

Pediatric MRI Safety

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Texas Children's
Hospital[®]

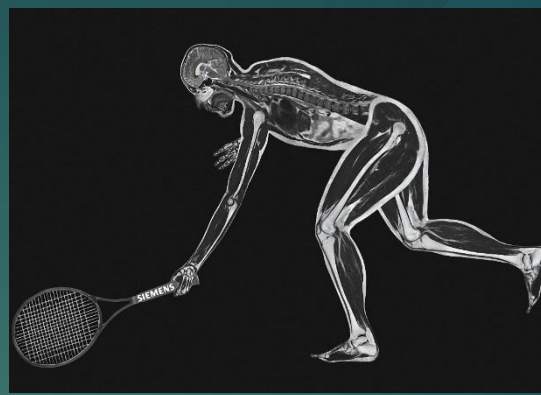
Disclosure

-
- ▶ Contrast agents not FDA approved in Pediatric Population

Learning Objectives

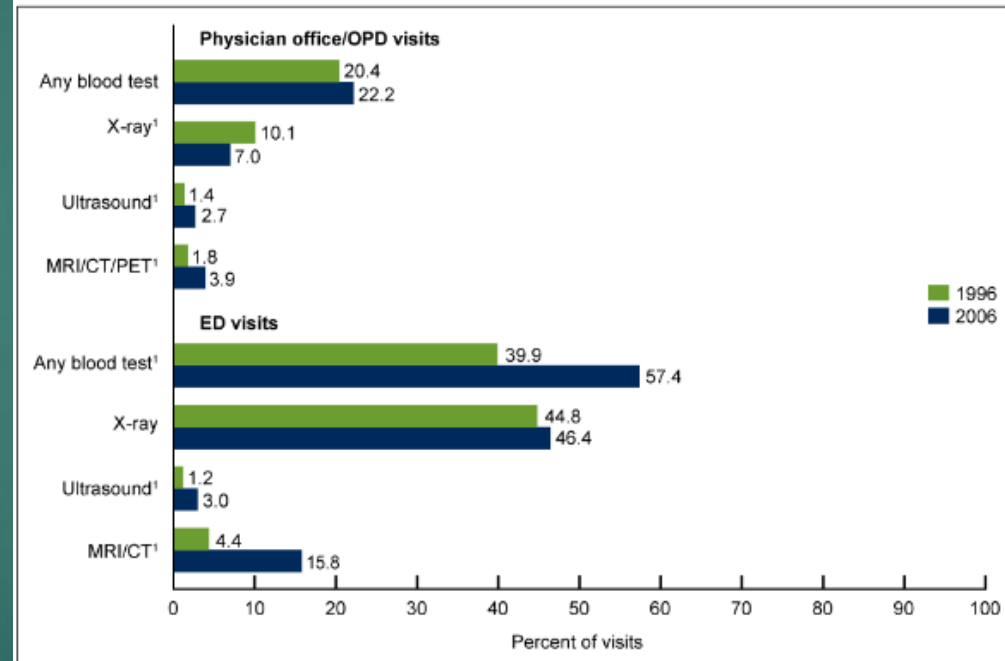
- ▶ MRI Safety in adults and pediatrics
- ▶ Recent advances in knowledge about pediatric MR safety
- ▶ Safe MR Practices to adopt in a pediatric population

MR Imaging



- ▶ Life Saver
- ▶ Huge advances over last decade
- ▶ Ionization Radiation free
- ▶ Considered safe for repeat studies
- ▶ ~10% annual growth of pediatric MRI (and all MRI) over last decade

Figure 2. Ambulatory care visits with selected tests or imaging ordered or provided among adults aged 55–64 years: United States, 1996 and 2006



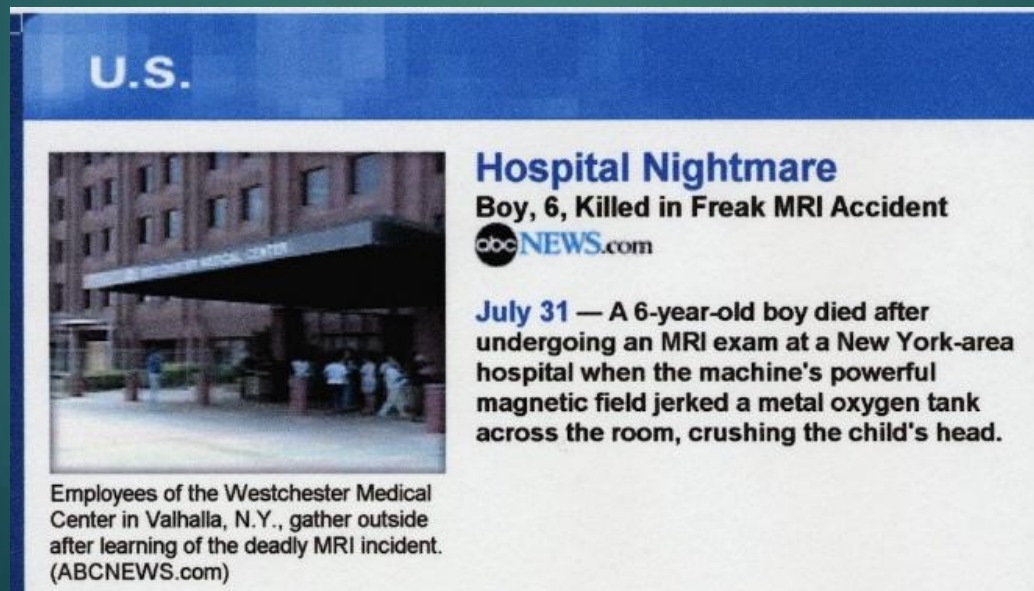
¹Statistically significant difference ($p < 0.05$) between 1996 and 2006.

