Contraindications to magnetic resonance imaging

T Dill

Heart 2008;94;943-948
doi:10.1136/hrt.2007.125039

NON-INVASIVE IMAGING

Contraindications to magnetic resonance imaging

T Dill

► Additional references are published online only at http://heart.bmj.com/content/vol94/issue7

Department of Cardiology/Cardiovascular Imaging, Kerckhoff Heart Center, Bad Nauheim, Germany

Correspondence to: Thorsten Dill, MD, Department of Cardiology/Cardiovascular Imaging, Kerckhoff Heart Center, Benekestrasse 2-8, 61231 Bad Nauheim, Germany; t.dill@kerckhoff-klinik.de

Magnetic resonance imaging (MRI) is a method that has evolved continuously during the past 20 years, yielding MR systems with stronger static magnetic fields, faster and stronger gradient magnetic fields, and more powerful radiofrequency transmission coils. It is increasingly being used and requested as several new indications have been established during the last few years—for example, cardiovascular MRI.

To evaluate the contraindications to MRI is equivalent to understanding the safety issues surrounding the use MRI.

MRI is often described as a "safe" modality due to the fact that, unlike *x* ray based systems, ionising radiation is not involved. However, there are hazards intrinsic to the MR environment that must be acknowledged and excluded. Most reported cases of MR related injuries and the few fatalities that have occurred have apparently been the result of failure to follow safety guidelines or have resulted from the use of inappropriate or outdated information related to the safety aspects of biomedical implants and devices. Therefore, for information on specific guidelines and devices, detailed sources of safety information—for example, dedicated websites (box 1)—are recommended.[1 2 w1 w2]

Risks associated with MRI may be attributed to one or to a combination of the three main mechanisms of the system:

1. *Strong static magnetic fields*—As a result of ferromagnetic interactions, an object or device may be moved, rotated, dislodged, or accelerated toward the magnet. The "projectile effect" means that, depending on the type of magnet and the intensity of the generated field, to varying extent, objects are attracted to the centre of the magnet (for example, helium or oxygen cylinders, ventilators, wheelchair, etc), possibly causing severe injuries and damage. Furthermore, articles such as metallic splinters, vascular clips, and cochlear implants may be dislodged. The strong magnetic field may also affect device function, as most, but importantly not all, currently implanted devices are either non-ferromagnetic or weakly ferromagnetic.
2. *Pulsed gradient magnetic fields*—Gradients are time-varying magnetic fields used to encode for various aspects of the image acquisition. They are much weaker than the main magnetic field. As they are repeatedly and rapidly turned on and off the rapid changing magnetic fields can induce electrical currents in electrically conductive devices and may directly cause neuromuscular stimulation.
3. *Pulsed radiofrequency fields*—The main biological effects of radiofrequency fields is their thermogenic effect. Some of the applied energy will be absorbed by the body and converted into heat. The specific absorption rate (SAR, expressed in watts/kilogram) increases with the square of the field strength and varies with different sequences. Metallic devices (for example, pacer leads) can concentrate radiofrequency energy which leads to local heating. Radiofrequency energy can also induce electrical currents in wires and leads which might induce arrhythmias.

The US Food and Drug Administration (FDA) has approved brief exposure to magnetic fields at all of the intensities currently in use for clinical purposes (from 0.2 to 3.0 Tesla (T), and even up to 8 T for research) on the grounds that is not harmful to the body, but this is only true for patients in general. Patients with cardiovascular devices, in particular, have to be evaluated carefully.[3 4]

Recently, another potential hazard has come into the focus, namely, nephrogenic systemic fibrosis attributed to the administration of gadolinium based MR contrast agents in patients with renal failure.[5]

With increasing numbers of cardiovascular MRI undertaken for ischaemia testing using either adenosine or dobutamine for pharmacological stress, contraindications to the administration of these substances have to be taken into account. Patient screening before an MR examination is most effective to prevent adverse events.[1 6 w3] Therefore, a checklist with possible contraindications appears to be useful. An example of such a checklist is given in box 2.

This article will summarise current recommendations on safety and resulting contraindications for MRI.

