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# SIGURNOST OSOBLJA I PACIJENATA KOD MAGNETSKE REZONANCIJE

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## APSTRAKT

Uvod. Magnetska rezonancija (MRI) predstavlja jednu od najznačajnijih dijagnostičkih metoda savremene medicine zbog superiornog prikaza mekih tkiva i odsustva jonizujućeg zračenja. Tehnologija MRI zasniva se na djelovanju snažnog statičkog magnetskog polja, radiofrekventnih impulsa i gradijentnih polja, što omogućava visokokvalitetne snimke, ali istovremeno nosi i značajne sigurnosne rizike. Cilj ovog rada bio je prikazati osnovne fizikalne principe MRI, uporediti MRI i CT kroz njihove prednosti i nedostatke, te detaljno analizirati sigurnosne procedure, rizike i mjere zaštite pacijenata i osoblja. U radu su opisane glavne opasnosti povezane sa MRI pregledima, uključujući projektilni efekat, zagrijavanje tkiva, opekotine, buku, klaustrofobiju, rizike povezane s implantatima i primjenom kontrastnih sredstava na bazi gadolinija. Posebna pažnja posvećena je sigurnosti implantata i razlikama u rizicima između sistema jačine 1,5 T, 3 T i 7 T. Analizirane su sigurnosne zone MRI odjela, značaj detaljnog screeninga pacijenata, kontrola pristupa MRI sali, kao i važnost MRI kompatibilne opreme. Rezultati ukazuju da većina incidenata u MRI nastaje usljed ljudske

# SAFETY OF STAFF AND PATIENTS IN MAGNETIC RESONANCE IMAGING

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## ABSTRACT

Introduction. Magnetic resonance imaging (MRI) is one of the most important diagnostic methods in modern medicine due to its superior visualization of soft tissues and the absence of ionizing radiation. MRI technology is based on the action of a strong static magnetic field, radiofrequency pulses, and gradient fields, enabling high-quality imaging while simultaneously presenting significant safety risks. The aim of this paper was to present the basic physical principles of MRI, compare MRI and CT through their advantages and disadvantages, and provide a detailed analysis of safety procedures, risks, and protective measures for patients and healthcare staff. The paper describes the main hazards associated with MRI examinations, including the projectile effect, tissue heating, burns, noise exposure, claustrophobia, risks related to implants, and the use of gadolinium-based contrast agents. Special attention is given to implant safety and differences in risks between 1.5 T, 3 T, and 7 T systems. MRI safety zones, the importance of detailed patient screening, access control to the MRI suite, and the use of MRI-compatible equipment are also analyzed. The findings indicate that most MRI-related incidents result from human error, inadequate screening, or insufficient staff education. The greatest risks are associated with ferromagnetic objects,

greške, neadekvatnog screeninga ili nedovoljne edukacije osoblja. Najveći rizici odnose se na feromagnetske predmete, neprovjerene implantate i nepoštovanje sigurnosnih procedura. Sa povećanjem jačine magnetskog polja rastu i rizici od projektilnog efekta, zagrijavanja tkiva, periferne nervne stimulacije i oštećenja sluha. Zaključak. Ova metoda je korisna, ali potencijalno opasna dijagnostička metoda ukoliko se sigurnosni protokoli ne primjenjuju dosljedno. Kontinuirana edukacija osoblja, strogo poštovanje sigurnosnih procedura i pravilna procjena pacijenata predstavljaju osnovne preduslove za bezbjedan rad u MRI okruženju.
**Ključne riječi:** kompjuterizovana tomografija, magnetna rezonancija, sigurnost pacijenta.

unverified implants, and failure to follow safety protocols. As magnetic field strength increases, the risks of projectile accidents, tissue heating, peripheral nerve stimulation, and hearing damage also increase. Conclusion. MRI is an extremely valuable but potentially hazardous diagnostic method if safety protocols are not consistently implemented. Continuous staff education, strict adherence to safety procedures, and proper patient assessment are essential prerequisites for safe work in the MRI environment.

**Keywords:** computed tomography, magnetic resonance, patient safety.

## UVOD

Magnetska rezonancija (MRI) jedna je od najmoćnijih dijagnostičkih metoda moderne medicine. Za razliku od rendgena ili kompjuterizovane tomografije (CT), MRI ne koristi jonizujuće zračenje. Njegova snaga leži u izuzetno jakom magnetskom polju, radiofrekventnim (RF) impulsima i gradijentnim poljima. Upravo ta tehnologija omogućava vrhunske snimke mekih tkiva – mozga, kičmene moždine, zglobova, mišića, ali istovremeno krije ozbiljne prijetnje ako se ne poštuju stroga sigurnosna pravila [1, 2]. Sigurnost u MRI nije „dodatak“ dijagnostici, ona je njen centralni dio. Većina teških incidenata posljedica je ljudske greške, lošeg skrininga, unošenja zabranjenih predmeta ili nedovoljne edukacije osoblja. Ovaj rad daje cjelovit pregled osnovnih fizikalnih principa, upoređuje MRI sa CT-om kroz prednosti i nedostatke, a zatim detaljno obrađuje sigurnosne procedure, posebnosti za različite jačine polja (1, 5 T, 3 T i 7 T), te ponašanje različitih implantata u tijelu [3]. Cilj ovog rada bio je prikazati osnovne fizikalne principe MRI, uporediti MRI i CT kroz njihove prednosti i nedostatke, te detaljno analizirati sigurnosne

## INTRODUCTION

Magnetic Resonance Imaging (MRI) is one of the most powerful diagnostic methods in modern medicine. Unlike X-ray imaging or computed tomography (CT), MRI does not use ionizing radiation. Its strength lies in an extremely strong magnetic field, radiofrequency (RF) pulses, and gradient fields. This technology enables high-quality imaging of soft tissues such as the brain, spinal cord, joints, and muscles while simultaneously posing serious risks if strict safety protocols are not followed [1,2]. Safety in MRI is not an “add-on” to diagnostics; it is a central component of the entire process. Most serious incidents are the result of human error, inadequate screening, introduction of prohibited objects, or insufficient staff training. This paper provides a comprehensive overview of the basic physical principles, compares MRI with CT in terms of advantages and disadvantages, and further discusses safety procedures, specific considerations for different magnetic field strengths (1.5 T, 3 T, and 7 T), as well as the behavior of various implants in the human body [3]. The aim of this paper was to present the basic physical principles of MRI, compare MRI and CT in terms of their advantages and disadvantages, and provide a detailed analysis of safety procedures, risks, procedure, rizike i mjere zaštite pacijenata i osoblja.

