclusion and exclusion criteria. De-duplication was performed in Covidence, a web-based systematic review management software.²⁵

Study selection and synthesis

Screening was performed in Covidence²⁵ at title and abstract level, with criteria shown below in Table 2 There were no population-specific demographics specified, as burns have been reported from young children⁹ to adults²⁶ and the same burn prevention strategies would also apply to animals in a veterinary or research situation.

Articles that were deemed relevant were then searched as full text against the eligibility criteria. The selected studies had to either be focused on MRI burn prevention or MRI safety.

Grey literature provided the remainder of the results. This included hand searching of reference lists, as well as dedicated searching of relevant industry publications, professional bodies’ and MRI learned societies’ guidance and recommendations. The International Society for Magnetic Resonance in Medicine (ISMRM)²⁷ list of international MRI safety documentation was also explored. Several primary textbooks were also reviewed and relevant chapters on safety were included. A final review by the authors was performed to ensure no important documents were omitted.

Data extraction and synthesis methods

Data was extracted using Covidence software and a customised data extraction template adapted from the

Cochrane Handbook.²⁸ Study characteristics including title, primary author, country, year, and study type. The aims and specific outcome questions were summarised. Two authoritative recommendation lists^{29,30} were employed to compile the 12 reference recommendations for which data items were collected. The sources were compared against this reference document and if they mentioned these recommendations, this data was collected. The original 12 data items were:

1. Change into gown or scrubs
2. Remove unnecessary metallic or electrically conductive items
3. Only trained staff should use and scan only MR acceptable items, following manufacturer instructions for MR conditional devices
4. Follow MR Safe/Conditional criteria for implants/ devices
5. Check integrity of all equipment, remove any damaged/unplugged/unused equipment, maintain equipment
6. Positioning of necessary electrically conductive materials
7. Padding to avoid contact; skin-to-skin, bore wall, electrically conductive materials
8. Awareness of resonant length conductors – specific to each field strength
9. Use lowest possible SAR
10. Monitor the patient during the MR procedure and respond to appropriate alerts
11. Recognise metal image artefacts early
12. Monitor and alert patients to concerns related to tattoos

After extraction was completed in Covidence, data was exported to a spreadsheet for data synthesis. Themes were identified using thematic analysis and similar recommendations were combined to create a final nine themes. Responses for each of the nine themes were copied to individual sheets as distinct data sets and filtered for positive responses. These were then analysed, and commonalities were coded using thematic analysis.³¹

Risk of bias assessment

The risk of bias assessment was performed using the Joanna Briggs Institute (JBI) Checklist for Text and Opinion and applied within the Covidence software.³² This checklist was suitable for the search results which contained a variety of papers including reviews, white papers and text and opinion pieces.³³ Each of the six elements of the checklist were entered into Covidence and during extraction, ‘yes’, ‘no’, ‘unsure’ or ‘not applicable’ were selected and a final decision of include or exclude were selected.

Results

Study selection

Total search results were 26,801 and 15,241 after duplicates removed. A detailed PRISMA flow diagram can be seen in Figure 1. Title and abstract screening reduced this to 201 for full-text review. After full-text review, 79 peer-reviewed papers were included, and an additional 19 grey literature sources resulted in 98 total sources.

Study characteristics

The key study characteristics are available in tabular format in Table S1. Of the final 98 sources included, 23 were considered guidance documents, manuals or recommendations, 23 were reviews, 11 were textbook chapters, 3 were commentaries, 5 were text and opinion while there were 7 experimental and 3 quantitative studies, 22 case reports and 1 other. Refer to Table 4 for the study characteristics. The publication year range was from 2010 to 2023 and included studies were from USA ($n = 50$), other countries (Belgium, Canada, Denmark, Europe, Finland, France, Germany, India, Jordan, Korea, Macedonia, New Zealand, South Africa, The Netherlands

and Turkey) ($n = 28$), United Kingdom ($n = 10$), Australia ($n = 5$), and Japan ($n = 5$). Most papers were written in relation to human imaging ($n = 89$) while others were written about animal imaging ($n = 3$), phantoms ($n = 3$) and results from virtual human simulations ($n = 3$). Of the papers written about human imaging, there was one dedicated to neonatal imaging.

Table 4. Key characteristics of sources found.

Literature type	Number of sources (References)
Guidance documents, manuals or recommendations	23 ^(6,14,15,16,53,65,68,70,71,103,104,105,110,113,116,118,119,125,127,132,133,139,158)
Reviews	23 ^(1,2,4,11,30,37,43,66,73,94,111,112,117,120,121,123,124,126,128,133,135,154,155)
Case Reports	22 ^(8,26,35,36,52,59,87,90,93,95,96,136,137,140,141,142,143,145,146,147,148,152)
Text book chapters	11 ^(29,44,47,69,106,107,108,109,117,129,130)
Experimental studies	7 ^(18,82,114,138,149,151,153)
Quantitative studies	3 ^(144,150,159)
Text and opinion	5 ^(67,115,134,156,157)
Commentary	3 ^(76,120,122)
Other	1 ⁽¹⁰¹⁾

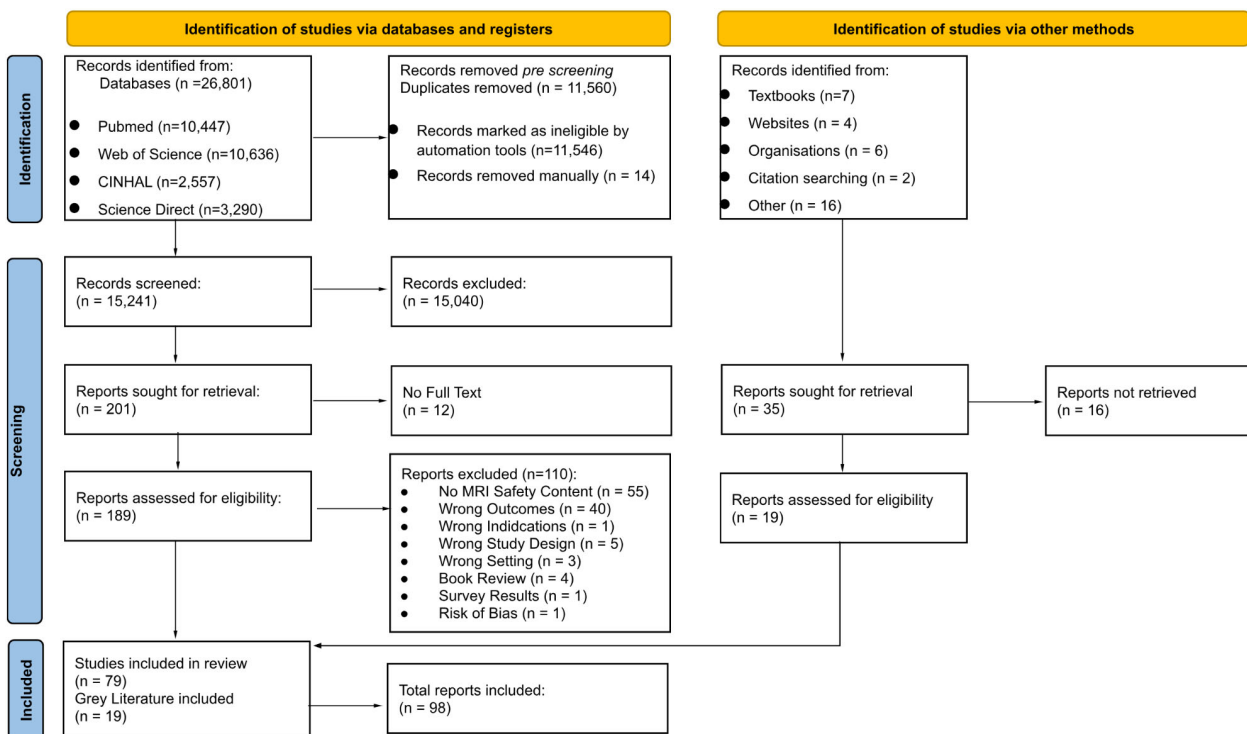


Figure 1. PRISMA diagram showing screening and final included numbers. From: Page et al.³⁴ For more information <http://www.prisma-statement.org/>.

Table 5. Summative table of results per primary theme and corresponding percentage of reporting of each topic within each theme.