METALLIC IMPLANTS

Vascular clips

If a clip is made of non-ferromagnetic material and if there are no concerns with MR associated heating, a patient may undergo MR immediately after implantation.[4] For endocranial clips, a written certification from the neurosurgeon is required[7]; if

Box 1 Relevant websites with additional information

- American College of Radiology. ACR practice guidelines for the performance of cardiovascular MRI: http://www.acr.org
- Food and Drug Administration recommendations. Center for Devices and Radiological Health. MDR data files: www.fda.gov/CDRH/mdrfile.html
- MRI safety. Institute for Magnetic Resonance Safety, Education, and Research: http://www.MRIsafety.com. or http://www.IMRSER.org
- North American Society for Cardiac Imaging: http://www.nasci.org.
- Society for Cardiovascular Magnetic Resonance: http://www.scmr.org

the clip is made of titanium or titanium alloy, the examination can be performed.[w4 w5] However, if the clip is declared to be ferromagnetic or otherwise incompatible with MR, the examination must be cancelled. In general, MR compatible materials have been increasingly used since the mid 1990s, so the risk of incompatibility is quite low but needs to be checked.

Foreign bodies

The potential danger of a metal foreign body—for example, a metallic splinter in the eye—has been reported since MR was first introduced for clinical purposes.[w6] If there is any doubt about the presence or location an *x* ray should be taken before the MRI. The same holds true for bullets or grenade fragments.[w7 w8] Shifting of metal foreign bodies under the influence of the magnetic field could damage vital structures—for example, vessels or nerves. It is an individual decision if the risk of an MR examination is outweighed by the benefit of an investigation.

Surgical sutures are made of various metallic and non-metallic materials and sometimes induce artefacts. The most widely used types in clinical practice have been tested at magnetic fields of 1.5 T and 3 T and were found to be safe for MRI.[8 w9]

Coronary and peripheral artery stents

Most coronary artery and peripheral vascular stents are made of stainless steel or nitinol. Some stents may be composed of, or contain, variable amounts of platinum, cobalt alloy, gold, tantalum, MP35N, or other materials.[1] That means most coronary and peripheral vascular stents are non-ferromagnetic or weakly ferromagnetic. Extensive studies have led to the conclusion that MR scanning of patients after stent implantation can be performed without risk at any time at 3 T or less.[4] There is no risk of dislodgement as implantation against the vessel wall provides sufficient stability and no increased risk for acute stent thrombosis (for bare metal stents as well as drug eluting stents (DES).[9 w10 w11] The effect of heating induced by the radiofrequency field on the polymer of DES is unknown. However, stents generally cause artefacts that impair evaluation of the stent itself.

Aortic stent grafts

The majority of endovascular aortic stent grafts are non-ferromagnetic or weak ferromagnetic and may be scanned immediately after implantation at 3 T or less. It is important to mention that there are exceptions[8] and scanning cannot be recommended for three particular stent grafts.[4]

Prosthetic heart valves and annuloplasty rings

Although prosthetic heart valves and annuloplasty rings are made from a variety of materials, numerous studies have demonstrated that MRI examinations are safe. Even mechanical heart valves that are composed of a variety of metals are not a contraindication for MR imaging at 3 T or less any time after implantation.[4 10 w12] Depending on the amount of metal contained, there are some minor interactions with the magnetic field, but the resulting forces are much less compared to those of the beating heart and pulsatile blood flow.

Sternal wires are usually made of stainless steel or alloy and are not a contraindication to MRI.[4]

Cardiac occluder devices

Devices for closure of persistent foramen ovale, atrial septal defect or left atrial appendage are usually made of non-ferromagnetic material (titanium, nitinol), the few made of stainless steel being weakly ferromagnetic. For those with non-ferromagnetic material MR imaging can be performed at 3 T or less any time after implantation; for those with weakly ferromagnetic material without the urgent need for an MRI examination an interval of 6 weeks is recommended.[4 11 w13]

Vena cava filters and embolisation coils

Neither studies in animals nor in man with implanted inferior vena cava (IVC) filters have shown filter displacement or any other complication due to MRI examination at 1.5 T or less. Older, weakly ferromagnetic filters should not be imaged before 6 weeks after implantation.[4]