**Osnovni fizikalni principi MRI – jednostavno objašnjenje**

Da bismo razumjeli zašto je sigurnost toliko specifična, moramo znati šta se zapravo događa unutar aparata. Magnetska rezonancija ne „fotografiše" tijelo kao rendgen, on detektuje magnetski odjek protona vodonika [3]. Tri ključne komponente su:

**1. Statičko magnetsko polje ($B_0$)** – ogroman, stalno uključen magnet. On djeluje na atome vodonika u našem tijelu (najviše ih ima u vodi i mastima). Bez polja, protoni su nasumično orijentisani. Kada uđemo u magnet, većina protona se postroji paralelno s poljem – poput igle kompasa prema sjeveru. Što je polje jače (1, 5 T, 3 T, 7 T), to je postrojavanje snažnije i signal je bolji – ali su i opasnosti veće [3, 4].

**2. Radiofrekventni impuls (RF)** – kratki, pažljivo podešeni radio talasi koji se šalju kroz tijelo. On „gurne" protone iz ravnoteže – oni su više okrenuti ka strani. Kada se RF isključi, protoni se vraćaju u prvobitno postrojavanje i pri tom otpuštaju signal koji aparat hvata. Upravo taj proces stvara sliku. Zagrijavanje tkiva (SAR – specifična stopa apsorpcije) nastaje upravo zbog RF energije – dio te energije se pretvara u toplotu [3, 5].

**3. Gradijentna polja** – dodatna, slabija magnetska polja koja se brzo uključuju i isključuju. Njihov zadatak je da označe poziciju – omoguće da znamo iz kojeg dijela tijela dolazi signal. Gradijenti proizvode glasnu buku (do preko 100 dB) jer se zavojnice tresu pod djelovanjem magnetskih sila (Lorenc-ove sile), a mogu stimulisati i nerve (osjećaj trnjenja ili trzaj mišića – periferna nervna stimulacija) [3, 6].

Magnetska rezonancija ne može raditi bez magneta. Zato je magnet uvijek aktivan, čak i kada se ne snima. To je ključna činjenica za sigurnost.

and protective measures for patients and healthcare personnel.

**Basic Physical Principles of MRI – A Simple Explanation**

To understand why MRI safety is so specific, it is necessary to understand what actually happens inside the scanner. Magnetic resonance imaging does not "photograph" the body like X-rays; instead, it detects the magnetic response of hydrogen protons [3]. Three key components are involved:

**1. Static Magnetic Field ($B_0$)**

This is a very strong, continuously active magnet. It affects hydrogen atoms in the human body (which are most abundant in water and fat). In the absence of a magnetic field, protons are randomly oriented. When a person enters the MRI scanner, most protons align parallel to the field—similar to a compass needle pointing north. The stronger the magnetic field (1.5 T, 3 T, 7 T), the stronger the alignment and the better the signal quality, but also the higher the associated risks [3,4].

**2. Radiofrequency (RF) Pulse**

These are short, precisely controlled radio waves transmitted into the body. They temporarily disturb the alignment of protons, moving them away from equilibrium. When the RF pulse is turned off, protons return to their original alignment and release energy, which is detected by the scanner and used to create images. Tissue heating (SAR – Specific Absorption Rate) occurs because part of the RF energy is converted into heat [3,5].

**3. Gradient Fields**

These are additional, weaker magnetic fields that are rapidly switched on and off. Their role is spatial encoding determining where the signal originates within the body. Gradient switching produces loud acoustic noise (often exceeding 100 dB) due to vibration of the coils under Lorentz forces. They can also stimulate peripheral nerves, causing tingling sensations or muscle twitching (peripheral nerve stimulation) [3, 6]. MRI cannot function without its main magnet. Therefore, the magnet remains active at

**Upoređivanje MRI i CT – prednosti i nedostaci**

Kompjuterizovana tomografija (CT) koristi rendgensko zračenje – jonizujuće zračenje koje može oštetiti DNK, iako je rizik po jednom pregledu mali. Magnetska rezonancija nema tog rizika, ali ima druga ograničenja. Tabela 1 sažima glavne razlike [7].

***Tabela 1. Poređenje MRI i CT***

| Karakteristika | MRI | CT |
|---|---|---|
| **Fizički princip** | Magnetska rezonanca | Rendgensko zračenje (jonizujuće) |
| **Jonizujuće zračenje** | Nema | Ima (mali, ali kumulativni rizik) |
| **Prikaz mekih tkiva** | Odličan – mozak, mišići, ligamenti, tumor | Slab – meka tkiva se slabo razlikuju |
| **Prikaz kostiju** | Slab (tamne su na snimku) | Odličan – detaljna anatomija |
| **Prikaz pluća** | Vrlo težak (malo vodonika) | Odličan – standard za plućne bolesti |
| **Brzina pregleda** | Spor (20–60 minuta) | Brz (nekoliko sekundi do minut) |
| **Buka** | Veoma glasna (90–120 dB) | Tiha (osim rotacije) |
| **Klaustrofobija** | Česta (uski tunel) | Rijetka (otvoreni prsten) |
| **Metal i implantati** | Stroga ograničenja (mogu biti opasni) | Uglavnom bezbedni (samo artefakti) |
| **Cijena i dostupnost** | Skupo, manje dostupno | Jeftinije, široko dostupno |
| **Hitna stanja (trauma)** | Nije praktično (sporo, metal) | Prvi izbor – brzi pregled cijelog tijela |

*Napomena: MRI = magnetska rezonancija; CT = kompjuterizovana tomografija*

## Prednosti MRI u odnosu na CT

· Bez zračenja – može se ponavljati bez straha od kumulativnog oštećenja (npr. praćenje multiple skleroze, djece) [7].