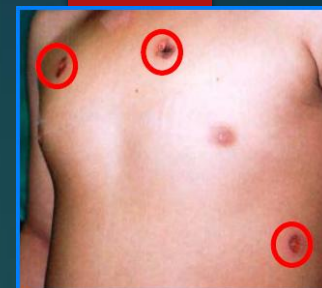
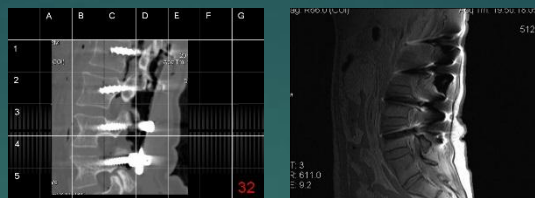
NOTE: OPD is outpatient department; ED is emergency department; MRI is magnetic resonance imaging; CT is computed tomography; PET is positron emission tomography.

SOURCE: CDC/NCHS, National Ambulatory Medical Care Survey and National Hospital Ambulatory Medical Care Survey.

MR Safety

- ▶ MR Safety aspects sometimes ignored
- ▶ Critical in pediatric patients
- ▶ If gone wrong, would be a catastrophe
- ▶ Pediatric specific guidelines not easily available





Projectile

Implants

RF
Heating

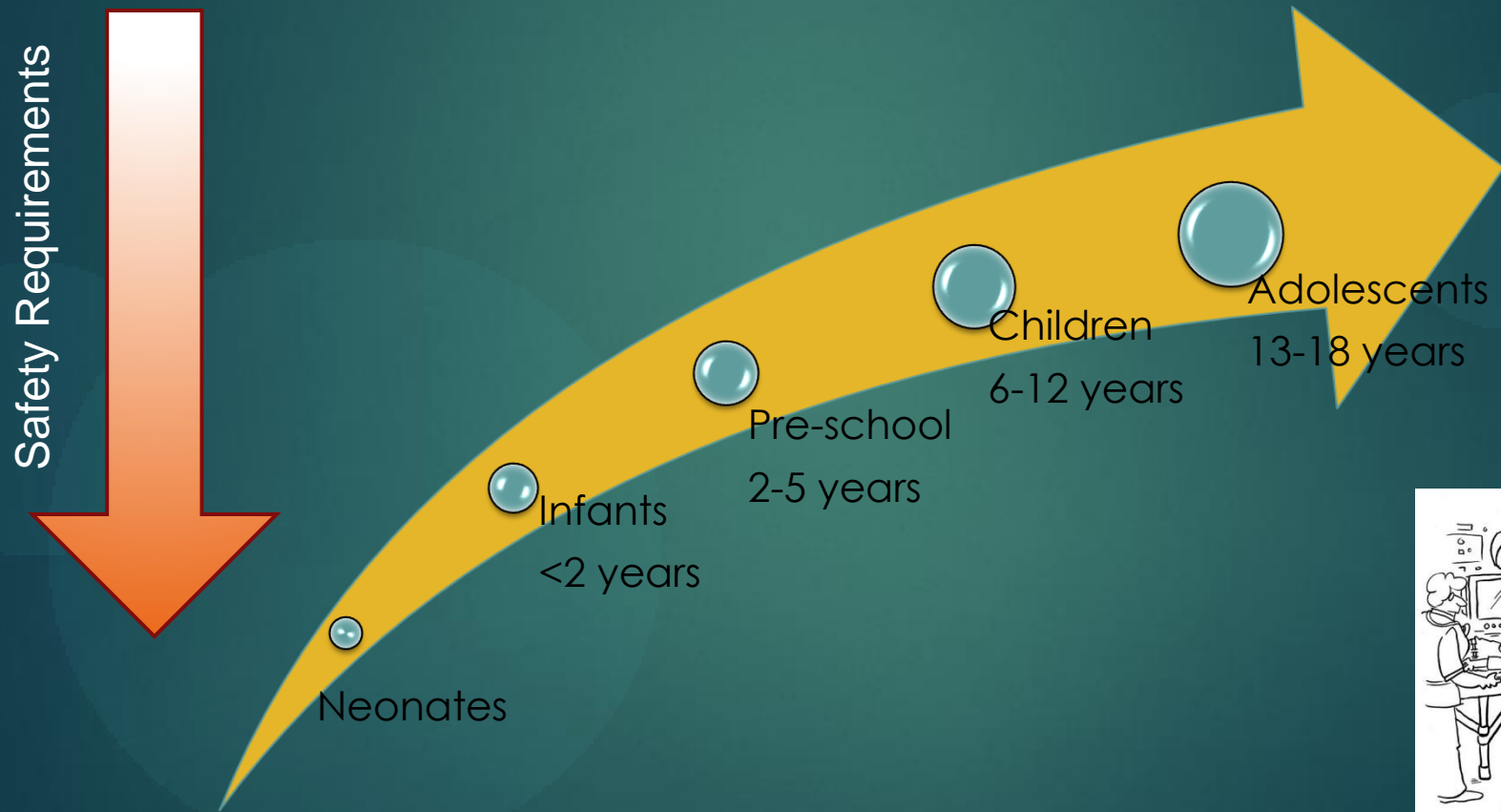
**MRI
Safety**

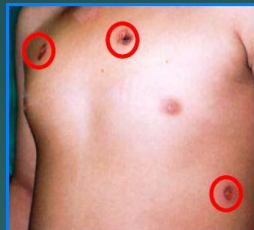
Contrast

PNS

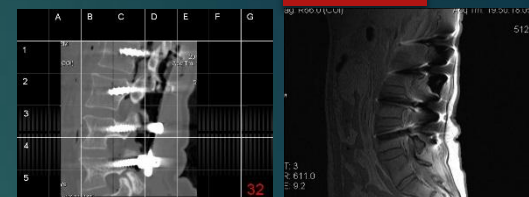


Pediatric MRI Safety





RF
Heating



Projectile

Implants

Pediatric MRI Safety

Sedation

Contrast

10% sedation rate in
pediatrics

PNS



Pediatric MRI Safety: ACR Recommendations

E. Pediatric MR Safety Concerns

1. Sedation and Monitoring Issues

Children form the largest group requiring sedation for MRI, largely because of their inability to remain

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Special Communication

ACR Guidance Document on MR Safe Practices: 2013

Expert Panel on MR Safety: Emanuel Kanal, MD,^{1*} A. James Barkovich, MD,² Charlotte Bell, MD,³ James P. Borgstede, MD,⁴ William G. Bradley Jr, MD, PhD,⁵ Jerry W. Froelich, MD,⁶ J. Rod Gimbel, MD,⁷ John W. Gosbee, MD,⁸ Ellisa Kuhni-Kaminski, RT,¹ Paul A. Larson, MD,⁹ James W. Lester Jr, MD,¹⁰ John Nyenhuis, PhD,¹¹ Daniel Joe Schaefer, PhD,¹² Elizabeth A. Sebek, RN, BSN,¹ Jeffrey Weinreb, MD,¹³ Bruce L. Wilkoff, MD,¹⁴ Terry O. Woods, PhD,¹⁵ Leonard Lucey, JD,¹⁶ and Dina Hernandez, BSRT¹⁶