Primary Theme	Results
Change patient into gown	44% recommended gowns 19% were concerned about metallic fibres in the fabric 11% were concerned with metallic components (zips, clasps etc) 4% were concerned about pockets and potentially hidden items
Remove unnecessary metallic or electrically conductive items	64% of papers discussed the process of acknowledging and removing excess items
Check integrity of all equipment	21% mentioning (either or both) removing damaged/unused equipment and/or checking or maintaining equipment 18% mentioned damaged coils/insulation 4% instructed to remove unplugged equipment 4% advised to remove equipment if it was not working 16% recommended regular inspection/maintenance
Positioning of necessary electrically conductive equipment	35% had recommendations for the positioning of necessary electrically conductive items 12% mentioned keeping electrically conductive materials down the centre of the bore in the z axis 22% recommended avoiding loops 28% mentioned preventing cables touching the patient 6% specifically mentioned external fixation or prosthesis
Awareness of resonant length	18% mentioning resonant length or frequency
Patient padding	55% discussed padding to prevent ‘something’ contacting the patient 46% of papers recommended avoiding skin-to-skin contact or closed loops 32% recommended padding between the patient and the bore/transmit RF coil 13% recommended padding between the patient and electrically conductive materials including coils, cables, monitoring etc
Monitor patient	45% included instructions to monitor patient
Awareness of artefacts	15% warned about unexpected artefacts
Awareness of tattoos	38% mentioned tattoos

Risk of bias results

The risk of bias results are available upon request. One article was excluded during critical appraisal due to insufficient reference to extant literature. All other sources met criteria sufficiently to be included.

Data synthesis results

During data synthesis, the sourced papers fitted in the following nine primary themes as can be seen in Table 5 above.

Discussion

There was limited consensus between all 98 sources found in the systematic review. Using scientific rationale guided by the results of the systematic review, the following sections will endeavour to provide guidance for radiographers to prevent RF-induced patient burns.

Change patients into a gown

There were many papers concerned about the risk of clothing containing metallic fibres to cause patient burns.³⁵⁻³⁷ The increasing use of silver or copper for their antimicrobial properties in athletic wear, underwear and socks increases the likelihood of MRI patients to be wearing such materials. While silver and copper are non-ferromagnetic, these materials are excellent electrical conductors and therefore the risk of induced current and subsequent heating does exist.³⁸ It should be noted that there are three distinct versions of fabric technology. One is where the silver fibres are part of the weave and components of the manufacturing process, while the other options are a ‘treatment’ to where either the polymer fibres or, the completed fabric is sprayed with microscopically small silver or copper ions.³⁹ There is yet to be any research to demonstrate the difference between these in terms of burns risk. As there is no requirement for manufactures to disclose impurities and no way to detect these fibres or

fabric treatments, changing into facility approved gowns or scrubs is an effective way to reduce the risk of a fabric-induced burn.³⁷ There is also a risk of heat-trapping with excess or inappropriate clothing, hindering a patient's normal thermoregulatory cooling system.^{26,37}

The recommendation to change into a gown or pocketless scrubs also avoids other metals potentially fixed to clothing, including fasteners. Pocketless scrubs will also remove the risk of unknown items carried in pockets.⁴³

It is generally considered that there is minimal risk of burns from small, non-ferrous metallic fasteners such as buttons less than 2 cm but they can cause artefact on the images.^{15,40} The FDA testing manual does not require testing of passive implants less than 2 cm and more than 3 cm from another passive implant.⁴⁰ However, this exclusion is not valid if part of the implant is outside the patient due to the heat conduction properties of the body.⁴⁰ Metal zips, if within the region of RF, may match the appropriate wavelength of the transmitted RF to result in resonance and induce heating in the conductor.⁴² There are also versions of wearable technology where the heart rate and respiratory sensors are built into the clothing.⁴¹ These would pose risks of burns from the antennae effects (resonance), device malfunction and image artefact.

The risk of burns due to clothing is only present when all or part of the item is exposed to the RF field and while many sources recommended changing into a gown, a facility may choose to only have patients remove clothing in or near the area exposed to RF during that scan.^{14,43} However, this may lead to patient confusion at subsequent examinations and a consistent policy reduces the risk of non-compliance.

Remove all unnecessary metallic or electrically conductive items

Contact with an object accounted for 257 thermal injuries reported to the FDA database between 2008 and 2017.² Many non-essential items should be removed for reasons beyond RF burns risks (such as induced currents due to exposure to gradient magnetic fields) and will not be further addressed.

Ferromagnetic detectors (FMDs) are increasingly seen as a tool to be used as an adjunct or 'final check' to ensure all ferrous materials have been removed prior to entering the magnet room.¹⁴ The ACR manual and MHRA safety guidelines recommend the use of FMDs as opposed to conventional metal detectors.^{14,15} These reduce the risk of projectiles and can detect some implants. However, there are many materials that are non-ferrous yet still electrically conductive, including

silver, copper and carbon fibre.⁴⁴ FMDs may provide a sense of security regarding the prevention of ferrous items entering the magnet room, but if non-ferrous items remain undetected, burns may still occur from this type of conductor.^{37,45} FMDs are an adjunct to and "not a replacement for a thorough screening practice" (¹⁴p12).

There is no consensus regarding wearing of jewellery. A practical approach would be to remove all jewellery where possible but if the patient is unable to easily remove it, permit non-ferromagnetic metals to be worn when not exposed to RF energies.⁴⁶ If exposed to RF, items should be assessed case by case.⁴⁷

There are wearable technologies designed to appear as rings⁴⁸⁻⁵⁰ that would be considered MR Unsafe due to electronics that could be damaged. Electrically conductive loops can be a cause of heating.⁵¹ As the heating effects of such small calibre loops, when exposed to electromagnetic fields, has been untested such devices should be removed. This would also eliminate any potential for image artefacts caused by such devices.

Hair extensions can contain metals and should be treated with caution as they may provide conditions for RF heating.^{52,53}

Drug and medication patches had highly variable recommendations. Applying a purely scientific approach, any patch not exposed to the RF poses no burns risk by either conduction, antennae or near field effects.^{6,54} A recent review⁵⁵ found that of 56 FDA-approved dermal drug patches, 13 had some metallic component while 6 had insufficient information to determine if metallic components were present. A site-specific protocol should be used. Guidance recommends medication patches should only be removed after consultation with the prescribing physician.^{14,16,56} On a practical level, informed patient consent and a cold compress may prevent excessive heating and increased drug delivery; however, caution remains around cooling strategies such as ice packs which may lead to a reduced drug delivery rate.¹⁴

Different studies have shown antimicrobial silver dressings to be safe to scan up to 3 T thus do not need to be removed, even if in the area of interest.^{57,58} However, the risks of thermal injury when large electrically conductive antimicrobial dressings are in place has not been tested and may warrant further research. There is one reported case of a burning sensation in the presence of zinc oxide ointment treatment where the scan was stopped before any burn could occur.⁵⁹

A recent surge in popularity of continuous glucose monitoring (CGM) and Flash Glucose Monitoring (Flash GM) for diabetes and even health and fitness purposes⁶⁰ have added another risk. Most of these devices are MR Unsafe and must be removed prior to scanning.⁶¹ These

devices typically have a 10-to-14-day use period and cannot be reused once removed.^{62,63}

There is also a lack of research regarding the heating risks of these devices. Adaptations to booking processes may be necessary to optimise booking the patient's scan to the end of their device's cycle to reduce unnecessary disposal.

Infectious diseases such as Covid-19 has highlighted the more frequent use of facemasks. If masks contain metal, they pose RF heating risks and some have been felt to be MR unsafe⁶⁴ and should be replaced with masks with no metal.⁶⁵

Most sources recommended removing unnecessary electrically conductive items wherever possible; however, there are some items that can be assessed on a case-by-case basis following department guidelines.