· Superioran prikaz mekih tkiva – razlikuje tumor od edema, sivu i bijelu masu, mijelinizaciju [3].

all times, even when scanning is not in progress. This is a fundamental safety consideration.

## Comparison of MRI and CT – Advantages and Disadvantages

Computed tomography (CT) uses X-rays, a form of ionizing radiation that can damage DNA, although the risk from a single examination is generally low. MRI does not involve ionizing radiation, but it has other limitations. Table 1 summarizes the main differences [7].

***Table 1. Comparison of MRI and CT***

| Characteristic | MRI | CT |
|---|---|---|
| **Physical principle** | Magnetic resonance | X-ray radiation (ionizing) |
| **Ionizing radiation** | None | Present (low but cumulative risk) |
| **Soft tissue visualization** | Excellent – brain, muscles, ligaments, tumors | Poor – low soft tissue contrast |
| **Bone imaging** | Poor (bones appear dark) | Excellent – detailed bone anatomy |
| **Lung imaging** | Very difficult (low hydrogen content) | Excellent – standard for pulmonary diseases |
| **Examination speed** | Slow (20–60 minutes) | Fast (a few seconds to minutes) |
| **Noise** | Very loud (90–120 dB) | Quiet (except gantry rotation) |
| **Claustrophobia** | Common (narrow tunnel) | Rare (open ring design) |
| **Metal and implants** | Strict limitations (may be dangerous) | Generally safe (mostly artifacts) |
| **Cost and availability** | Expensive, less available | Cheaper, widely available |
| **Emergency situations (trauma)** | Not practical (slow, metal sensitivity) | First choice – rapid whole-body assessment |

**Note:** MRI = Magnetic Resonance Imaging; CT = Computed Tomography.

## Advantages of MRI Compared to CT

- No ionizing radiation – MRI can be repeated safely without cumulative radiation risk (e.g., in follow-up of multiple sclerosis or pediatric patients) [7].
- Superior soft tissue contrast – allows clear differentiation between tumor and edema, gray and

· Više kontrastnih mehanizama – T1, T2, difuzija, perfuzija, funkcionalni MRI (fMRI) daju podatke o funkciji tkiva, ne samo anatomiji.
· Nema kalcifikacijskih artefakata – bolji za zadnju lobanjsku jamu i moždano stablo.

**Nedostaci MRI u odnosu na CT**
· Dugačak pregled – zahtijeva nepomičnost, teško za djecu, starije, bolesnike s bolom.
· Kontraindikacije – pejsmejker, klipse, fragmenti – značajan broj pacijenata ne može na MRI [8, 9].
· Klaustrofobija – do 15% pacijenata ne završi pregled bez sedacije.
· Cijena i nedostupnost – CT je brz, jeftin i prisutan u gotovo svakoj bolnici.
· Loš prikaz kostiju i pluća – za frakture i pneumoniju CT je daleko bolji.

**Klinički primjeri – šta odabrati?**
· Sumnja na plućnu emboliju → CT (brzo, vidi plućne arterije)
· Sumnja na tumor mozga → MRI (odličan prikaz mekog tkiva)
· Trauma s višestrukim prijelomima → CT (brzo, cijelo tijelo)
· Bol u koljenu, sum na oštećenje meniskusa → MRI (vidi hrskavicu, ligamente)
· Akutni moždani udar → CT prvo (da se isključi krvarenje), zatim MRI za procjenu zone infarkta.

**Najveća opasnost – magnetsko polje i projektilni efekat**
Magnetsko polje kliničkih skenera najčešće iznosi 1, 5 T ili 3 T, dok je Zemljino polje svega 0,00005T. Dakle, MRI magnet je desetinama hiljada puta jači. On je stalno aktivan, čak i kada se ne snima [1, 2]. Zato je najpoznatija i najdramatičnija opasnost projektilni efekat: feromagnetski predmet (makaze, boca s kisikom, invalidska kolica, ključevi, infuzione pumpe, telefoni, čak i makaze za zavoje) može naglo poletjeti prema magnetu ogromnom silom, uzrokovati teške povrede ili smrt i oštetiti aparat

white matter, and visualization of myelination patterns [3].
- Multiple contrast mechanisms – T1, T2, diffusion, perfusion, and functional MRI (fMRI) provide not only anatomical but also functional information about tissues.
- No calcification artifacts – better visualization of the posterior cranial fossa and brainstem structures.

**Disadvantages of MRI Compared to CT**
- Long examination time – requires patient immobility, which is challenging for children, elderly patients, and those in pain.
- Contraindications – pacemakers, aneurysm clips, and metallic fragments exclude a significant number of patients from MRI examination [8,9].
- Claustrophobia – up to 15% of patients cannot complete the scan without sedation.
- Cost and availability – CT is faster, cheaper, and more widely available in most hospitals.
- Poor bone and lung imaging – CT is significantly superior for fractures and pulmonary conditions.

**Clinical Examples – What to Choose?**
- Suspected pulmonary embolism → CT (fast, excellent visualization of pulmonary arteries)
- Suspected brain tumor → MRI (superior soft tissue contrast)
- Major trauma with multiple fractures → CT (rapid whole-body assessment)
- Knee pain with suspected meniscal injury → MRI (excellent for cartilage and ligaments)
- Acute stroke → CT first (to exclude hemorrhage), followed by MRI for detailed infarct evaluation.

**The Greatest Hazard – Magnetic Field and Projectile Effect**
The magnetic field strength in clinical scanners is typically 1.5 T or 3 T, whereas the Earth's magnetic field is approximately 0.00005 T. This means that MRI systems are tens of thousands of times stronger. Importantly, the magnet is always active, even when imaging is not being performed [1,2]. The most well-known and dramatic hazard is the projectile effect: ferromagnetic objects (such as scissors, oxygen

[3]. Zbog toga je cijela MRI zona strogo kontrolisana. Postoje četiri sigurnosne zone (prema standardu American College of Radiology) [1, 2]:

· Zona I – javni prostor (čekaonice, hodnici).