Earlier embolisation coils are made of stainless steel and consequently are weakly ferromagnetic, while recent coils are made from platinum or other alloy and are non-ferromagnetic. Both types of coils have been tested and found to be safe for MRI. It is recommended that for the weakly ferromagnetic coils an MRI examination should be deferred until 6 weeks after implantation.[4]

Haemodynamic monitoring and temporary pacing devices

Pulmonary artery monitoring catheters and temporary transvenous pacing leads contain non-ferromagnetic but electrically conductive material. During an MRI examination radiofrequency pulses might induce currents that could lead to thermal injuries.[12 w14] Therefore, it is a contraindication to examine patients with such catheters by MRI. To date there is no report that pulmonary artery catheters without electrically conductive material and epicardial pacing leads have caused complications. Thus, scanning of such patients is possible but should be done under careful supervision.[4]

Heart 2008;**94**:943–948. doi:10.1136/hrt.2007.125039

Box 2 Example of a check list with potential contraindications to an MRI examination

If any of the following is checked, evaluation of the individual risk has to be performed before the MRI examination

- Aneurysm clip(s)
- Any metallic fragment or foreign body
- Coronary and peripheral artery stents
- Aortic stent graft
- Prosthetic heart valves and annuloplasty rings
- Cardiac occluder devices
- Vena cava filters and embolisation coils
- Haemodynamic monitoring and temporary pacing devices, eg, Swan–Ganz catheter
- Haemodynamic support devices
- Cardiac pacemaker
- Implanted cardioverter-defibrillator (ICD)
- Retained transvenous pacemaker and defibrillator leads
- Electronic implant or device, eg, insulin pump or other infusion pump
- Permanent contraceptive devices, diaphragm, or pessary
- Cochlear, otologic, or other ear implant
- Neurostimulation system
- Shunt (spinal or intraventricular)
- Vascular access port and/or catheter
- Tissue expander (eg, breast)
- Joint replacement (eg, hip, knee, etc)
- Any type of prosthesis (eg, eye, penile, etc)
- Tattoo or permanent makeup
- Known claustrophobia
- Body piercing jewellery
- Hearing aid
- Renal insufficiency
- Known/possible pregnancy or breast feeding

Modified from: Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology* 2004;**232**:635–52.

External pulse generators have not been assessed for their MRI safety and should not be used in the MR environment.

Haemodynamic support devices

Devices such as intra-aortic balloon pumps and left and right ventricular assist devices have not been evaluated in regard to MRI safety. However, the fact that they contain ferromagnetic materials, moving parts and electrical components lead to the recommendation that MRI is contraindicated.[4]

Permanent cardiac pacemakers and implantable cardioverter-defibrillators

There is great controversy related to the question as to whether MRI in patients with permanent cardiac pacemakers and implantable cardioverter-defibrillators (ICDs) is contraindicated or not.[13 14 w15–20] The fact that there is an estimated likelihood of 50–75% that a patient with a pacemaker or an ICD will have a clinical indication for MRI scanning during the device's lifetime illustrates that this issue is of great relevance, because numbers of both MRI examinations and implantable cardiac devices are increasing.[w15] However, there are a variety of mechanisms by which MRI can affect pacemakers and ICDs. The devices are made of metal of varying ferromagnetic qualities and complex electrical systems and at least one lead is implanted into the myocardium. The potential for device dislodgement, programming changes, asynchronous pacing, activation of antitachycardiac therapies, inhibition of pacing output, and induced lead currents that could result in heating and cardiac stimulation has led to concerns regarding the performance of MR examinations in patients with permanent pacemakers and ICDs.[4] Clinical data are limited, with most existing studies relating to non-cardiac scanning of pacemakers at low field strengths. Moreover, clinically used field strengths have increased to 3 T with currently unknown device interactions.[w21] Further, MRI of pacemaker and ICD patients is contraindicated by MRI manufacturers because of serious concerns about tissue damage, induced arrhythmias and electromagnetic compatibility. An FDA statement summarised that the risks have not yet been characterised and mitigated sufficiently to justify the routine use of MRI examinations in patients with pacemakers and ICDs.[15 w18]