2. Pediatric Screening Issues

Children may not be reliable historians and, especially for older children and teenagers, should be

3. MR Safety of Accompanying Family or Personnel:

Although any age patient might request that others accompany them for their MR examination, this is far

ACR recommendations: Sedation

E. Pediatric MR Safety Concerns

1. Sedation and Monitoring Issues

Children form the largest group requiring sedation for MRI, largely because of their inability to remain motionless during scans. Sedation protocols may vary from institution to institution according to procedures

Adherence to standards of care mandates following the sedation guidelines developed by the American Academy of Pediatrics (14,15), the American Society of Anesthesiologists (16), and the Joint Commission on Accreditation of Healthcare Organizations (17). In

- ❖ Essential for good image quality
- ❖ Continuum of sedation¹
 - ❖ Mild, moderate, deep sedation
- ❖ MRI scan times are unpredictable
 - ❖ Anesthesia used for longer scans
- ❖ Sedation increased hospital stay >1.5 hours

1. Schulte-Uentrop et al. Curr Opin Anesthesiology 2010, 23:513–517

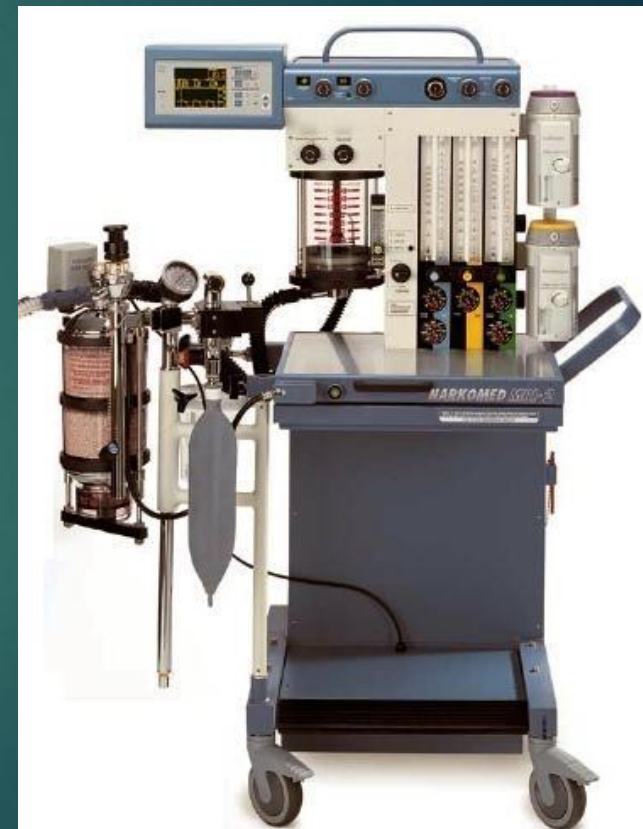
Sedation: Anesthesiologist Issues

- ▶ Thermal regulation issues, especially in neonates – hypothermia¹
- ▶ Evidence of neurotoxicity, learning disability with repeated anesthesia^{2,3}
- ▶ Deeper sedation than intended⁴
- ▶ Reaction to a code in zone III/ IV⁴