· Zona II – prijem pacijenata, mjesto gdje se obavlja početni screening.

·Zona III – kontrolisana zona. Pristup samo obučenom osoblju. Ovdje počinje stroga kontrola feromagnetskih predmeta.

· Zona IV – sama MRI sala s magnetom. Neprovjeren predmet ne smije ući.

Pacijent se iz Zone II vodi u Zonu III i IV samo nakon što je potpuno provjeren. Screening pacijenta jeste najvažnija sigurnosna procedura. Prije svakog pregleda pacijent (ili njegov zakonski zastupnik) mora ispuniti detaljan upitnik. Medicinska sestra ili tehničar provjeravaju [1, 5, 10]:

· Pejsmejker ili ICD (implantabilni kardioverter-defibrilator)

· Aneurizmatske klipse u mozgu

· Kohlearni implantat

· Neurostimulator (npr. za Parkinsonovu bolest, hronični bol)

· Metalni fragmenti u oku ili drugim dijelovima tijela (posebno od starih ratnih povreda ili industrijskih nesreća)

· Stentovi, filteri za krvne sudove [10]

· Ortopedski implantati (proteze, vijci, pločice)

· Insulinska pumpa ili senzor za kontinuirano mjerenje glukoze

· Trudnoća (prvo tromjesečje – relativna kontraindikacija).

Nikada se ne smije pretpostavljati. Ako dokumentacija o implantatu ne postoji ili je nepotpuna, pregled se odlaže dok se ne dobiju tačne informacije od proizvođača ili hirurga [3].

Implantati – detaljna procjena po jačinama polja. Ponašanje implantata ovisi o materijalu, obliku, položaju i jačini magnetskog polja. Postoje tri kategorije [10, 11]:

cylinders, wheelchairs, keys, infusion pumps, mobile phones, and even bandage scissors) can be violently pulled toward the magnet with extreme force, potentially causing severe injury, death, and equipment damage [3]. For this reason, the entire MRI environment is strictly controlled. According to the standard zoning system of the American College of Radiology, the MRI suite is divided into four safety zones:

- Zone I – Public area (waiting rooms, corridors)
- Zone II – Patient reception and initial screening area
- Zone III – Controlled access area; only trained personnel allowed. Strict ferromagnetic control begins here.
- Zone IV – MRI scanner room; no unverified objects are permitted.

Patients are transferred from Zone II to Zones III and IV only after complete screening. Patient screening is the most critical safety procedure. Before every scan, the patient (or legal guardian) must complete a detailed questionnaire. Nurses or radiology technologists verify [1, 5,10]:

- Pacemaker or ICD (implantable cardioverter-defibrillator)
- Aneurysm clips in the brain
- Cochlear implants
- Neurostimulators (e.g., for Parkinson’s disease or chronic pain)
- Metallic fragments in the eyes or body (especially from old war injuries or industrial accidents)
- Vascular stents and filters [10]
- Orthopedic implants (prostheses, screws, plates)
- Insulin pumps or continuous glucose monitoring systems
- Pregnancy (first trimester – relative contraindication).

Assumptions must never be made. If documentation regarding an implant is missing or incomplete, the examination must be postponed until accurate information is obtained from the manufacturer or surgeon [3].

**Implant Safety – Evaluation by Field Strength**

· MR Safe – potpuno bezbjedan u svim MRI okruženjima (npr. titanijske proteze, keramika, plastika).
·MR Conditional – bezbjedan samo pod određenim uslovima (npr. maksimalna jačina polja, maksimalni SAR, specifične sekvence).
· MR Unsafe – nikako ne smije u MRI. Tabela 2 jasno prikazuje sigurnost implantata [8, 9, 10, 11, 12].

*Tabela 2. Sigurnost implantata na 1,5 T, 3 T i 7 T*

| **Tip implantata** | **1,5 T** | **3 T** | **7 T** | **Ključni rizik i napomena** |
|---|---|---|---|---|
| **Srčani pejsmejker / ICD** | **Conditional** | **Conditional** | **Unsafe** | Kvar, neovlaštena stimulacija, zagrijavanje elektroda [5, 6]. |
| **Neurostimulator** | **Conditional** | **Conditional** | **Unsafe** | Isto kao pejsmejker. |
| **Kohlearni implant** | **Conditional** | **Conditional** | **Unsafe** | Rizik od dislokacije magneta; noviji modeli do 3 T uz zavoj [12]. |
| **Aneurizmatska klipsa** | **Safe / Conditional** | **Safe / Conditional** | **Unsafe** | Ako nije poznat model – apsolutna kontraindikacija [8]. |
| **Ortopedska proteza** | **Safe** | **Safe** | **Nije testirano** | Minimalan rizik (titanijum); artefakti. |
| **Dentalni implantati** | **Safe** | **Safe** | **Povećan rizik** | Većina titanijumska – sigurna. |
| **Intraokularno strano tijelo** | **Unsafe** | **Unsafe** | **Unsafe** | Apsolutna kontraindikacija! |
| **Stentovi** | **Safe*** | **Safe*** | **Nije standardizovano** | Nakon endotelizacije su sigurni [8]. *Nakon 6–8 sedmica. |

Implant behavior depends on material, shape, position, and magnetic field strength. According to standardized classification systems developed by organizations such as American Society for Testing and Materials (ASTM International), implants are categorized into three groups:

- MR Safe – completely safe in all MRI environments (e.g., titanium prostheses, ceramics, plastics)
- MR Conditional – safe only under specific conditions (e.g., field strength limits, SAR limits, specific imaging protocols)
- MR Unsafe – must never enter the MRI environment.

Table 2 provides a detailed overview of implant safety across different magnetic field strengths [8,9,10,11,12].