Check integrity of all equipment

This recommendation is designed to determine if equipment associated with the patient is properly maintained and to identify any damages or faults to ensure unsafe equipment is removed before scanning. Cracks and splits in insulation of cables can expose the patient to the internal wires and potentially create a conductive loop where burns could occur or even cause tissue or clothing to ignite.⁶⁶ Appropriate maintenance of certain equipment is conducted by manufacturers and the ACR requires annual RF coil quality control for accreditation purposes.⁶⁷⁻⁶⁹ Damaged, or malfunctioning equipment should be removed from the patient and taken out of service until inspected and repaired.^{29,47,70,71}

It is also important to remove any unplugged equipment from the bore during image acquisition to ensure active and passive detuning circuits, that block resonance induction, are functioning to prevent decoupling failure, coil damage and burns.^{67,72,73}

Adhere to conditions of all necessary electrically conductive materials

It is important that necessary electrically conductive items are MR Safe or MR Conditional and relevant instructions and conditions be followed.⁷⁴ MRI instruction for use manuals further reiterate that "it is the obligation of the MRI operator to be aware of these conditions and to ensure that these conditions are strictly adhered to."⁷⁴ It is particularly pertinent for patient monitoring devices such as ECG and pulse oximetry. MRI conditional devices will have adaptations, such as fibre optics, shielding, carbon electrodes and plastic coatings, that ensure the electrically conductive components have reduced risk of burns when used as per manufacturer's instructions.⁷⁵ All ECG and

other monitoring equipment associated with the patient should be considered MR Unsafe until checked. Only approved MR Conditional ECG electrodes and monitoring devices should be applied as per manufactures instructions by MRI trained staff.^{70,71}

There were several cautions against using blanket policies for clearing patients and scanning outside device labelling. Input from medical physicists, MRI Medical Director's amongst others, with written consent from the patient, are recommended when developing such policies. Consideration of manufacturer's recommendations and adequate staff training are also necessary to ensure all equipment and devices are used in a safe manner.^{16,76}

The recommendation to position necessary electrically conductive materials along the centre of the bore is to avoid the large RF intensity found at the edges of the bore.³⁰

It is also important to avoid forming any loops between electrically conductive materials. These materials could consist of ECG leads, coil cables, the scanner bore as well as the patient. These must be separated and insulated from each other^{16,69} to prevent resonant circuitry⁷² and capacitive coupling.^{6,70}

External fixation devices such as those for lower limbs and halo collars for the cervical spine may be MRI Conditional, however, it is important to recognise that these may be electrically conductive and contact with any other wires or cables should be avoided.⁷⁰ There were 11 reports of thermal injuries caused by stereotaxic headframes between 2008 and 2017.²

Awareness of unavoidable, potentially electrically conductive materials would also include surgical staples and bio-hacking implants such as RadioFrequency Identification (RFID) and Near Field Communication (NFC) devices. Provided the staples are non-ferromagnetic and outside the RF exposure field, the patient can be scanned without incident.¹⁴ However, if they are within the area of RF irradiation, warn the patient of potential heating and apply a heat sink.¹⁴ Patient bio-hacking involving NFC and RFID chips typically poses no major contraindications to MRI.⁷⁷ Several studies have shown RFID chips to be MRI Safe or Conditional with no loss of function and no concerning levels of heating but potentially large artefacts.⁷⁸⁻⁸¹ It should also be noted that RFID chips can be used as hospital ID, linen, access port or in breast implants and similar precautions should be used in these locations.⁸² Testing of Vivokey Spark 2 NFC devices found they pose no risk in MRI.⁸³ Any bio-hacking implant containing a magnet must undergo case-by-case assessment as these are generally unsafe.⁸⁴

Be aware of resonant length

Resonant heating can occur when the length of linear electrically conductive material matches the half wavelength of the MR field strength, which can vary depending on the surrounding material.^{4,17,30} This can occur very rapidly in a matter of seconds and is one of the suggested causes of tattoo burns.³⁰ Points to consider are

- conditions applicable at one field strength will not carry across to another³⁰
- only part of the conductor needs to be exposed to the RF for current to be induced.^{4,41,85}

Pad the patient to avoid contact burns

Skin-to-skin contact burns can happen anywhere on the patient, even beyond the RF field.⁸⁶ Contact burns accounted for 147 reported injuries to the MAUDE database between 2008 and 2017.² Fortunately, these are easily preventable.⁸⁶ Common locations are between the legs^{8,87,88} or finger and thigh.⁸⁹ These can be exacerbated by patient sweat and thus prevented by ensuring there is dry, water resistant, non-conductive material as guided by the manufacturer between any skin surfaces that may be in contact.⁸⁸ These loop burns can occur outside the RF and Tang *et al*¹⁸ performed modelling for thumb to thigh contact and this was measuring above the local SAR limit of 10 W/kg up to 70 cm from the isocentre.

Padding to protect patients' skin from touching the bore is necessary to prevent burns from near field effects. Reports exist of patients burning elbows⁹⁰ and the anterior abdominal wall.⁹¹ There are points along the wall of the bore where RF transmission is more concentrated, making burns more likely at these points if the patient is not properly insulated from the inner bore. For this effect, proximity to (rather than contact with) is critical so thicker insulation will work more effectively than a thin non-conductive pad. This heating may be exacerbated by large areas of contact not being able to cool through convection due to skin contacting the bore.⁹²

Forensic analysis by lawyers into burn risks and informed consent has shown that proper padding is so effective when used correctly, there is no need to inform patients of burns risk, however, it would be prudent to reiterate the importance of the padding to the patient to prevent movement.^{93,94}

Monitor patients during scanning

Many superficial burns such as those associated with tattoos and skin-to-skin contact are felt instantaneously

and the patient can alert the MRI radiographer to uncomfortable sensations promptly.^{94,95} It is suggested that burns induced by antennae effect occur so quickly the patient may not react in time to prevent it, however, stopping the scan can reduce the severity.⁹⁶ Conversely, burns associated with near field effects close to the bore often have a delayed reaction.⁶ There are case reports of burns where the patient felt discomfort during the procedure but did not alert the radiographers, assuming this was a normal sensation.^{8,97} Other instances, however, describe how the patients' alerts were dismissed and after the scan, burns were evident.⁹⁴ This emphasises the duty of care that radiographers have to communicate with their patients about potential risks and the importance of the call bell/buzzer if they have any discomfort.³⁷

External monitoring can assist to monitor a patient's condition during the scan (especially when they are uncommunicative) but used incorrectly, can increase the risk of burns and thus should be used as per manufacturer's instructions. MRI manufacturer instructions recommend examining the patient between sequences to check for localised heating and potential burns.⁷⁴

Be aware of artefacts as indicators of potential unknown foreign bodies

Radiographers should have an awareness of artefacts from the first localiser that appears on the screen. Artefacts could represent unknown foreign bodies, potentially electrically conductive materials or coil failures which could all potentially burn a patient.³⁵ Radiographers should be aware of and investigate artefacts immediately to prevent any burns occurring.³⁷

Be aware of tattoos and certain cosmetics exposed to the RF field

Tattoos have been linked with heating and RF burns.⁹⁸ It is proposed that the mechanism through which this occurs is via the antennae effect.⁴ However, it has also been suggested that the ferromagnetic pigments of some tattoos are actually interacting with the static field.⁹⁹ While 6 tattoo or permanent makeup incidents were reported to the FDA between 2008 and 2017,² other studies found no burns.^{100,101} A comprehensive literature review found only 17 published reports, all with full, fast recovery and no lasting sequelae.¹⁰² Tattoo reactions have been reported by patients instantaneously, so patients should be warned to squeeze the buzzer if any discomfort is felt and a cold compress may be applied if a tattoo will be exposed to RF.^{6,95} If the patient had reduced

communication capabilities, prophylactic application of a cold compress would be prudent.^{1,14,103,104} However, this should not be a wet towel which can create a conductive loop and risk of burns via this mechanism.⁴

Summary

Analysis of the final 9 recommendations reviewed, found that the following condensed proposals to “Remove, Insulate and Communicate” (RIC), encompass the essential actions to prevent skin burns and should be implemented in MRI practice, as presented in Figure 2 and Figure 3 below. These recommendations are derived from the systematic review and the guidance from many MRI safety experts. Padding patients, insulating them from conductive materials, removing unneeded conductive items from the bore as well as positioning patients to prevent large calibre loops, has been promoted by Gilk and Kanak.¹² They surmised that such actions could have prevented up to 97% of the burns that were recorded by the FDA over a 2-year period.¹²

Limitations

A systematic review of 98 different sources ranging from guidance manuals, textbooks, original research, white papers, articles, and virtual simulations provided a range of valuable independent recommendations. There were some overlaps with several distinct and reputable sources

all containing similar content and the same author.^{29,70,71} These were all included as evidence of common places radiographers will search for recommendations. The intermittent occurrence of MRI burns makes controlled trials and other in vivo experiments difficult, however, there are experimental studies using various phantoms and virtual human models. These were still mostly excluded from results unless they reviewed, commented on or proposed guidance/recommendations for safe MRI practices. There were limitations to the scope of the reviewed recommendations. As mentioned previously, this paper does not discuss any implanted or active devices and only horizontal fields up to 3 T and is targeted at preventing skin burns only. While the underlying principles are the same, further assessments are warranted for any other scenarios. Some recommendations are based on consensus, while others were formed using virtual modelling or a scientific approach. Other limitations include the biases and inherent theoretical and epistemological commitments of the researchers performing thematic analysis.³¹ A further limitation was the lack of evidence for the mechanism of burns occurring due to metal in fabrics. Further research is required to investigate whether metal-infused fabrics or those containing metal fibres are more problematic. Controlled experimentation with thermal cameras, phantoms and monitoring equipment could be performed to demonstrate heating and how burns from these materials occur.