1. Young et al., Eur J Anaesthesiol 1996;13:400–3
2. Bong et al. Ped. Neuroscience, Volume 117 • Number 6
3. Yu et al., F1000Research 2013, 2:166

Sedation: MRI Personnel Issues

- ▶ Monitoring devices
 - ▶ Ventilator, anesthetic gas measurement, pulse oximetry, ECG monitor, blood pressure measurement and respiratory frequency monitor
- ▶ Adverse reaction to sedation/ code
 - ▶ Disabled children response
- ▶ No feedback from patient



Sedation: Safe Practices to Follow

- ▶ Vigilance during screening
 - ▶ Incident at Texas Childrens
- ▶ No accompanying personnel if sedated
- ▶ Try and reduce sedation
 - ▶ 'Feed and Bundle' in neonates, infants^{1,2}
 - ▶ Child Life Support (15% reduction in 5-10 year group)³
 - ▶ Movie with eyeglasses



1. Shariat et al., *Pediatr Cardiol* (2015) 36:809–812
2. Neubauer et al., *Acta Paediatrica* 100:1544–1547
3. Durand et al., *J Am Coll Radiol* 2015;12:594-598

ACR recommendations: Screening

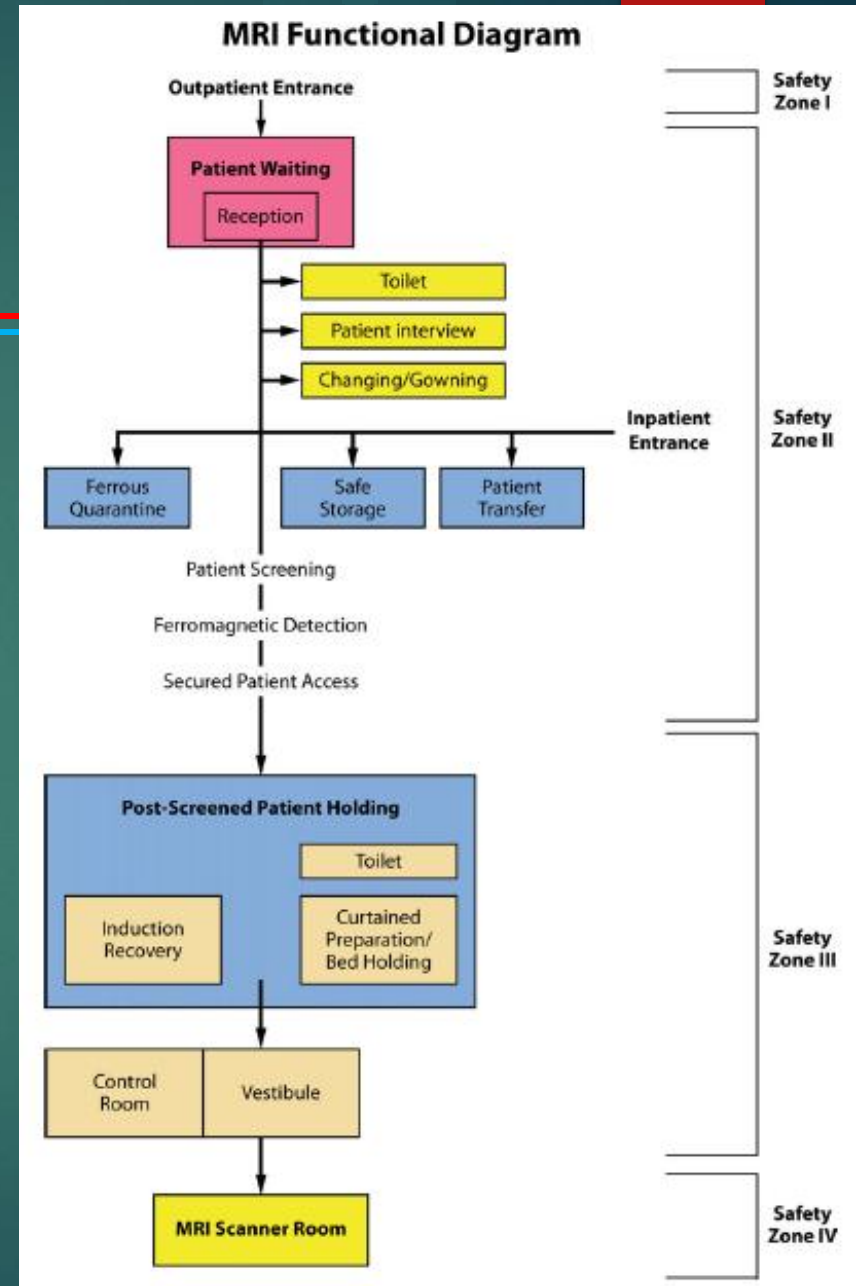
2. Pediatric Screening Issues

Children may not be reliable historians and, especially for older children and teenagers, should be questioned both in the presence of parents or guardians and separately to maximize the possibility that all potential dangers are disclosed. Therefore, it is recommended that they be gowned before entering Zone IV to help ensure that no metallic objects, toys, etc. inad-