*Table 2. Safety of Implants at 1.5 T, 3 T, and 7 T MRI Systems*

| **Implant Type** | **1.5 T** | **3 T** | **7 T** | **Key Risk and Remarks** |
|---|---|---|---|---|
| **Cardiac pacemaker / ICD** | Conditional | Conditional | Unsafe | Device malfunction, unintended stimulation, lead heating [5,6]. |
| **Neurostimulator** | Conditional | Conditional | Unsafe | Similar risks as pacemakers. |
| **Cochlear implant** | Conditional | Conditional | Unsafe | Risk of magnet displacement; newer models may be scanned up to 3 T with appropriate head bandaging [12]. |
| **Aneurysm clip** | Safe / Conditional | Safe / Conditional | Unsafe | If the exact model is unknown, MRI is absolutely contraindicated [8]. |
| **Orthopedic prosthesis** | Safe | Safe | Not tested | Minimal risk (titanium); image artifacts may occur. |
| **Dental implants** | Safe | Safe | Increased risk | Most are made of titanium and |

| | | | | |
|---|---|---|---|---|
| **Insulinska pumpa / CGM** | **Unsafe** | **Unsafe** | **Unsafe** | Moraju se ukloniti prije ulaska u MRI salu. |

**Legenda: Safe** = MR siguran | **Conditional** = MR kondicionalan | **Unsafe** = MR nesiguran

*Napomena: Za svaki implantat neophodna je provjera tačnog modela i konzultacija baze podataka (npr. mrisafety.com) prije snimanja.*

Postupak sa implantatom:

1. Identifikovati tačan model i proizvođača.
2. Konsultovati dokumentaciju ili on-line bazu podataka
3. Provjeriti uslove: maksimalno polje (T), maksimalni SAR, dozvoljene sekvence.
4. Ako bilo koji uslov nije ispunjen ili nije poznat – ne skenirati [3, 11].

## Opasnost od zagrijavanja i opekotina

Radiofrekventna energija (RF) tokom snimanja zagrijava tkivo. Što je polje jače, veća je i apsorbovana energija (SAR). Opekotine su jedna od češćih komplikacija. Posebno rizično [5]:

· Kablovi i elektrode koji formiraju petlju (indukcija struje)
· Metalni dijelovi odjeće (patentni zatvarači, dugmad, ukrasi)
· Mokra koža (znoj, urin) – smanjuje otpor i povećava zagrijavanje
· Kontakt kože s kožom (npr. butine, podlaktice)
· Tetovaže i trajna šminka – pigmenti mogu sadržavati metalne okside

Prevencija:

· Ukloniti svu metalnu odjeću i nakit.
· Postaviti kablove ravno, bez petlji, i odvojiti ih od kože.
· Koristiti izolacijske jastučiće između dijelova tijela.
· Pratiti SAR vrijednosti na konzoli i ne prelaziti propisane granice [5].

## Buka i zaštita sluha

Gradijentna polja proizvode glasne zvuke zbog brzog uključivanja i isključivanja (Lorencove sile tresu zavojnice). Nivo buke može biti [3, 6]:

· 1, 5 T: do 110 dB

| | | | | |
|---|---|---|---|---|
| | | | | are generally considered safe. |
| **Intraocular foreign body** | Unsafe | Unsafe | Unsafe | Absolute contraindication. |
| **Stents** | Safe* | Safe* | Not standardized | Considered safe after endothelialization [8]. *After 6–8 weeks. |
| **Insulin pump / CGM** | Unsafe | Unsafe | Unsafe | Must be removed before entering the MRI suite. |

Safe = MR Safe | Conditional = MR Conditional | Unsafe = MR Unsafe; **Note:** For every implant, verification of the exact model and consultation of a dedicated MRI safety database (e.g., MRIsafety.com) are essential before imaging is performed

## Procedure for Managing Patients with Implants

1. Identify the exact implant model and manufacturer.
2. Consult the manufacturer's documentation or an online MRI safety database.
3. Verify the required conditions: maximum field strength (T), maximum SAR, and permitted imaging sequences.
4. If any condition is not met or cannot be confirmed, the patient must not be scanned [3,11].

## Heating Hazards and Burns

Radiofrequency (RF) energy used during MRI examinations can cause tissue heating. The stronger the magnetic field, the greater the absorbed energy (SAR). Burns are among the most common MRI-related complications. Particularly high-risk situations include [5]:

- Cables and electrodes forming loops (current induction)
- Metallic components in clothing (zippers, buttons, decorative elements)
- Wet skin (sweat, urine), which reduces resistance and increases heating
- Skin-to-skin contact (e.g., between thighs or forearms)
- Tattoos and permanent makeup, as pigments may contain metallic oxides.

**Prevention:**

· 3 T: do 120 dB
· 7 T: i preko 120 dB
Ove vrijednosti su iznad praga bola i mogu izazvati trajno oštećenje sluha. Obavezna zaštita: pacijent i osoblje koje ulazi u Zonu IV moraju koristiti čepiće ili zaštitne slušalice. Kod malih pacijenata i novorođenčadi dodatno se postavljaju duple zaštite [3].

**Klaustrofobija i psihološka sigurnost**
Uski tunel, buka, dugotrajno nepokretno ležanje i osjećaj gušenja izazivaju anksioznost i paniku kod značajnog broja pacijenata. Osoblje treba [5]:
· Prije pregleda detaljno objasniti šta će se dešavati.
· Održavati glasovni kontakt tokom snimanja.
· Dati pacijentu signalnu kuglu (panic ball) da može prekinuti pregled.
· Procijeniti potrebu za laganom sedacijom ili anestezijom kod visoko anksioznih pacijenata, djece ili pacijenata s kognitivnim smetnjama.