The current recommendations on safety of magnetic resonance imaging in patients with cardiovascular devices state that the studies published in which patients with permanent pacemakers and ICDs have been scanned safely were conducted in very experienced centres. It is important to note that the number of patients with adverse events is unknown, and therefore implanted pacemakers and ICDs should still be considered a strong relative contraindication to routine MRI and is discouraged.[4] Under special circumstances, if there is no other diagnostic tool available and the potential benefit for the patient outweighs the risk, MRI might be performed in an experienced centre with expertise in MRI and cardiology.[16] In recent years technological developments have led to a substantial reduction in the proportion of ferromagnetic material inside pacemakers, resulting in considerably reduced sensitivity to electromagnetic interference,[w22] and industry efforts to manufacture MRI compatible devices is continuing.

Matters to take into consideration for patients with pacemakers and ICDs are listed in box 3.

Retained transvenous pacemaker and defibrillator leads

Following the removal of a patient's pacemaker or ICD, transvenous or epicardial electrodes might be left in situ, for several clinical reasons. For epicardial leads for temporary pacing after surgery it has been reported that no cardiac symptoms and no changes on the ECG appear.[w23] Epicardial leads for an ICD have not been addressed in studies so far and pose a contraindication. MRI examination in patients with retained transvenous leads is discouraged because, as for patients with implanted pacemakers or ICDs, there is a risk of heating and excitation. Fractured leads are a contraindication for MRI.

Box 3 Considerations for patients with permanent pacemakers/ implanted cardioverter-defibrillators (ICD)

Indication
- Inability to adequately assess patient with other diagnostic techniques
- Dedicated informed consent relating to potential risks

Patient assessment
- Underlying cardiac rhythm
- Time since device implantation
- Body part to be scanned and imaging sequences to be used
- Magnet field strength

Device information
- Device location, type, pre-scan function and programming, leads, battery voltage
- Patient: non-pacemaker dependent or pacemaker dependent (in this case asynchronous pacing with avoidance of chest or abdomen scanning)
- ICD device programmed to: antitachycardic therapy, pacing, cardioversion and defibrillation off
- Physician experienced in device programming on site

Monitoring
- Continuously monitoring of consciousness, heart rate, blood pressure, and oxygen saturation
- Visual and acoustic contact throughout the procedure with the patient
- Instruction of the patient to report any unusual sensations or problems
- Ability for immediate scan termination and evacuation of the patient from the scanner
- Staff trained in advanced cardiac life support

Post-MRI
- Evaluation of device function and eventually reprogramming

Modified from: Shinbane JS, Coletti PM, Shellock FG. MR in patients with pacemakers and ICDs: defining the issue. *J Cardiovasc Magnetic Resonance* 2007;**9**:5–13.

Permanent contraceptive devices

Intrauterine contraceptive devices are made of either non-ferromagnetic material (plastic) or weak ferromagnetic material (metal components, typically with copper). Therefore, heating and displacement might be the consequence of MRI. However, the results of various studies indicate that these devices are safe when patients are examined using magnets of 1.5 T or less.[17 w24] For information on a specific product, reference should be made to the manufacturer's information and to dedicated websites (box 1). The same holds true for diaphragms used for contraceptive purposes as they contain metal rings to keep them in position, some of which are made of ferromagnetic materials. It is a general recommendation to inform the patient that displacement of the device might have occurred following the procedure, with consequently inappropriate anti-contraceptive effects. Therefore, the correct position of the device should be checked by ultrasound after the intervention.