- ❖ Proper, comprehensive screening essential for pediatric population
 - ❖ Implants, MR unsafe materials on patients, accompanying personnel, sedation monitoring devices
- ❖ Double screen
 - ❖ Once privately for teenage patients (tattoos, piercings)
 - ❖ Scanning Technologist final one to sign off
- ❖ Gown all patients compulsorily

Screening

- ▶ Educate all MR personnel – level I and level II
- ▶ Implement zoning
- ▶ Have a continuous education policy, at least once a year
- ▶ Once patient in zone IV, scanning technologist has final say
 - ▶ Effective communication essential

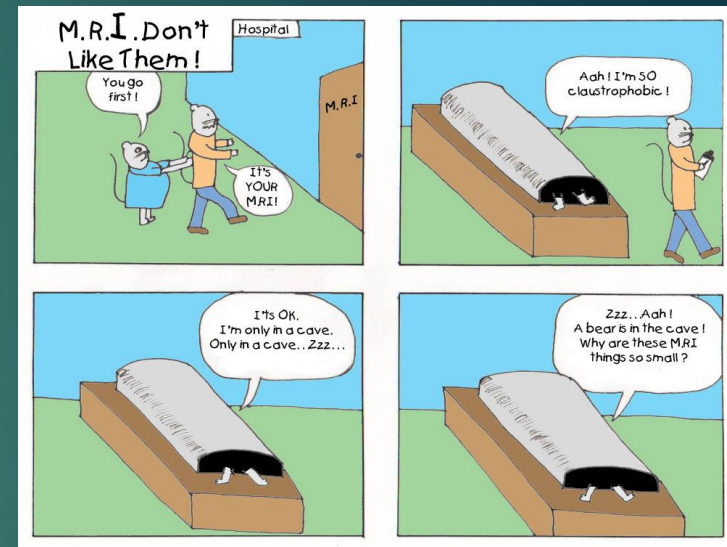


ACR Recommendations: Accompanying family

3. MR Safety of Accompanying Family or Personnel:

Although any age patient might request that others accompany them for their MR examination, this is far more common in the pediatric population. Those accompanying or remaining with the patient should be screened using the same criteria as anyone else entering Zone IV.

- ▶ Accompanying family more common in pediatric population
- ▶ Implement one person only rule
- ▶ Safety screening for the accompanying adult
 - ▶ TCH incident
- ▶ Restrict entry for sedated kids

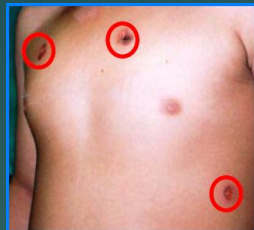


Implementation of ACR Guidelines: MRI Safety Committee

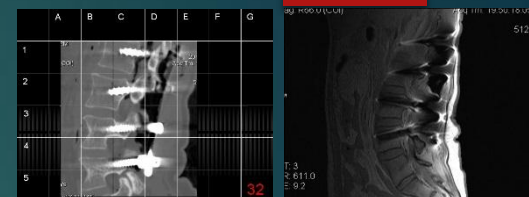
- ▶ Effective way to implement ACR guidelines
 - ▶ Effective feedback mechanism
- ▶ Committee comprises of:
 - ▶ MRI Safety Officer, RSO, lead technologist/Manager, anesthesiologist, nurse, radiologist, department leader
 - ▶ Empowered to design policy for MRI safety
- ▶ Meet quarterly
- ▶ Designate a MRI Safety Officer
 - ▶ Technologist, RSO, MRI physicist, MRI manager, Radiologist
 - ▶ Researching implants, zoning

MRI Safety Committee

- ▶ Discuss any recent incidences, near misses
- ▶ Safety related workflow and image quality issues
- ▶ Design and implement hospital specific new policies
- ▶ @ TCH,
 - ▶ Implant policy for smooth workflow
 - ▶ Screening sticker policy
 - ▶ Contrast adverse reaction policy
 - ▶ No family accompanying sedated patients
 - ▶ Switch to macrocyclic contrast agents



RF
Heating



Projectile

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Pediatric MRI Safety

Sedation

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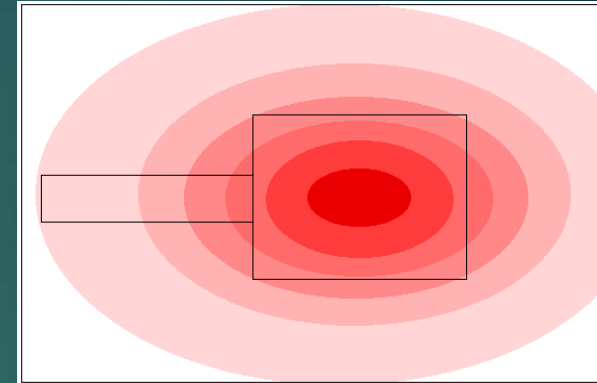
10% sedation rate in
pediatrics