**Kontrastna sredstva – gadolinij**
MRI kontrastna sredstva na bazi gadolinija (npr. gadobutrol, gadopentetat) poboljšavaju vidljivost tumora, upala i vaskularnih lezija. Rizici [7]:
· Alergijske reakcije (osip, mučnina, rijetko anafilaksija)
· Nefrogena sistemska fibroza – teška, ponekad fatalna bolest koju dobijaju bolesnici s teškom bubrežnom insuficijencijom. Zato se prije kontrasta mora provjeriti kreatinin i procijeniti eGFR. Posebno oprezni kod dijabetičara, starijih i hroničnih bubrežnih bolesnika.
· Dugoročna retencija gadolinija u mozgu i kostima – klinički značaj još nije u potpunosti razjašnjen, ali se preporučuje upotreba samo kada je klinički indicirano [7].
Posebnosti prema jačini polja: 1, 5 T, 3 T i 7 T.

a. 1,5 Tesla – standardni nivo rizika

Najčešći skener u kliničkoj praksi. Sigurnosni protokoli su dobro poznati, većina implantata testirana je upravo na 1, 5 T. Projektilni efekat

- Remove all metallic clothing, jewelry, and accessories.
- Position cables straight, without loops, and keep them away from direct skin contact.
- Use insulating pads between body parts that may touch.
- Monitor SAR values on the scanner console and ensure recommended limits are not exceeded [5].

**Acoustic Noise and Hearing Protection**
Gradient magnetic fields generate loud sounds due to rapid switching on and off, causing coil vibration through Lorentz forces. Noise levels may reach [3,6]:
- 1.5 T: up to 110 dB
- 3 T: up to 120 dB
- 7 T: more than 120 dB.

These levels exceed the threshold of pain and may result in permanent hearing damage. Therefore, hearing protection is mandatory. Patients and any personnel entering Zone IV must wear earplugs or protective headphones. For pediatric patients and neonates, double hearing protection is recommended [3].

**Claustrophobia and Psychological Safety**
The narrow tunnel, loud noise, prolonged immobility, and sensation of confinement may provoke anxiety and panic in a considerable number of patients. Healthcare personnel should [5]:
- Provide a detailed explanation of the procedure before the examination.
- Maintain verbal communication with the patient throughout the scan.
- Provide the patient with an emergency call device (panic ball) to stop the examination if necessary.
- Assess the need for mild sedation or anesthesia in highly anxious patients, children, or individuals with cognitive impairment.

**Contrast Agents – Gadolinium**
Gadolinium-based contrast agents (e.g., gadobutrol, gadopentetate) enhance the visualization of tumors, inflammatory processes, and vascular lesions. Potential risks include [7]:

postoji, ali je predvidljiv. Zagrijavanje se kontroliše standardnim SAR granicama. Buka do 110 dB. Iako se čini „najbezbednijim“, i dalje je neophodan temeljan screening [1, 3].

b. 3 Tesla – značajno povećani rizici

Na 3 T magnetska sila je četiri puta veća nego na 1, 5 T. Male feromagnetske čestice ili predmeti postaju opasni projektil. SAR može biti dva do četiri puta veći za iste sekvence – veći rizik od opekotina. Mnogi implantati koji su kondicionalni na 1, 5 T nisu odobreni za 3 T; oni koji jesu često zahtijevaju strože uvjete (kraće sekvence, niži SAR). Periferna nervna stimulacija javlja se češće [3, 5]. Buka prelazi 115 dB. Trudnoća se na 3 T ne preporučuje rutinski – ako postoji izbor, 1, 5 T je poželjniji.

Osoblje na 3 T mora dodatno provjeravati: tetovaže, trajnu šminku, kablove i elektrode, te dvostruko osigurati da nema neprovjerenog metala.

c. 7 Tesla – ultravisiona polja, nova sigurnosna paradigma

Skeneri od 7 T još su uglavnom istraživački, rijetko klinički. Magnetska sila je oko 20 puta veća nego na 1, 5 T. Projektilni efekat je ekstreman – čak i nemagnetni metali mogu pokazivati interakciju. Pri kretanju kroz polje (ulazak ili izlazak) pacijenti i osoblje mogu osjetiti vrtoglavicu, mučninu i magnetofosfene – bljeskove svjetlosti izazvane stimulacijom retine [4, 6]. Zagrijavanje tkiva dostiže kritične nivoe; mnoge sekvence nisu dozvoljene. Gotovo nijedan implantat nije kondicionalan za 7 T – pejsmejkeri, klipse, stentovi, pa čak i titanijumske proteze predstavljaju apsolutnu kontraindikaciju [4, 10].

Trudne osobe (pacijentice ili osoblje) ne smiju ulaziti u Zonu IV. Osoblje mora proći specijalnu obuku, a radnici s implantatima nemaju pristup. Tabela 3 prikazuje jasno poređenje rizika po jačini polja [3, 4, 6].

- Allergic reactions (rash, nausea, and, rarely, anaphylaxis)
- Nephrogenic Systemic Fibrosis (NSF) – a severe and sometimes fatal condition occurring in patients with advanced renal insufficiency. Therefore, serum creatinine levels and estimated glomerular filtration rate (eGFR) should be assessed before contrast administration. Particular caution is required in diabetic patients, older adults, and individuals with chronic kidney disease.
- Long-term gadolinium retention in the brain and bones. Although its clinical significance remains unclear, gadolinium should be used only when clinically indicated [7].

**MRI Safety According to Magnetic Field Strength: 1.5 T, 3 T, and 7 T**

a. 1.5 Tesla – Standard Risk Level

The 1.5 T scanner is the most commonly used MRI system in clinical practice. Safety protocols are well established, and most implants have been tested at this field strength. Although the projectile effect remains a concern, it is generally predictable. Tissue heating can be controlled using standard SAR limits, and noise levels may reach up to 110 dB. Despite being considered the “safest” MRI field strength, thorough patient screening remains essential [1,3].

b. 3 Tesla – Significantly Increased Risks

At 3 T, magnetic forces are substantially greater than at 1.5 T. Even small ferromagnetic particles or objects can become dangerous projectiles. SAR may be two to four times higher for identical imaging sequences, increasing the risk of burns. Many implants classified as MR Conditional at 1.5 T are not approved for use at 3 T; those that are approved often require stricter conditions, including lower SAR limits and shorter imaging sequences. Peripheral nerve stimulation also occurs more frequently [3, 5]. Noise levels commonly exceed 115 dB. Routine MRI during pregnancy at 3 T is generally not recommended when a 1.5 T alternative is available. Personnel working with 3 T systems should pay particular attention to:

- Tattoos and permanent makeup
- Cables and electrodes

***Tabela 3. Poređenje rizika po jačini polja***

| Rizik | 1,5 T | 3 T | 7 T |
|---|---|---|---|
| **Projektilna sila (relativno)** | 1× | ~4× | ~20× |
| **SAR / rizik od opekotina** | Nizak | Umjeren do visok | Vrlo visok |
| **Implantati** | Dobro testirani | Djelimično testirani | Skoro nikako testirani |
| **Periferna nervna stimulacija** | Rijetka | Povremena | Česta |
| **Magnetofosfeni** | Ne | Rijetko | Često (pri kretanju) |
| **Buka** | Do 110 dB | Do 120 dB | >120 dB |
| **Klinička upotreba** | Standardna | Široka | Istraživačka |
| **Edukacija osoblja** | Standardna | Proširena | Specijalna |

*Napomena: SAR = specifična stopa apsorpcije; podaci su relativni i okvirni; stvarni rizici ovise o specifičnom protokolu i opremi.*

## Sigurnost osoblja

Osoblje koje radi u MRI mora biti [1, 2, 5]:

· Edukovano – poznavati fizikalne osnove, zone, procedure u hitnim stanjima.

· Redovno obučavano – najmanje jednom godišnje simulacije incidenata (projektil, quench, kardiopulmonalna reanimacija u zoni IV).

· Upoznato sa sopstvenim implantatima – član osoblja s pejsmejkerom, klipsom ili kohlearnim implantom ne smije ulaziti u Zonu III i IV.

· Trudne radnice – mogu raditi u zoni II i III uz oprez, ali ne smiju biti u zoni IV tokom snimanja (posebno na 3 T i 7 T). Nema dokazanog rizika od polja na fetus, ali se primjenjuje princip opreza [5].

MRI kompatibilna oprema – u Zonu IV smije samo oprema koja je izričito označena kao MR Safe ili MR Conditional za tu jačinu polja. Obična kolica, infuzione pumpe, ventilatori, boce s kiseonikom – mogu poletjeti prema magnetu ili prestati raditi [1].

## Hitna stanja u MRI

Ako pacijent kolabira, dobije aritmiju, prestane disati – najvažnije pravilo glasi: ne unositi standardnu reanimacionu opremu u MRI salu.

- Verification that no unapproved metallic objects enter the MRI environment.

c. 7 Tesla – Ultra-High Field MRI and a New Safety Paradigm

Seven-Tesla MRI systems remain primarily research tools, with limited clinical use. Magnetic forces are dramatically higher than those encountered at 1.5 T. The projectile effect becomes extremely powerful, and even some non-ferromagnetic metals may exhibit interactions with the magnetic field. During movement into or out of the magnetic field, patients and personnel may experience dizziness, nausea, and magnetophosphenes (flashes of light caused by retinal stimulation) [4,6]. Tissue heating can reach critical levels, and many imaging sequences are restricted. Very few implants have been approved for use at 7 T, and many devices considered safe or conditional at lower field strengths require individual evaluation before scanning [4,10]. Pregnant patients and pregnant staff members should not enter Zone IV. Personnel working with 7 T systems require specialized training, and staff members with implants are generally restricted from entering the ultra-high-field MRI environment. Table 3 presents a detailed comparison of risks associated with different MRI field strengths [3,4,6].

***Table 3. Comparison of Risks According to MRI Field Strength***

| Risk Factor | 1.5 T | 3 T | 7 T |
|---|---|---|---|
| **Projectile force (relative)** | 1× | ~4× | ~20× |
| **SAR / burn risk** | Low | Moderate to high | Very high |
| **Implant compatibility** | Well tested | Partially tested | Rarely tested |
| **Peripheral nerve stimulation** | Rare | Occasional | Frequent |
| **Magnetophosphenes** | No | Rare | Common (during movement) |
| **Noise level** | Up to 110 Db | Up to 120 dB | >120 Db |
| **Clinical use** | Standard | Widespread | Primarily research |
| **Staff training requirements** | Standard | Advanced | Specialized |

Standardni defibrilator, kolica, boce s kiseonikom su feromagnetni. Postupak [1, 3]:
1. Odmah izvući pacijenta iz Zone IV (magnetske sale) u Zonu III ili van prostora.
2. Tek onda započeti kardiopulmonalnu reanimaciju i koristiti defibrilator.
3. Pozvati hitnu pomoć.

### Quench – hitno gašenje magneta

Quench se pokreće isključivo u slučajevima ozbiljne opasnosti (npr. kada je osoba priklještena ili postoji neposredna životna ugroženost). Tokom quench-a tečni helijum naglo isparava, magnet gubi svoju supraprovodljivost, a magnetno polje se urušava. Potencijalne opasnosti uključuju:
- gušenje usled istiskivanja kiseonika gasovitim helijumom,
- hladne povrede i promrzline (temperature niže od −250 °C),
- smanjenu vidljivost,
- paniku i dezorijentaciju.

Osoblje mora biti upoznato sa evakuacionim putevima, alarmnim sistemima i procedurama za vanredne situacije i ne sme ostati u prostoriji sa MR skenerom tokom događaja gašenja magneta (quench). Osoblje mora biti upoznato sa evakuacionim putevima, alarmnim sistemima i procedurama za postupanje u vanrednim situacijama i nikada ne sme ostati u prostoriji sa MR skenerom tokom događaja gašenja magneta (quench) [1].

### Prevencija i kontrola infekcija

MR zavojnice (kalemovi), sto za pacijenta, slušalice i prateća oprema svakodnevno dolaze u kontakt sa velikim brojem pacijenata. Mere za prevenciju i kontrolu infekcija obuhvataju [5]:
- rutinsku dezinfekciju svih kontaktnih površina između pregleda pacijenata;
- upotrebu jednokratnih ili zaštitnih navlaka za MR zavojnice (kalemove), kada je to potrebno;

**Note:** SAR = Specific Absorption Rate. The values presented are approximate and relative; actual risks depend on the specific MRI protocol, scanner design, and equipment used.