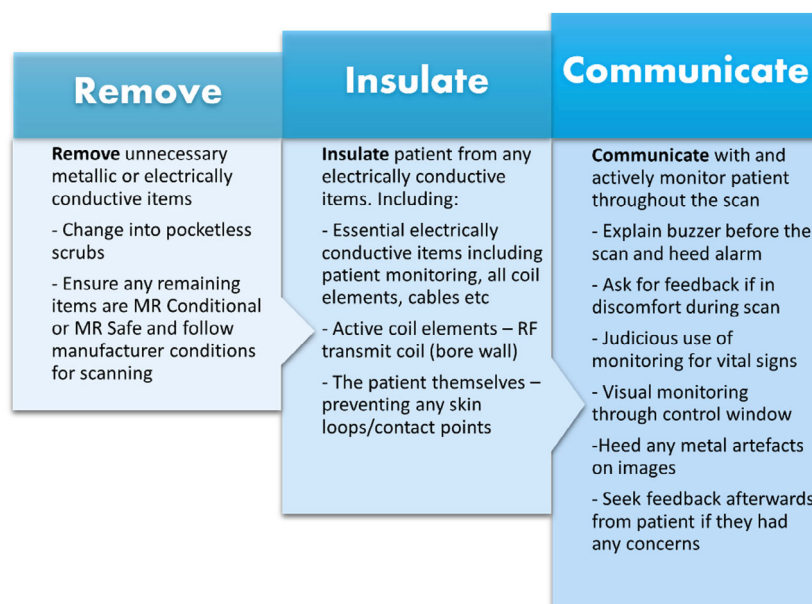


Figure 2. The acronym R.I.C. (Remove, Insulate, Communicate) can be used to prevent most skin burns in MRI based on the analysis of this review.

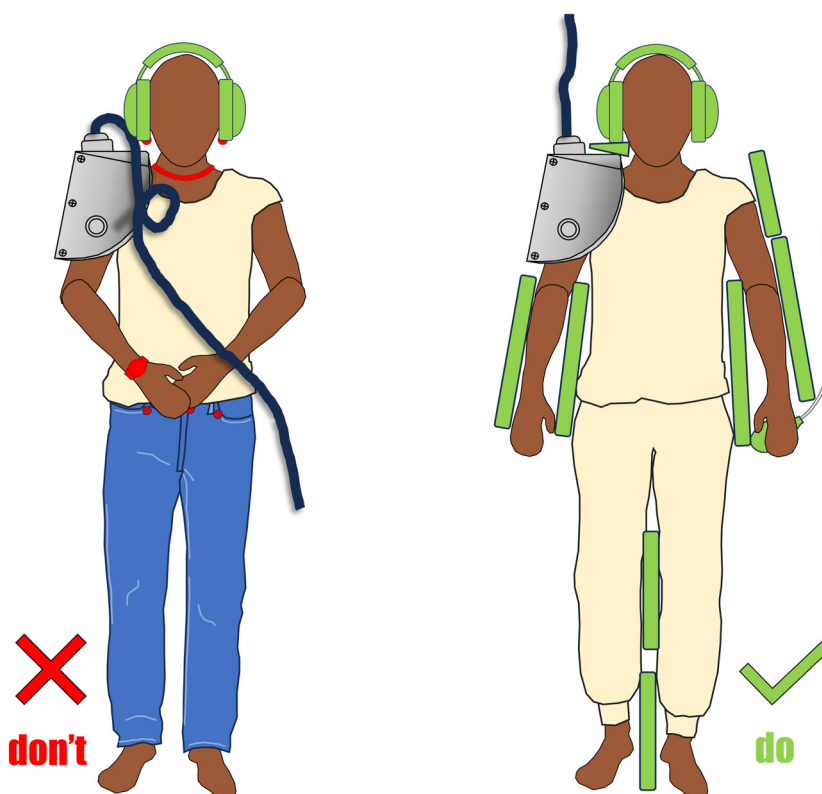


Figure 3. Do's and Don'ts to prevent most skin burns in MRI based on the analysis of this review. Figure shows a typical patient with a shoulder coil in place.

Conclusion

With thermal injuries accounting for the largest number of reported adverse events to regulatory bodies, strategies to prevent patient burns and heating are essential. Analysis of all recommendations reviewed and promoted are summarised with the acronym R.I.C., as described above. This could provide a simple method for training MRI staff on what actions are necessary to prevent patient skin burns caused by inappropriate practice.

Acknowledgements

The authors would like to thank Dr Emanuel Kanal MD, FACR, FISMRM, MRMD, MRSE, AANG for reviewing this article. And Dr Frank G. Shellock, Ph.D., FACR, FISMRM, FACC, Director of MRI Safety and Adjunct Clinical Professor of Radiology and Medicine, Keck School of Medicine, University of Southern California, Los Angeles, CA for his encouragement of this project.

Funding information

There was no funding for this study.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Mittendorf L, Young A, Sim J. A narrative review of current and emerging MRI safety issues: What every MRI technologist (radiographer) needs to know. *J Med Radiat Sci* 2021; **69**: 250–60.
2. Delfino JG, Krainak DM, Flesher SA, Miller DL. MRI-related FDA adverse event reports: A 10-yr review. *Med Phys* 2019; **46**: 5562–71.
3. Grainger D. MHRA update IPeM MR Safety 2021. Medicines and Healthcare products Regulatory Agency, United Kingdom, 2021.
4. Tang M, Yamamoto T. Progress in understanding radiofrequency heating and burn injuries for safer MR imaging. *Magn Reson Med* 2022; **22**: 7–25.