PNS



MRI

- ▶ Powerful magnets – 1.5 – 3T
 - ▶ 1T = 10,000 Gauss
- ▶ Earth's magnetic field: ~ 0.5 Gauss
- ▶ Modern magnets actively shielded
 - ▶ Fringe field extent is small (5 G)
 - ▶ Spatial gradient is huge (Projectile, torque)
- ▶ RF used for excitation : 64/128 MHz (SAR/ RF burns)
- ▶ Fast switching gradients (dB/dt, PNS)
- ▶ Gd based exogenous contrast agents



Projectile

U.S.




Employees of the Westchester Medical Center in Valhalla, N.Y., gather outside after learning of the deadly MRI incident. (ABCNEWS.com)

Hospital Nightmare

Boy, 6, Killed in Freak MRI Accident

abcNEWS.com

July 31 — A 6-year-old boy died after undergoing an MRI exam at a New York-area hospital when the machine's powerful magnetic field jerked a metal oxygen tank across the room, crushing the child's head.

The  force of the device's 10-ton magnet is about 30,000 times as powerful as Earth's magnetic field, and 200 times stronger than a common refrigerator magnet.

The canister fractured the skull and injured the brain of the young patient, Michael Colombini, of Croton-On-Hudson, N.Y., during the procedure Friday. He died of the injuries on Sunday, the hospital said.

The routine imaging procedure was performed after Colombini underwent surgery for a benign brain tumor last week. Westchester Medical Center officials said he was under sedation at the time of the deadly accident.

Hospital Takes 'Full Responsibility'

6 year old – Pediatric Patient

Potential Projectiles - examples



Pediatric MRI Safety: Projectiles

- ▶ Ferromagnetic implants, other monitoring devices
 - ▶ Alloys containing iron, nickel, cobalt
- ▶ Compulsory gowning for pediatric patients
- ▶ Screen sedated patients carefully
 - ▶ Recent incident at Texas Children's
- ▶ If unsure, do your research, ask vendor
- ▶ Minimize devices in MRI scanner room

Pediatric MRI Safety: Implants

- ▶ Implant decision making nerve wracking
 - ▶ Especially in sedated kids
 - ▶ Rigorous screening essential
- ▶ No implant is MR Safe
 - ▶ MRI conditional, MRI unsafe
- ▶ Pediatric patients come with wide array of implants
 - ▶ Inclusive of most adult implants
 - ▶ Shunts, DBS etc.
 - ▶ Also, tattoos, piercings etc.



Pediatric MRI Safety: Implants

- ▶ Screen for prior MRI of patients
 - ▶ Have X-ray policy ready
- ▶ Establish good communication between various departments
 - ▶ Surgery
- ▶ Have list of prior encountered implants
- ▶ Have contact number/name for common implant manufacturers ready
 - ▶ Have them send out a MR safety letter about implants.
 - ▶ Document any newly encountered implants