Cochlear implants

Cochlear implants are an accepted means of treating profound bilateral deafness by direct electrical stimulation of the auditory nerve. These systems consist of complex electric and metal components. Various systems are in use and the implantation numbers are increasing. This makes the compatibility of cochlear implants with MRI an increasingly relevant topic. Numerous devices have been tested for MRI safety.[1] In general it is most important to know precisely which implant is present and the intended MRI procedure. Force and torque induced by the magnetic field of the MRI represent a hazard for the implant. Thus, cochlear implants represent a relative contraindication to MRI and only after careful evaluation of the individual risk can an MRI possibly be performed.[w25]

OTHER POTENTIAL CONTRAINDICATIONS

Tattoos and cosmetics

Both tattoos and cosmetics may contain particles of iron oxides or other metals that, by interacting with the magnetic field, can cause sensations of heat, burns, swelling or local irritation during an MRI examination.[18 w26] If possible cosmetics should be removed before scanning. The same holds true for piercing material. If removal is not possible an icepack/cold compress may be used. In a review of the literature Shellock concludes that neither tattoos nor cosmetics are a contraindication for MRI, provided that appropriate precautions are taken.[19]

Claustrophobia

Claustrophobic reactions happen in 1–15% of all patients who undergo an MR examination and consequently cannot be imaged or require sedation. The extent of claustrophobia is very variable and depends on the type of scanner, position in the scanner, gender, and age. When a patient reports that he or she is suffering from claustrophobia it has to be taken seriously; besides the possible option of sedating the patient, the incidence of claustrophobia can be reduced by a factor of three by using recently developed scanners with a conical shaped short magnet bore and reduced acoustic noise.[20]

Pregnancy and postpartum

Diagnostic imaging might be required during pregnancy for several reasons. MRI has been used to evaluate obstetric, placental, and fetal abnormalities in pregnant patients for many years.[21 w27] The existing safety issues are related to possible adverse biological effects by the magnetic fields. Many research investigations have been conducted to determine the effects of MRI during pregnancy. The guidelines for MR in pregnant patients state: "MRI may be used in pregnant women if other non-ionizing forms of diagnostic imaging are inadequate or if the examination provides important information that would otherwise require exposure to ionising radiation (eg, fluoroscopy, computed tomography). Pregnant patients should be informed that, to date, there has been no indication that the use of clinical MR imaging during pregnancy has produced deleterious effects." For clinical use this means that the

MRI contraindications: key points

- It is necessary to update continuously knowledge regarding the safety issues related to MR technology, as well as to the technology of implants, devices, contrast agents, and other aspects related to the magnetic resonance imaging (MRI) examination.
- MRI has become an increasingly used imaging modality in many fields of medicine, including cardiovascular imaging; therefore, careful patient screening before the examination, accurate evaluation of the individual risk, and qualified patient supervision is mandatory.
- Most reported cases of MR related injuries and the few fatalities that have occurred have apparently been the result of failure to follow safety guidelines or from the use of inappropriate or outdated information related to the safety aspects.

individual case has to be evaluated and if the diagnostic information outweighs concerns about potential negative effects, the MRI examination can be performed with oral and written informed consent provided.[19 w28]

MRI AND CONTRAST AGENT

Today, MR contrast media are administered in 40–50% of all MRI examinations.[22] With increasing numbers of indications for MRI (for example, cardiovascular MRI, MR angiography) the proportion of examinations with usage of contrast agent will further increase. Therefore, it is important to assess each patient's individual risk from contrast administration before starting the examination.

Paramagnetic contrast media during pregnancy and breast feeding

Although gadolinium containing contrast media cross the placental barrier, no published data of teratogenic or mutagenic effects on the fetus related to the administration of gadopentetate dimeglumine, gadoteridol, gadobenate dimeglumine or gadoversetamide in pregnant women exist.[w29–32] The fact that the chelate of gadolinium remains in the amniotic fluid, and the gadolinium ion could dissociate from the chelate (which would be toxic), underlines that administration of contrast agent should be handled in a highly restrictive manner. Paramagnetic contrast media are filtered and eliminated by the kidneys; however, the mammary gland can also contribute to their excretion to a small extent, and so breast milk may contain an extremely small amount of contrast medium. The amount of medium transferred via breast milk is over 100 times less than the maximum intravenous gadolinium dose recommended for neonatal use, the intestinal absorption of ingested gadolinium is extremely small (0.04–0.08% of the amount ingested), and the absorbed amount is rapidly excreted by the kidneys.[23 w33] On the basis of these findings, breast feeding can be continued without reservation after the administration of paramagnetic contrast media to the mother.[21]