5. Shellock FG, Slimp GL. Severe burn of the finger caused by using a pulse oximeter during MR imaging. *AJR Am J Roentgenol* 1989; **153**: 1105.
6. Elster A. Thermal injuries: how do burns occur in MRI? Available from: <https://www.mriquestions.com/thermal-burns.html> (accessed June 14, 2022).
7. Hardy PT, Weil KM. A review of thermal MR injuries. *Radiol Technol* 2010; **81**: 606–9.
8. Tagell L, Alcheikh A, Jurevics R, Nair AP. Thigh burn – A magnetic resonance imaging (MRI) related adverse event. *Radiol Case Rep* 2020; **15**: 2569–71.
9. Haik J, Daniel S, Tessone A, Orenstein A, Winkler E. MRI induced fourth-degree burn in an extremity, leading to amputation. *Burns* 2007; **35**: 294–6.
10. Kihlberg J, Hansson B, Hall A, Tisell A, Lundberg P. Magnetic resonance imaging incidents are severely underreported: a finding in a multicentre interview survey. *Eur Radiol* 2021; **32**: 477–88.
11. Rogg J. Key elements of clinical magnetic resonance imaging safety: it takes a village. *Magn Reson Imaging Clin N Am* 2020; **28**: 471–9.
12. Gilk T, Kanal E. RSNA – MRI accidents and adverse events. 2012; Available from: <https://www.youtube.com/watch?v=c-iMRYXhlzg>.
13. Kanal E, Barkovich AJ, Bell C, et al. ACR guidance document for safe MR practices: 2007. *AJR Am J Roentgenol* 2007; **188**: 1447–74.
14. Kanal E, Greenberg T, Hoff MN, et al. ACR Manual on MR Safety. American College of Radiology, United Kingdom, 2020.
15. Medicines and Healthcare Products Regulatory Agency. Safety Guidelines for Magnetic Resonance Imaging Equipment in Clinical Use. 2021. Available from: <https://www.mhra.gov.uk>.
16. Royal Australian New Zealand College of Radiologists. MRI safety guidelines. 2021. Version 3. Available from: <https://www.ranzcr.com/college/document-library/mri-safety-guidelines>.
17. Dempsey MF, Condon B. Thermal injuries associated with MRI. *Clin Radiol* 2001; **56**: 457–65.
18. Tang M, Okamoto K, Haruyama T, Yamamoto T. Electromagnetic simulation of RF burn injuries occurring at skin-skin and skin-bore wall contact points in an MRI scanner with a birdcage coil. *Phys Med* 2021; **82**: 219–27.
19. Grainger D. MHRA MRI safety guidance: Review of key changes and emerging issues. *Imaging Oncol* 2015; 42–7. Available from: https://www.sor.org/getmedia/13566cb-8cac-4fc1-b183-8cd24f3a8285/io_2015_lr.pdf_1 Accessed January 10, 2024.
20. Blankholm AD, Hansson B. Incident reporting and level of MR safety education: A Danish national study. *Radiography* 2020; **26**: 147–53.
21. OECD Data. Magnetic resonance imaging (MRI) exams. 2021. Available from: <https://data.oecd.org/healthcare/magnetic-resonance-imaging-mri-exams.htm> (accessed June 16, 2022).
22. Performance Analysis Team. Diagnostic imaging dataset annual statistical release 2020–21. NHS. Available from: <https://www.england.nhs.uk/statistics/statistical-work-areas/diagnostic-imaging-dataset/diagnostic-imaging-dataset-2020-21-data/> (accessed November 18, 2021).
23. Baker C, Hewis J, Nugent B, Grainger D, Malamateniou C. Systematic Review of MRI Safety in Relation to Induced Patient Burns. PROSPERO: International prospective register of systematic reviews. 2022. Available from: https://www.crd.york.ac.uk/prospere/display_record.php?ID=CRD42022303629.
24. Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med* 2009; **6**: e1000097.
25. Veritas Health Innovation. Covidence systematic review software. Veritas Health Innovation, Melbourne, Australia, 2022. Available from: www.covidence.org.
26. Watari T, Tokuda Y. MRI thermal burn injury: an unrecognized consequence of wearing novel, high-tech undergarments. *QJM* 2018; **111**: 495–6.
27. International Society for Magnetic Resonance in Medicine. MR Safety Guidance, Documents and Links. Available from: <https://www.ismrm.org/mr-safety-links/mr-safety-resources-page/> (accessed June 18, 2022).
28. McKenzie JE, Brennan SE, Ryan RE, Thomson HJ, Johnston RV. Chapter 9: Summarizing study characteristics and preparing for synthesis. In: Higgins J, Thomas J, Chandler J, et al. (eds). *Cochrane Handbook for Systematic Reviews of Interventions* version 6.3. Cochrane, United Kingdom, 2022. Available from www.training.cochrane.org/handbook.
29. Shellock FG. Reference Manual for Magnetic Resonance Safety, Implants, and Devices. Biomedical Research Publishing Group, United States, 2020.
30. Stafford RJ. The physics of magnetic resonance imaging safety. *Magn Reson Imaging Clin N Am* 2020; **28**: 517–36.
31. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol* 2006; **3**: 77–101.
32. McArthur A, Klugárová J, Yan H, Florescu S. Innovations in the systematic review of text and opinion. *Int J Evid Based Healthc* 2015; **13**: 188–95.
33. Ma L, Wang Y, Yang Z, Huang D, Weng H, Zeng X. Methodological quality (risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better? *Mil Med Res* 2020; **7**: 7.
34. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021; **372**: n71.
35. Tokue H, Tokue A, Tsushima Y. Unexpected magnetic resonance imaging burn injuries from jogging pants. *Radiol Case Rep* 2019; **14**: 1348–51.

36. Pietryga JA, Fonder MA, Rogg JM, North DL, Bercovitch LG. Invisible metallic microfibre in clothing presents unrecognized MRI risk for cutaneous burn. *Am J Neuroradiol* 2013; **34**: E47–50.
37. Styan T, Hoff M. The dangers of fabric in MRI. *Curr Probl Diagn Radiol* 2023; **52**: 6–9.
38. Jersey C. List of conductors. Available from: <https://sciencing.com/list-conductors-8716914.html> (accessed August 12, 2022).
39. Ionic+ mineral antimicrobial product sell sheet. Available from: <https://noblebiomaterials.com/wp-content/uploads/2021/05/noble-ionicmineral-antimicrobial-product-sell-sheet.pdf> (accessed July 25, 2022).
40. Food and Drug Administration. Testing and labelling medical devices for safety in the magnetic resonance (MR) environment. (accessed May 19, 2021).
41. Andrei M. This smart T-shirt uses carbon to double as a heart monitor. 2021. Available from: <https://www.zmescience.com/science/this-smart-t-shirt-uses-carbon-to-double-as-a-heart-monitor/> (accessed September 19, 2022).
42. Dempsey MF, Condon B, Hadley DM. Investigation of the factors responsible for burns during MRI. *J Magn Reson Imaging* 2001; **13**: 627–31.
43. Stikova E. Magnetic resonance imaging safety: principles and guidelines. *Prilozi* 2012; **33**: 441–72.
44. Schaefer G, Melzer A, Pozos RS. Chapter 26 Devices and Materials in MRI. Springer Handbook of Medical Technology, 1. Aufl. edn, Springer, Germany, 2011.
45. Elster A. Metal detectors. Available from: <http://mriquestions.com/metal-detectors.html> (accessed August 18, 2022).
46. Shellock F. Safety topic/article 239: Body piercing jewelry and MRI safety. 2022.
47. Foster L, Tanenbaum LN, Crues JV. MRI Bioeffects, Safety, and Patient Management, 2. edn, Biomedical Research Publishing Group, United States, 2022.
48. St. John T, Natale N. Introducing the NEW Prevention Circul+ Ring. Available from: <https://www.prevention.com/health/a37545188/prevention-circul-ring/> (accessed August 8, 2022).
49. McLelar RingPay. Available from: <https://mclear.com/> (Accessed August 8, 2022).
50. Oura Ring. Available from: <https://ouraring.com/> (accessed August 8, 2022).
51. Shimizu Y, Fukuda K, Ueda H, Sekine T, Kazuyamatsumoto AI, et al. Mechanism of burn injury during magnetic resonance imaging (MRI)—simple loops can induce heat injury. *Front Bioeng Biotechnol* 2001; **11**: 117–29.
52. Kapoor R, Wang J, Zavala AM, Truong AT, Truong D. Metallic microbeads for hair extensions: Hidden dangers for magnetic resonance imaging. *Radiol Case Rep* 2022; **17**: 3274–6.
53. The Society and College of Radiographers. Safety in Magnetic Resonance Imaging. The Society and College of Radiographers, United Kingdom, 2019.
54. Shellock F. Safety topic/article 198: Transdermal medication patches and other drug delivery patches. 2022. Available from: http://www.mrisafety.com/TMDL_list.php?mastertable=SafetyInformation&masterkey1=198.
55. Afanasjeva J, Gabay M, Poznanski T, Kerns S. Transdermal Patch Administration and Magnetic Resonance Imaging (MRI)—2020. *Hosp Pharm* 2022; **57**: 117–20.
56. Gilk Radiology Consultants. Transdermal Patch/MRI Risk Decision Tree. Gilk Radiology Consultants, United States, 2017.
57. Escher KB, Shellock FG. An in vitro assessment of MRI issues at 3-Tesla for antimicrobial, silver-containing wound dressings. *Ostomy Wound Manage* 2012; **58**: 22–7.
58. Bailey JK, Sammet S, Overocker J, et al. MRI compatibility of silver based wound dressings. *Burns* 2018; **44**: 1940–6.
59. Tjalma WAA. Burning of an ulcerated breast cancer during MRI: a lesson to be learned. *JBR-BTR* 2014; **97**: 125.
60. Supersapiens CGM. Available from: <https://www.supersapiens.com/en-EN/> (accessed August 8, 2022).
61. Shellock F. FreeStyle Libre Pro Flash Glucose Monitoring System. Available from: http://www.mrisafety.com/TMDL_view.php?editid1=9203.
62. FreeStyle Libre 2. 2020. Available from: <https://www.freestylelibre.com.au/> (accessed August 8, 2022).
63. Dexcom Continuous Glucose Monitors. Available from: <https://www.dexcom.com/en-AU> (accessed August 8, 2022).
64. Keenan BE, Lacan F, Cooper A, Evans SL, Evans J. MRI safety, imaging artefacts, and grid distortion evaluated for FFP3 respiratory masks worn throughout the COVID-19 pandemic. *Clin Radiol* 2022; **77**: e660–6.
65. Food & Drug Administration. Wear Face Masks with No Metal During MRI Exams: FDA Safety Communication. 2021. Available from: <https://www.fda.gov/medical-devices/safety-communications/wear-face-masks-no-metal-during-mri-exams-fda-safety-communication> (accessed October 9, 2022).
66. Coskun O. Magnetic resonance imaging and safety aspects. *Toxicol Ind Health* 2011; **27**: 307–13.
67. Kwok WE. Basic principles of and practical guide to clinical MRI radiofrequency coils. *Radiographics* 2022; **42**: 898–918.
68. Chakraborty CS, Johnson AM, Miller W, et al. CAR Standard for Magnetic Resonance Imaging. Canadian Association of Radiologists (CAR), Ottawa, Canada, 2011; 9–11.
69. McRobbie DW, Moore EA, Graves MJ, Prince MR. MRI from Picture to Proton. Cambridge University Press, West Nyack, 2017.