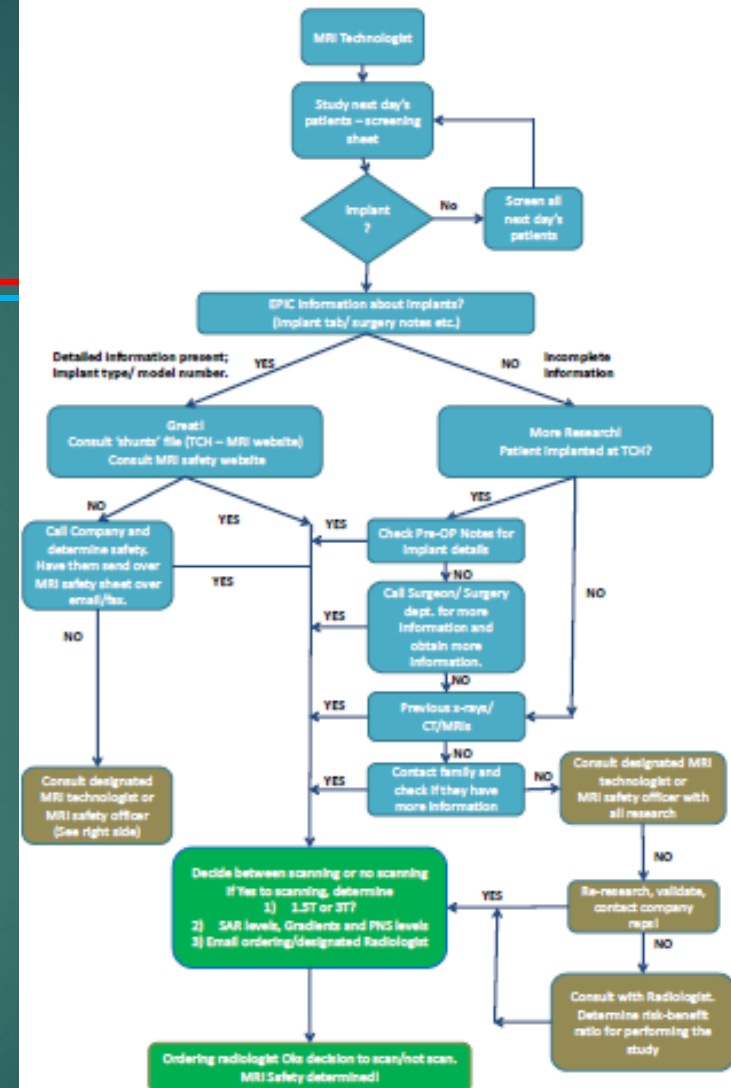
Implants Decision Making Hierarchy

- Pre screen the patients
- If technologist cannot determine safety, escalate to lead tech/ Safety officer
- If still undecided, communicate with medical director/ ordering Radiologist
 - Risk to Benefit ratio

Electrocardiography.

- k. Final determination of whether or not to scan any given patient with any given implant, foreign body, etc. is to be made by the level 2 designated attending MR radiologist, the MR medical director, or specifically designated level 2 MR personnel following criteria for acceptability predetermined by the medical director. These risks include, among others, consideration of mechanical and thermal risks associated with MR imaging of implants, as well as assessments of the safety of exposure of the device to the electromagnetic forces used in the MR imaging process.

Implant Decision Making Hierarchy



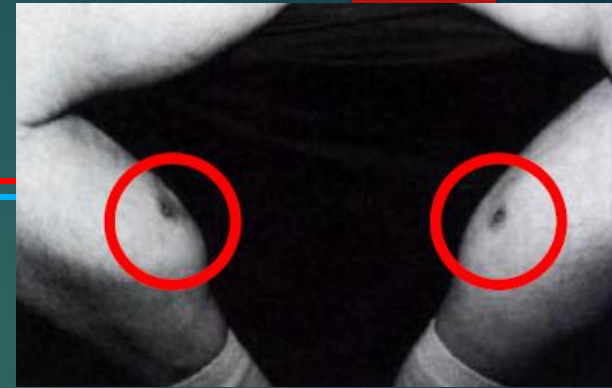
For determining implant safety for patients the day of imaging, follow the same procedure starting from looking at the implant tab. This practice is discouraged for pre-scheduled patients with either their EPIC implant tab populated or a filled screening sheet.

Document Mandatory:

- 1) Any new implant encountered!
- 2) New/updated contact information for implant manufacturer/representative

Pediatric MRI Safety: RF Heating

- ▶ RF – non-ionizing radiation
- ▶ RF heating and burns are frequent
 - ▶ Burns most common cause of MR safety related incidents¹
 - ▶ SAR – heat deposition by RF (local, global)
 - ▶ Heating burns in leads, implants
 - ▶ Heating burns – body as a loop



Specific Absorption Rate (SAR)

Site	Dose	Time (min) equal to or greater than:	SAR (W/kg)
whole body	averaged over	15	>4
head	averaged over	10	>3.2

Pediatric MRI Safety: RF Heating

- ▶ Critical to input the right weight of patient
- ▶ Proper positioning, insulation using pads
- ▶ Check for MRI compatible leads
- ▶ Re-emphasis through-out the scan



Pediatric MRI Safety: Contrast

- ▶ Gadolinium based contrast agents widely used
 - ▶ Reduction in T1
 - ▶ Highlights tumors, abnormal vasculature, perfusion deficits
- ▶ Different types
 - ▶ Linear non-ionic (Omniscan™, Optimark™)
 - ▶ Linear ionic (Magnevist™, Multihance™, Ablavar™)
 - ▶ Macrocyclic (Dotarem™, Gadovist™, Prohance™)

Pediatric MRI Safety: Contrast

- ▶ Nephrogenic Systemic Fibrosis
- ▶ MR Safety issues: Contrast adverse reaction¹
 - ▶ Nausea, vomiting, more serious adverse events
 - ▶ Allergies more common in children (FDA guidance)
 - ▶ Accumulation of Gadolinium in body²
- ▶ Accumulation of contrast in body
 - ▶ Switch to macro-cyclic contrast agents³
 - ▶ @ TCH, efforts on to move to macro-cyclic agents