Renal insufficiency

Nephrogenic systemic fibrosis (NSF) is a sclerosing disorder found in patients with impaired renal function after MRI examinations with gadolinium based contrast agents (GBCA); symptoms usually develop up to 4 weeks after exposure.[5] NSF is characterised clinically by symmetric, coalescing, indurated dermal plaques most typically found on the extremities, particularly the lower legs and forearms, although fibrosis may be found in other organs (for example, striated muscle, myocardium, lungs, and dura mater).[5 w34–36]

The exact mechanism for the development of NSF remains uncertain. GBCA are renally eliminated and so all patients with impaired renal function are at risk of retaining GBCA after exposure. NSF affects only patients with renal insufficiency and some cofactors are under discussion—for example, previous major surgery, deep vein thrombosis, or metabolic acidosis. The current recommendations state that the use of GBCA is strongly discouraged in patients with glomerular filtration rates of <30 ml/min, in any patient with hepato-renal syndrome, or in liver transplant recipients.[24] Even haemodialysis 12 h or more after GBCA exposure does not protect from the development of NSF.[25] There seem to be differences between the currently approved GBCA in regard to their potential to cause NSF.[5]

CONCLUSION

It is necessary to update continuously our knowledge regarding the safety issues related to MR technology, as well as to the technology of implants, devices, contrast agents, and other aspects related to the MRI examination. MRI has become an increasingly used imaging modality in many fields of medicine; therefore, careful patient screening before the examination, accurate evaluation of the individual risk on the basis of current

You can get CPD/CME credits for Education in Heart

Education in Heart articles are accredited by both the UK Royal College of Physicians (London) and the European Board for Accreditation in Cardiology—you need to answer the accompanying multiple choice questions (MCQs). To access the questions, click on **BMJ Learning: Take this module on BMJ Learning** from the content box at the top right and bottom left of the online article. For more information please go to: http://heart.bmj.com/misc/education.dtl

- **RCP credits:** Log your activity in your CPD diary online (http://www.rcplondon.ac.uk/members/CPDdiary/index.asp)—pass mark is 80%.
- **EBAC credits:** Print out and retain the BMJ Learning certificate once you have completed the MCQs—pass mark is 60%. EBAC/ EACCME Credits can now be converted to AMA PRA Category 1 CME Credits and are recognised by all National Accreditation Authorities in Europe (http://www.ebac-cme.org/newsite/?hit = men02).

Please note: The MCQs are hosted on BMJ Learning—the best available learning website for medical professionals from the BMJ Group. If prompted, subscribers must sign into *Heart* with their journal's username and password. All users must also complete a one-time registration on BMJ Learning and subsequently log in (with a BMJ Learning username and password) on every visit.

recommendations (refer to dedicated websites or literature), and qualified patient supervision is mandatory.

Competing interests: In compliance with EBAC/EACCME guidelines, all authors participating in Education in *Heart* have disclosed potential conflicts of interest that might cause a bias in the article. The author has no competing interests.