70. Shellock FG. Safety topic/article166: Guidelines to prevent excessive heating and burns associated with MRI. 2022. Available from: http://mrisafety.com/SafetyInformation_view.php?editid1=166.
71. Institute for Magnetic Resonance Safety, Education, and Research (IMRSE). Guidelines to prevent excessive heating and burns associated with magnetic resonance procedures. Institute for Magnetic Resonance Safety, Education, and Research, Playa Del Rey, CA, 2015.
72. Panych LP, Madore B. The physics of MRI safety. *J Magn Reson Imaging* 2018; **47**: 28–43.
73. Tsai LL, Grant AK, Mortelet KJ, Kung JW, Smith MP. A practical guide to MR imaging safety: What radiologists need to know. *Radiographics* 2015; **35**: 1722–37.
74. Philips Medical Systems. Ingenia Instructions for Use. 2020.
75. Bailey J, Wilhelm M. Skin burns associated with use of the Quatrode ECG electrode during MRI utilizing accessory coils. *Vet Anaesth Analg* 2001; **28**: 101.
76. Keevil S. Safety in magnetic resonance imaging. *Med Phys Int* 2016; **4**: 26–34.
77. Graafstra A. MRI compatibility of x-series transponders. (accessed August 14, 2015).
78. Steffen T, Luechinger R, Wildermuth S, Kern C, Fretz C, Lange J, et al. Safety and reliability of radio frequency identification devices in magnetic resonance imaging and computed tomography. *Patient Saf Surg* 2010; **4**: 2.
79. Haifley KA, Hecht S. Functionality of implanted microchips following magnetic resonance imaging. *J Am Vet Med Assoc* 2012; **240**: 577, 9.
80. Piesnack S, Frame ME, Oechtering G, Ludewig E. Functionality of veterinary identification microchips following low- (0.5 tesla) and high-field (3 tesla) magnetic resonance imaging. *Vet Radiol Ultrasound* 2013; **54**: 618–22.
81. Fram BR, Rivlin M, Beredjiklian PK. On emerging technology: what to know when your patient has a microchip in his hand. *J Hand Surg Am* 2020; **45**: 645–9.
82. Oliver-Allen M, Valencerina S, Shellock FG. Evaluation of MRI issues at 3-Tesla for a hospital identification (ID) wristband. *Magn Reson Imaging* 2012; **30**: 299–303.
83. Sautter M, Sautter N, Shellock FG. Near field communication (NFC) device: Evaluation of MRI issues. *Magn Reson Imaging* 2022; **92**: 82–7.
84. Graafstra A. xG3 Injectable Biomagnet. Available from: <https://dangerousthings.com/product/xG3/> (accessed April 22, 2022).
85. Kanal E. Standardized approaches to MR safety assessment of patients with implanted devices. *Magn Reson Imaging Clin N Am* 2020; **28**: 537–48.
86. Knopp MV, Essig M, Debus J, Zabel H-, Van Kaick G. Unusual burns of the lower extremities caused by a closed conducting loop in a patient at MR imaging. *Radiology* 1996; **200**: 572, 5.
87. Mandel NS, Ramdial JL, Marcus EN. A second-degree burn after MRI. *Cleve Clin J Med* 2017; **84**: 348–9.
88. Ito Y, Omoto Y, Habe K, et al. Magnetic resonance (MR) imaging-induced deep second-degree burns of lower extremities by conducting loop. *J Eur Acad Dermatol Venereol* 2007; **21**: 1140–1.
89. Vister J, Lv E, Steens SCA, Meijer FJA. Burn injuries during MR scanning: a case report. *Ned Tijdschr Geneesk* 2014; **158**: A7927.
90. Vaughn H, Declan ABL. MRI-induced deep tissue burn presenting to the emergency department. *Am J Emerg Med* 2022; **58**: 352.
91. Lee C, Kang B, Song S, Koh B, Choi JS, Lee WM. MRI induced second-degree burn in a patient with extremely large uterine leiomyomas: A case report. *J Korean Soc Radiol* 2015; **73**: 424.
92. Mills C. MR Safety Week Topic RF Burns. British Association of MR Radiographers, United Kingdom, 2021.
93. Eising EG, Hughes J, Nolte F, Jentzen W, Bockisch A. Burn injury by nuclear magnetic resonance imaging. *Clin Imaging* 2010; **34**: 293–7.
94. Deveci C, Atilgan M, Demirçin S. The forensic aspect of thermal injuries during MRI: A case report with a review of literature *Rom J Leg Med* 2021; **29**: 49, 52.
95. Ross JR, Matava MJ. Tattoo-induced skin “burn” during magnetic resonance imaging in a professional football player. *Sports Health* 2011; **3**: 431–4.
96. Sung SJ, Park YS, Cho JY. Full thickness burn on the finger due to pulse oximetry during magnetic resonance imaging in a conscious patient. *Arch Plast Surg* 2016; **43**: 612–3.
97. Landman A, Goldfarb S. Magnetic resonance-induced thermal burn. *Ann Emerg Med* 2008; **52**: 308–9.
98. Wagle WA, Smith M. Tattoo-induced skin burn during MR imaging. *Am J Roentgenol* 2000; **174**: 1795.
99. Tope WD, Shellock FG. Magnetic resonance imaging and permanent cosmetics (tattoos): Survey of complications and adverse events. *J Magn Reson Imaging* 2002; **15**: 180–4.
100. Callaghan MF, Negus C, Leff AP, Creasey M, Burns S, Glensman J, Bradbury D, Williams E, Weiskopf N. Safety of tattoos in persons undergoing MRI. *N Engl J Med* 2019; **380**: 495, 6.
101. Lohner V, Enkirch SJ, Hattingen E, Stöcker T, Breteler MMB. Safety of tattoos, permanent make-up, and medical implants in population-based 3T magnetic resonance brain imaging: the Rhineland study. *Front Neurol* 2022; **13**: 795573.
102. Alsing KK, Johannesen HH, Hansen RH, Serup J. Tattoo complications and magnetic resonance imaging: A comprehensive review of the literature. *Acta Radiol* 2020; **61**: 1695–700.