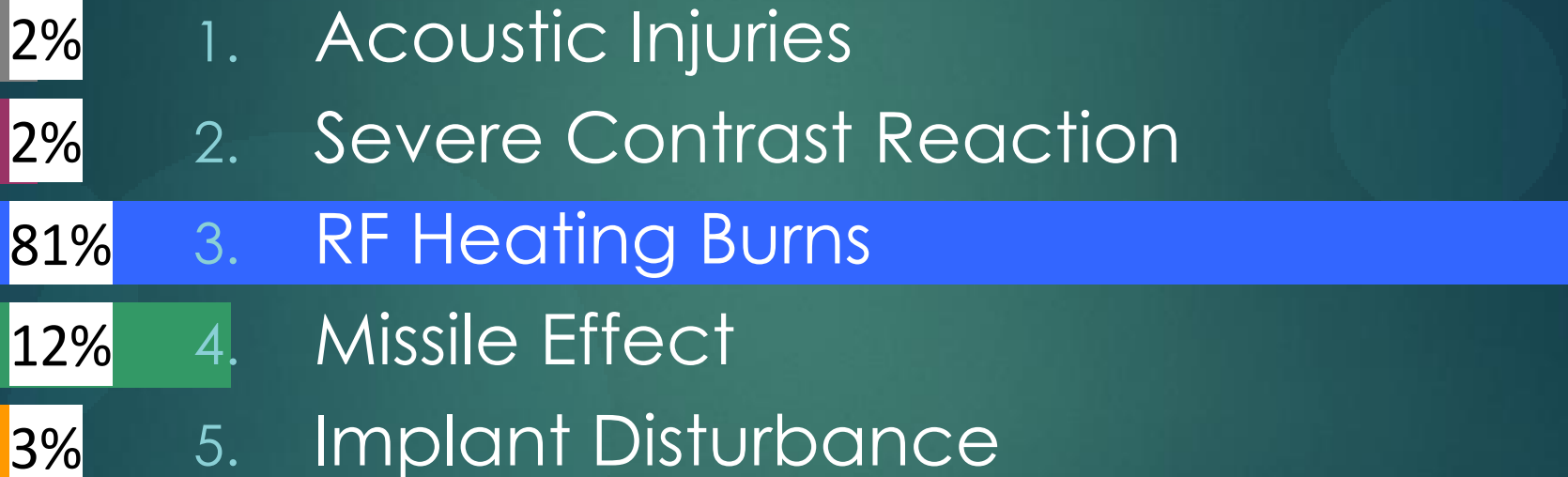
1. Hao et al Jn OF MRI36:1060–1071 (2012)
2. Morris et al., AJNR Am J Neuroradiol. 2007 Nov-Dec;28(10):1964-7
3. Balassy et al., Pediatr Radiol DOI 10.1007/s00247-015-3394-9

Other Pediatric MRI Safety Issues

- ▶ Peripheral Nerve Simulation
- ▶ Acoustic Noise
 - ▶ < 99 dB
 - ▶ 3T > 1.5 T
- ▶ Genotoxic effects of MRI¹
- ▶ Effect on pre-term babies
- ▶ Fetus imaging

1. Simi et al., Mutation Research 645 (2008) 39–43

The Most Commonly Encountered MRI Safety Issue is...

- 
- | Rank | Safety Issue | Percentage |
|------|--------------------------|------------|
| 1. | Acoustic Injuries | 2% |
| 2. | Severe Contrast Reaction | 2% |
| 3. | RF Heating Burns | 81% |
| 4. | Missile Effect | 12% |
| 5. | Implant Disturbance | 3% |
1. Acoustic Injuries
 2. Severe Contrast Reaction
 3. RF Heating Burns
 4. Missile Effect
 5. Implant Disturbance

The Most Commonly Encountered MRI Safety Issue

- RF Heating Burns...[Reference: MAUDE]
 - Tattoos
 - Implants – could be 100 different things
 - Wires and Leads (Most common)
 - Piercings/ Jewelry
 - Patient crossing legs/ hands...
- Different from tissue temperature increase due to RF energy deposition

It is critical to provide the MR technologist with the infant's actual body weight to

- 0% 1. Manage MRI scanner table vibrations
- 81% 2. Avoid excessive RF exposure
- 0% 3. Determine safety of an implanted object
- 19% 4. Determine sedation time/limitations
- 0% 5. Set fastest possible imaging protocol

It is critical to provide the MR technologist with the infant's actual body weight to

- ▶ Avoid excessive RF exposure

Pediatric MRI: Image Quality Considerations

- Think in tandem with safety / artifacts
- Extreme size variations
 - Appropriate coil selection
- Various implants/needs
 - Imaging with Artifacts
- Tailor sequences for
 - Varying sizes
 - Varying restrictions based on MRI conditional implants
 - Patient motion for non-compliant kids

To Conclude...

- ▶ MRI is a life saver
- ▶ Thing life long burden in pediatric patient
 - ▶ Contrast, sedation, MRIs
- ▶ Enable reduction of sedation
- ▶ Implants Safety and Screening
- ▶ Think RF heating and burns
- ▶ MRI Safety Committee



http://www.lifewithelizagrace.com/2009_07_01_archive.html

MRI is a life saver

Acknowledgements

- ▶ Frank Goerner, Ph.D. – RSO, Texas Children's Hospital
- ▶ Anne Sawyer, RT – FDA
 - ▶ <http://www.fda.gov/downloads/MedicalDevices/NewsEvents/WorkshopsConferences/UCM283562.pdf>
- ▶ Radiology department colleagues at TCH

Thank You!

References

- ▶ ACR Safety Document (JMRI 2013)
 - ▶ Small Pediatric Reference
- ▶ **Ensuring Safety for Infants Undergoing Magnetic Resonance Imaging**
 - ▶ Laura A. Stokowski, RN, MS. Adv Neonatal Care. 2005;5(1):14-27.
 - ▶ <http://www.medscape.com/viewarticle/499273>