### Staff Safety

Personnel working in MRI environments must be [1,2,5]:
- Educated – with a thorough understanding of MRI physics, safety zones, and emergency procedures.
- Regularly trained – including at least annual simulation exercises covering incidents such as projectile accidents, quench events, and cardiopulmonary resuscitation (CPR) in relation to Zone IV.
- Aware of their own implants – staff members with pacemakers, aneurysm clips, cochlear implants, or other potentially unsafe devices must not enter Zones III and IV.
- Pregnant employees – may work in Zones II and III with caution but should not remain in Zone IV during scanning, particularly in 3 T and 7 T environments. Although no proven harmful effects of MRI fields on the fetus have been demonstrated, the precautionary principle is applied [5].

Only equipment explicitly labeled as MR Safe or MR Conditional for the specific field strength may enter Zone IV. Standard wheelchairs, infusion pumps, ventilators, and oxygen cylinders may become dangerous projectiles or malfunction in the magnetic field [1].

### Emergency Situations in MRI

If a patient collapses, develops a cardiac arrhythmia, or stops breathing, the most important rule is:
Never bring standard resuscitation equipment into the MRI scanner room.
Conventional defibrillators, emergency carts, and oxygen cylinders are often ferromagnetic and therefore hazardous in the MRI environment.
Emergency Procedure [1, 3]
1. Immediately remove the patient from Zone IV (the magnet room) to Zone III or another safe area.
2. Initiate cardiopulmonary resuscitation (CPR) and use a defibrillator only after the patient has been removed from the magnetic field.

- primenu standardnih mera predostrožnosti, uključujući higijenu ruku i upotrebu zaštitnih rukavica.

**Edukacija – temelj bezbednosti u magnetnoj rezonanci**

Bezbednost u magnetnoj rezonanci zavisi manje od tehnologije, a mnogo više od ljudskog ponašanja. Možda je najopasnija izjava u odeljenju za magnetnu rezonancu: „Pretpostavljam da je bezbedno.“ Zbog toga su kontinuirana edukacija, simulacije vanrednih situacija, jasno definisani protokoli i efikasna timska komunikacija ključni elementi bezbednosti u magnetnoj rezonanci [2,3].

Svaki novi član osoblja treba da završi formalnu obuku iz bezbednosti u magnetnoj rezonanci pre nego što počne samostalno da radi, a godišnja obnova znanja kroz dodatnu obuku trebalo bi da bude obavezna.

## ZAKLJUČAK

Magnetska rezonancija je izuzetno korisna, ali potencijalno veoma opasna tehnologija ako se ne poštuju sigurnosna pravila. Njene prednosti – odsustvo jonizujućeg zračenja i superioran prikaz mekih tkiva – dolaze po cijenu stroge kontrole magnetskog polja, RF energije i implantata. CT ostaje nezamjenjiv za brze preglede, kosti, pluća i traumu, dok MRI dominira u neurologiji, ortopediji i onkologiji mekih tkiva. Sigurnost podrazumijeva dobar screening svakog pacijenta, kontrolu pristupa kroz četiri zone, edukaciju cjelokupnog osoblja, pravilnu opremu (samo MRI kompatibilnu), stalni nadzor pacijenta tokom pregleda, pripremljenost za hitna stanja (reanimacija izvan sale, quench procedure). Većina nesreća u MRI može se spriječiti, ali samo ako se sigurnosna pravila poštuju bez izuzetka. Sigurnost nije dodatak dijagnostici – ona je centralni dio rada sa magnetskom rezonancom.

3. Activate the emergency response system and summon emergency medical assistance.

**Quench – Emergency Magnet Shutdown**

A quench is initiated only in cases of severe danger (e.g., entrapment of a person or life-threatening emergency). During a quench, liquid helium rapidly evaporates, the magnet loses its superconductivity, and the magnetic field collapses. Potential hazards include:

- Asphyxiation due to oxygen displacement by helium gas
- Cold injuries and frostbite (temperatures below −250°C)
- Reduced visibility
- Panic and confusion.

Personnel must be familiar with evacuation routes, alarm systems, and emergency procedures and should never remain inside the scanner room during a quench event [1].

**Infection Prevention and Control**

MRI coils, patient tables, headphones, and accessories come into contact with numerous patients each day. Infection control measures include [5]:

- Routine disinfection of all contact surfaces between patients
- Use of disposable or protective covers for coils when appropriate
- Adherence to standard precautions, including hand hygiene and glove use.

**Education – The Foundation of MRI Safety**

MRI safety depends less on technology than on human behavior. Perhaps the most dangerous statement in an MRI department is: *"I assume it is safe."* For this reason, continuous education, incident simulations, clearly defined protocols, and effective team communication are essential components of MRI safety [2,3]. Every new staff member should complete formal MRI safety training before working independently, and annual refresher training should be mandatory.

## CONCLUSION

Magnetic Resonance Imaging (MRI) is an extremely valuable diagnostic tool but can become potentially hazardous if safety regulations are not strictly followed. Its major advantages the absence of ionizing radiation and superior soft-tissue visualization come at the cost of rigorous control of magnetic fields, radiofrequency energy, and implant-related risks. Computed Tomography (CT) remains indispensable for rapid assessment, trauma imaging, bone evaluation, and pulmonary diagnostics, whereas MRI is the imaging modality of choice in neurology, musculoskeletal imaging, and soft-tissue oncology. MRI safety requires comprehensive patient screening, controlled access through the four MRI safety zones, continuous education of all personnel, the exclusive use of MRI-compatible equipment, ongoing patient monitoring throughout the examination, and preparedness for emergency situations, including resuscitation outside the scanner room and proper management of quench events. Most MRI-related accidents are preventable, but only when safety procedures are followed without exception. Safety is not an addition to diagnostic imaging it is an integral and essential component of MRI practice.

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