103. Clausen L, Cook J, Garlock A, et al. Radiologic technologist best practices for MR safety. American Society of Radiologic Technologists, Albuquerque, NM, 2018.
104. Wang JF, Hindman NM. Prevention of thermal burns from magnetic resonance imaging in patients with tattoos. *J Am Acad Dermatol* 2019; **80**: e101–2.
105. European Society of Radiology (ESR), European Federation of Radiographer Societies (EFRS). Patient Safety in Medical Imaging: a joint paper of the European Society of Radiology (ESR) and the European Federation of Radiographer Societies (EFRS). *Insights Imaging* 2019; **10**: 45.
106. Westbrook C, Talbot J. MRI in Practice, 5th edn. Wiley, Hoboken, NJ, 2019.
107. Dale BM, Brown MA, Semelka RC. MRI: Basic principles and applications. John Wiley & Sons, Ltd, Chichester, West Sussex; Hoboken, NJ, 2015.
108. Bushong SC, Clarke GD. Magnetic resonance imaging: Physical and biological principles. Elsevier Mosby, St. Louis, MO, 2014.
109. McRobbie DW. Essentials of MRI safety. Wiley-Blackwell, Hoboken, NJ, 2020.
110. Foster L, Tanenbaum LN, Crues JV. CHAPTER 28 MRI safety policies and procedures for an outpatient facility. In: Crues JV (ed). MRI bioeffects, safety, and patient management, 2nd edn, 2020.
111. Van der Heide UA, Frantzen-Steneker M, Astreinidou E, Nowee ME, van Houdt PJ. MRI basics for radiation oncologists. *Clin Transl Radiat Oncol* 2019; **18**: 74–9.
112. Sobol WT. Recent advances in MRI technology: Implications for image quality and patient safety. *Saudi J Ophthalmol* 2012; **26**: 393–9.
113. Ghadimi M, Sapra A. Magnetic resonance imaging contraindications. StatPearls [Internet]. StatPearls Publishing, Treasure Island, FL, 2024. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK551669/>.
114. Yang X, Zheng J, Wang Y, Long SA, Kainz W, Chen J. Body-loop related MRI radiofrequency-induced heating hazards: Observations, characterizations, and recommendations. *Magn Reson Med* 2022; **87**: 337–48.
115. Cross NM, Hoff MN, Kanal KM. Avoiding MRI-related accidents: A practical approach to implementing MR safety. *J Am Coll Radiol* 2018; **15**: 1738–44.
116. Association of Anaesthetists of Great Britain and Ireland, Farling PA, Flynn PA, et al. Safety in magnetic resonance units: An update. *Anaesthesia* 2010; **65**: 766–70.
117. Simmons A, Hakansson K. Magnetic resonance safety. In: Modo M, Bulte JWM (eds). Magnetic resonance neuroimaging methods and protocols. Humana Press, Totowa, NJ, 2011.
118. Greenberg TD, Hoff MN, Gilk TB, et al. ACR guidance document on MR Safe practices: Updates and critical information 2019. *J Magn Reson Imaging* 2019; **51**.
119. Taylor J, Hampshire V. Basic research support for shared magnetic resonance imaging resources. *Lab Anim* 2015; **44**: 435–7.
120. Durbridge G. Magnetic resonance imaging: fundamental safety issues. *J Orthop Sports Phys Ther* 2011; **41**: 820–8.
121. Smith JA. Hazards, safety, and anesthetic considerations for magnetic resonance imaging. *Top Companion Anim Med* 2010; **25**: 98–106.
122. MacIntyre S. Regulating MR. Safety standards. *Radiol Technol* 2021; **93**: 75–89.
123. Weidman EK, Dean KE, Rivera W, Loftus ML, Stokes TW, Min RJ. MRI safety: a report of current practice and advancements in patient preparation and screening. *Clin Imaging* 2015; **39**: 935–7.
124. Watson RE, Tesfaldet M, Warren J, Hoff MN. MR imaging safety events: Analysis and improvement. *Magn Reson Imaging Clin N Am* 2020; **28**: 593–600.
125. Gilk TB. MR imaging safety: Siting and zoning considerations. *Magn Reson Imaging Clin N Am* 2020; **28**: 481–8.
126. Serai SD, Ho M-L, Artunduaga M, Chan SS, Chavhan GB. Components of a magnetic resonance imaging system and their relationship to safety and image quality. *Pediatr Radiol* 2021; **51**: 716–23.
127. Franco J. Magnetic resonance imaging safety. *Radiol Technol* 2020; **91**: 343–56.
128. Sammet S. Magnetic resonance safety. *Abdom Radiol* 2016; **41**: 444–51.
129. Nitz WR, Hoffmann K-P, Pozos RS. Springer handbook of medical technology. 2011. Available from: <https://doi.org/10.1007/978-3-540-74658-4>.
130. Moore S. Chapter 41 – Magnetic resonance imaging. Elsevier, Philadelphia, 2022.
131. Hillenbrand CM, Reykowski A. MR imaging of the newborn: A technical perspective. *Magn Reson Imaging Clin N Am* 2012; **20**: 63–79.
132. Food and Drug Administration. MRI burn prevention poster. *J Radiol Nurs* 2016; **35**: 62.
133. Kim SJ, Kim KA. Safety issues and updates under MR environments. *Eur J Radiol* 2017; **89**: 7–13.
134. Ott LK. Shielding from harm: The MRI screening tool—the first line of defense in MRI safety. *J Radiol Nurs* 2015; **34**: 179–82.
135. Ayasrah M. Analysis of collected magnetic resonance imaging incidents in Jordan. *Mater Today Proc* 2023; **80**: 3092–7.
136. Hudson D, Abrantes L. Heattech clothing technology and potential for thermal injury in MRI. *BJR Case Rep* 2023; **9**: 20220012.
137. Chabridon AI, Payen M. Auquit-Auckbur I. MRI-induced third-degree finger burn by pulse oximetry: A case report. *J Magn Reson Imaging* 2023; **58**: 977–9.
138. Serup J, Alsing KK, Olsen O, Koch CB, Hansen RH. On the mechanism of painful burn sensation in tattoos

- on magnetic resonance imaging (MRI). Magnetic substances in tattoo inks used for permanent makeup (PMU) identified: Magnetite, goethite, and hematite. *Skin Res Technol* 2023; **29**: e13281.
 139. Thomas H, Peter Y. A practical guide for radiographers focussing on safety during magnetic resonance imaging. *J Med Imaging Radiat Sci* 2022; **53**: 714–9.
 140. Mathew T, John SK, Deepalam SK, Sharath Kumar GG. MRI-induced thermal burn: A rare, unusual, unrecognized side effect of MRI scan. *Neurol India* 2022; **70**: 1318–9.
 141. Turner S, Singh SM. Skin burn after magnetic resonance imaging in a patient with an implantable cardioverter-defibrillator. *HeartRhythm Case Rep* 2022; **8**: 539–40.
 142. Gach HM, Mackey SL, Hausman SE, et al. MRI safety risks in the obese: The case of the disposable lighter stored in the pannus. *Radiol Case Rep* 2019; **14**: 634–8.
 143. Abdel-Rehim S, Bagirathan S, Al-Benna S, O’Boyle C. Burns from ECG leads in an MRI scanner: Case series and discussion of mechanisms. *Ann Burns Fire Disasters* 2014; **27**: 215–8.
 144. Yang HH, Charette MF, Talbot N. Do magnetic resonance imaging technologists in canada always ask patients to change before examinations? *J Med Imaging Radiat Sci* 2016; **47**: 124–8.
 145. Takahashi T, Fujimoto N, Hamada Y, Tezuka N, Tanaka T. MRI-related thermal injury due to skin-to-skin contact. *Eur J Dermatol* 2016; **26**: 296–8.
 146. Wright BB, Burgoyne LL. A neck burn of unexpected etiology during magnetic resonance imaging of a one year old boy. *J Clin Anesth* 2014; **26**: 86–7.
 147. Friedstat JS, Moore ME, Goverman J, Fagan SP. An unusual burn during routine magnetic resonance imaging. *J Burn Care Res* 2013; **34**: e110–1.
 148. Bertrand A, Brunel S, Habert MO, et al. A new fire hazard for MR imaging systems: Blankets-case report. *Radiology* 2018; **286**: 568–70.
 149. Alsing KK, Johannesen HH, Hvass Hansen R, Dirks M, Olsen O, Serup J. MR scanning, tattoo inks, and risk of thermal burn: An experimental study of iron oxide and organic pigments: Effect on temperature and magnetic behavior referenced to chemical analysis. *Skin Res Technol* 2018; **24**: 278–84.
 150. Pickup L, Nugent B, Bowie P. A preliminary ergonomic analysis of the MRI work system environment: Implications and recommendations for safety and design. *Radiography* 2019; **25**: 339–45.
 151. Gayton JC, Sensiba P, Imbrogno BF, Venkatarayappa I, Tsatalis J, Prayson MJ. The effects of magnetic resonance imaging on surgical staples: an experimental analysis. *J Trauma* 2011; **70**: 1279–81.
 152. Kluger N, Brun-Lévéque P, Gral N. Painful burning sensation on a tattoo during magnetic resonance imaging. *Int J Dermatol* 2019; **58**: E82–3.
 153. Hayat S, Cho Y, Oh S, Yoo H. RF-induced heating of various tattoos at magnetic resonance imaging systems. *IEEE Access* 2021; **9**: 100951–61.
 154. Kasalak Ö, Yakar D, Dierckx RA, Kwee TC. Patient safety incidents in radiology: frequency and distribution of incident types. *Acta Radiol* 2021; **62**: 653–66.
 155. Hudson D, Jones AP. A 3-year review of MRI safety incidents within a UK independent sector provider of diagnostic services. *BJR Open* 2019; **1**.
 156. Massat MB. Twenty years of MRI safety: A progress report. *Appl Radiol* 2020; **49**: 38–40.
 157. Durkin SE. Tattoos, body piercing, and healthcare concerns. *J Radiol Nurs* 2012; **31**: 20–5.
 158. Food and Drug Administration. MRI burn prevention. Food and Drug Administration, 2020. Available from: <https://www.fda.gov/media/94630/download?attachment>.
 159. Mittendorff L, Young A, Lee A, Sim JH. New Zealand and Australian MRI technologists’ (radiographers) MRI safety knowledge and confidence levels. *Radiography* 2023; **29**: 697–704.
- ## Supporting Information
- Additional supporting information may be found online in the Supporting Information section at the end of the article.
- Table S1.** Key characteristics of included sources.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Key characteristics of included sources.