REFERENCES

1. **Shellock FG.** *Reference manual for magnetic resonance safety, implants, and devices, 2006 ed*. Los Angeles: Biomedical Research Publishing, 2006.
► **Extensive overview of MRI compatibility of implants and devices.**
2. **Shellock FG.** *Pocket guide to MR procedures and metallic objects: update 2001*. Philadelphia: Lippincott Williams & Wilkins, 2001.
3. **Prasad SK,** Pennell DJ. Safety of cardiovascular magnetic resonance in patients with cardiovascular implants and devices. *Heart* 2004;**90**:1241–4.
4. **Levine GN,** Gomes AS, Arai AE, *et al*. Safety of magnetic resonance imaging in patients with cardiovascular devices: an American Heart Association scientific statement from the Committee on Diagnostic and Interventional Cardiac Catheterization, Council on Clinical Cardiology, and the Council on Cardiovascular Radiology and Intervention. Endorsed by the American College of Cardiology Foundation, the North American Society for Cardiac Imaging, and the Society for Cardiovascular Cardiology Magnetic Resonance. *Circulation* 2007;**116**:2878–91.
► **Recently published comprehensive scientific statement summarising safety issues for MRI in patients with cardiovascular devices.**
5. **Cowper SE.** Nephrogenic systemic fibrosis: an overview. *J Am Coll Radiol* 2008;**5**:23–8.
► **Excellent summary of the current knowledge on nephrogenic systemic fibrosis.**
6. **Kanal E,** Barkovich AJ, Bell C, *et al*. ACR Blue Ribbon Panel on MR Safety. ACR guidance document for safe MR practices: 2007. *Am J Roentgenol* 2007;**188**:1447–74.
► **Excellent article summarising all information required on MR safety.**
7. **Shellock FG,** Kanal E. Aneurysm clips: effects of long-term and multiple exposures to a 1.5-T MR system. *Radiology* 1999;**210**:563–5.
8. **Shellock FG.** Biomedical implants and devices: assessment of magnetic field interactions with a 3.0-Tesla MR system. *J Magn Reson Imaging* 2002;**16**:721–32.
9. **Porto I,** Selvanayagam J, Ashar V, *et al*. Safety of magnetic resonance imaging one to three days after bare metal and drug-eluting stent implantation. *Am J Cardiol* 2005;**96**:366–8.
10. **Edwards MB,** Taylor KM, Shellock FG. Prosthetic heart valves: evaluation of magnetic field interactions, heating, and artifacts at 1.5 T. *J Magn Reson Imaging* 2000;**12**:363–9.
11. **Shellock FG,** Valencerina S. Septal repair implants: evaluation of magnetic resonance imaging safety at 3 T. *Magn Reson Imaging* 2005;**23**:1021–5.
12. **Dempsey MF,** Condon B. Thermal injuries associated with MRI. *Clin Radiol* 2001;**56**:457–65.
13. **Fisher JD.** MRI: safety in patients with pacemakers or defibrillators: is it prime time yet? *Pacing Clin Electrophysiol* 2005;**28**:263.
14. **Martin ET.** Can cardiac pacemakers and magnetic resonance imaging systems co-exist? *Eur Heart J* 2005;**26**:325–7.
15. **Faris OP,** Shein M. Food and Drug Administration perspective: magnetic resonance imaging of pacemaker and implantable cardioverter-defibrillator patients. *Circulation* 2006;**114**:1232–3.
16. **Shinbane JS,** Coletti PM, Shellock FG. MR in patients with pacemakers and ICDs: defining the issue. *J Cardiovasc Magnetic Resonance* 2007;**9**:5–13.
► **Very good overview summarising the current controversy on MRI in patients with pacemakers and ICDs.**
17. **Shellock FG.** New metallic implant used for permanent contraception in women: evaluation of MR safety. *Am J Radiol* 2001;**178**:1513–16.
18. **Whitney D,** Shellock FG. Magnetic resonance imaging and permanent cosmetics (tattoos): survey of complications and adverse events. *J Magn Reson Imaging* 2002;**15**:180–4.
19. **Shellock FG,** Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology* 2004;**232**:635–52.
► **Extensive review providing an overview on MR biologic effects, safety issues, and current guideline recommendations.**
20. **Dewey M,** Schink T, Dewey CF. Claustrophobia during magnetic resonance imaging: cohort study in over 55.000 patients. *J Magn Reson Imaging* 2007;**26**:1322–7.
21. **Stecco A,** Saponaro A, Carriero A. Patient safety issues in magnetic resonance imaging: state of the art. *Radiol Med* 2007;**112**:491–508.
► **Review summarising current safety issues and contraindications to MRI.**
22. **Shellock FG,** Kanal E. Safety of magnetic resonance imaging contrast agents. *J Magn Reson Imaging* 1999;**10**:477–84.
23. **Hylton M.** Suspension of breastfeeding following gadopentetate dimeglumine administration. *Radiology* 2000;**216**:325–6.
24. **Bongartz G.** Imaging in the time of NFD/NSF: do we have to change our routines concerning renal insufficiency? *MAGMA* 2007;**2**:57–62.
25. **Wiginton CD,** Kelly B, Oto A, *et al*. Gadolinium based contrast exposure, nephrogenic systemic fibrosis, and gadolinium detection in tissue. *AJR Am J Roentgenol* 2008;**190**:1–9.