QUESTIONNAIRE A20(26) Part 1 of 2

Systematic review of MRI safety literature in relation to radiofrequency thermal injury prevention

INSTRUCTIONS

- Read through the article and answer the multiple-choice questions provided below.
- **Some questions may have more than one correct answer;** in which case you must mark **all** the correct answers.

Background and Rationale

Question 1: Regarding the manifestation of thermal injuries caused by MRI exposure, which statement accurately reflects the reported timing of these adverse events?

- A:** All burns are felt immediately by the patient during the scanning process
- B:** Burns only occur during sequences that last longer than 20 minutes
- C:** Burns are unpredictable and while some are instantaneous, other significant burns may manifest even 24 h after MRI
- D:** Thermal injuries are only identified immediately if the patient is under sedation

Question 2: According to research cited regarding the reporting of MRI incidents, what is the estimated status of adverse event documentation?

- A:** Incidents are overreported due to strict mandatory guidelines
- B:** Incidents are severely underreported by 1/3 and Rogg suggests this is due to voluntary reporting
- C:** 97% of all minor heating sensations are successfully logged in the FDA database
- D:** Reporting is consistent globally across all safety advisory bodies

Clothing and Fabric Risks

Question 3: Why do antimicrobial clothing items treated with silver or copper pose a risk during MRI examinations despite being non-ferromagnetic?

- A:** These materials are excellent electrical conductors and therefore the risk of induced current and subsequent heating does exist
- B:** The materials react chemically with the helium used to cool the magnet
- C:** Silver and copper fibres disrupt the static magnetic field causing geometric distortion
- D:** These metals become highly radioactive when exposed to radiofrequency pulses

Question 4: Under what condition can metal zips on patient clothing result in heating during a scan?

- A:** Only if the zip is made of a ferromagnetic material like iron
- B:** If the zip is longer than 15 cm regardless of position
- C:** If the zip is within the region of RF and matches the appropriate wavelength to result in resonance
- D:** If the zip is pulled down

Object Removal and Screening

Question 5: TRUE/FALSE: Ferromagnetic detectors (FMDs) are recommended as a complete replacement for conventional screening practices because they can detect all conductive materials including silver and carbon fiber.

- A:** TRUE
- B:** FALSE

Question 6: Regarding jewelry that cannot be easily removed, what approach is suggested for items not exposed to RF energies?

- A:** They must be cut off immediately
- B:** Permit non-ferromagnetic metals to be worn when not exposed to RF energies
- C:** They should be covered in lead shielding
- D:** The scan must be cancelled immediately

Question 7: Why should small calibre electrically conductive loops, such as those found in some wearable technology rings, be removed prior to scanning?

- A:** They always cause projectile accidents
- B:** The heating effects of such small calibre loops, when exposed to electromagnetic fields, has been untested
- C:** They interfere with the gradient coils specifically
- D:** They will permanently demagnetize the scanner

Question 8: Which approach is recommended regarding the management of drug and medication patches?

- A:** All patches must be removed immediately regardless of type
- B:** Patches should be covered with a cold compress to increase the drug delivery rate
- C:** Any patch not exposed to the RF poses no burns risk and removal should be based on physician consultation
- D:** Patches should be covered with conductive tape to shield them from RF energy

Question 9: Based on cited studies, what is the recommendation regarding antimicrobial silver dressings?

- A:** They have been shown to be safe to scan up to 3 T thus do not need to be removed
- B:** They must always be removed due to high burn risk
- C:** They are only safe if the silver content is less than 5%
- D:** They require a specialized cooling gel to be applied

Question 10: How should most Continuous Glucose Monitoring (CGM) and Flash Glucose Monitoring (Flash GM) devices be managed prior to an MRI scan?

- A:** They can be left in place if covered with a master cast
- B:** They are safe to scan provided the battery is turned off
- C:** They should be repositioned to the ankle to avoid the isocentre
- D:** Most of these devices are MR Unsafe and must be removed prior to scanning

THE END

QUESTIONNAIRE A20(26) Part 2 of 2

Systematic review of MRI safety literature in relation to radiofrequency thermal injury prevention

INSTRUCTIONS

- Read through the article and answer the multiple-choice questions provided below.
- **Some questions may have more than one correct answer;** in which case you must mark **all** the correct answers.

Question 1: What action is recommended regarding facemasks if they contain metal?

- A: They can be worn if taped down
- B: They should be folded to reduce surface area
- C: They should be replaced with masks with no metal as they pose RF heating risks
- D: They are safe if worn under a secondary cloth mask

Equipment Integrity and Positioning

Question 2: Why is it critical to check the insulation of cables associated with MRI equipment?

- A: To ensure the colour coding is still visible
- B: Damaged insulation increases the acoustic noise of the scan
- C: It prevents the cables from tangling during table movement
- D: Cracks and splits can expose the patient to internal wires and potentially create a conductive loop where burns could occur

Question 3: Why is it important to remove unplugged equipment from the bore during image acquisition?

- A: To ensure active and passive detuning circuits, blocking resonance induction, are functioning
- B: To prevent the equipment from becoming a projectile
- C: Unplugged equipment causes significant ghosting artefacts on the images
- D: To save space within the bore for patient comfort

Question 4: TRUE/FALSE: All ECG and patient monitoring equipment should be considered MR Unsafe until checked and verified as MR Conditional.

- A: TRUE
- B: FALSE

Question 5: To avoid the large RF intensity found at the edges of the bore, where should necessary electrically conductive materials be positioned?

- A: Tucked tightly under the patient mattress
- B: Along the centre of the bore
- C: Attached directly to the bore wall
- D: Wrapped around the patient's extremities

Question 6: TRUE/FALSE: Patient bio-hacking involving NFC and RFID chips typically poses no major contraindications to MRI and several studies show they are often MRI Safe or Conditional.

- A: TRUE
- B: FALSE

Physics of Heating and Padding

Question 7: Resonant heating is described as occurring when the length of a linear electrically conductive material matches which specific physical parameter?

- A: The full wavelength of the static magnetic field
- B: The frequency of the gradient switching
- C: The half wavelength of the MR field strength
- D: The circumference of the bore opening

Question 8: Why is proximity to the bore wall critical regarding thermal injury, even if there is no direct contact?

- A: The bore wall is extremely cold and causes cryogenic burns
- B: The bore wall vibrates intensely causing friction burns
- C: The static magnetic field is strongest at the wall, attracting iron in the blood
- D: There are points along the wall where RF transmission is more concentrated

Patient Monitoring and Artefacts

Question 9: In the context of patient monitoring, how do burns associated with near-field effects close to the bore typically manifest compared to antenna effects?

- A:** They are felt instantaneously like an electric shock
- B:** They cause immediate itching
- C:** They often have a delayed reaction
- D:** They are always accompanied by a loud popping sound

Summary Recommendations

Question 10: What does the acronym R.I.C., proposed as a simplified method for preventing skin burns, stand for?

- A:** Review, Inspect, Correct
- B:** Remove, Insulate, Communicate
- C:** Resuscitate, Intubate, Circulate
- D:** Research, Investigate, Calibrate

THE END



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ANSWER SHEET

A20(26)

Systematic review of MRI safety literature in relation to radiofrequency thermal injury prevention

*Time spent on activity												hour min											
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PART 1						PART 2																	
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3						8						3						8					
4						9						4						9					
5						10						5						10					

How relevant was the content of this activity to your scope of practice?			
			
Not at all	Somewhat	Mostly	Extremely

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