Evolution of Radiology: Focus on MSK MRI

Nov 8th, 1895: The Birth of Radiology

Radiographs
CT
MR
Signal
Sequences
Coils
Magnets
Safety
Hardware

- 11/8/95 Wilhelm Conrad Röntgen produces "X-rays"
- 12/28/95 Röntgen presents: "On a New Kind of Rays"
- 2/11/96 Jones publishes: "The Discovery of a Bullet Lost in the Wrist by Means of the Roentgen Rays"

First Radiograph
Röntgen's wife

1901:Röntgen wins 1st Nobel prize in physics

X-rays as Diagnostic Tool

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Can see:	Can't see:
➢Bones	➢Inside skull
✓Fractures	✓Can't see the brain
➢Joint width, surfaces	➢Inside joints
✓Arthritis	✓Can't see tears
❖Osteophytes	❖Ligaments, Tendons
❖Erosions	❖Menisci, Cartilage

Radiographs: 2D projection of 3D patient

- Radiographs flatten everything
  - ✓Can't tell what's in front, what's behind
- With radiographs: NEED MULTIPLE VIEWS!

"One view = No views"

"One view = No views"

Radiographs
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Need Multiple Views

Radiographs
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Small finger

- Not a subtle fracture
- Fragment overlap each other so perfectly on PA view, are undetectable

For Joints: Need 3 Views!

Radiographs
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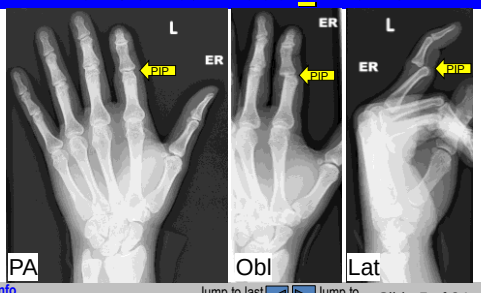

CT: Giant Leap Forward

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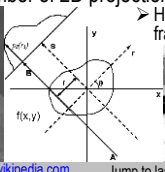
CT: Computed Tomography (*Tomo* [Gr]: part, slice)
CAT: Computed Axial Tomography
1917 Johann Radon, Austrian mathematician, proved image of a 3D object could be reconstructed from an infinite number of 2D projection images of the object.

- Had to await the advent of main-frame computers in the 1970's.



Evolution of Radiology: Focus on MSK MRI

Hounsfield & EMI Brain Scanner

Radiographs
CT
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1972: Godfrey Hounsfield, a British electrical engineer at EMI Laboratories, developed EMI Brain Scanner.

- **Finally, could see through the skull into the brain!**
  - ✓Awarded Nobel Prize for Medicine 1979; Knighted 1981.
  - ✓"Hounsfield Units" is the scale we use to measure CT density.
- EMI: "Electric and Musical Industries"

Why CT is So Great

Radiographs
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MR
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Safety
Hardware

Can see the brain
- ➢Strokes, bleeds, tumors

Can see organs (lungs, liver, bowel)
- ➢Tumors, trauma, acute/chronic diseases

Can see fractures otherwise missed
- ➢Cervical spine, pelvis

And now with ultra-fast, multi-slice…
- ➢Can scan the heart in a single beat!
  - ✓Can see coronary arteries, pulmonary emboli

Hospitals have CT scanners in the ER

CT Usage Increasing in ERs

Radiographs
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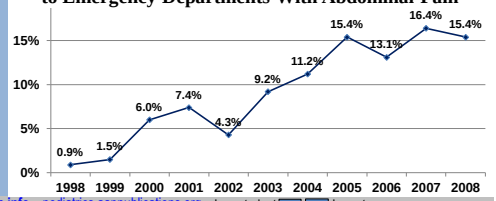
Hardware

Pediatrics Nov 2012 Vol 130, # 5, p 1–7 PEDIATRICS Published online October 8, 2012
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Computed Tomography Use Among Children Presenting to Emergency Departments With Abdominal Pain



☢ Biggest Problem with CT ☢

Radiographs
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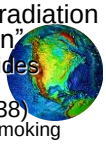
High radiation dose

We are exposed to low levels of radiation every day, "Background Radiation"



- ➢Earth: naturally occurring radionuclides
  - ✓Uranium-238, potassium-40
- ➢Atmosphere: Radon-222 (from U-238)
  - ✓2nd leading cause of lung cancer after smoking
- ➢Space: cosmic rays
  - ✓Airline crews, who spend a lot of time in the upper atmosphere, receive 2x typical background dose.

Ave background dose ≈ 2.4mSv/year

☢ Radiation from Diagnostic Imaging ☢

Radiographs
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Ave background dose ≈ 2.4mSv/year

Chest Radiograph ≈ 0.06mSv
- ➢≈1 week of background radiation

Chest CT ≈ 7.0mSv
- ➢***≈3 YEARS of background radiation***

How much radiation is too much?

*"Risks of medical imaging at effective doses below **50 mSv** for single procedures or **100 mSv** for multiple procedures over short time periods are too low to be detectable and may be nonexistent."*

Other Problems with CT

Radiographs
CT
MR
Signal
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Hardware

Usually requires IV contrast
- ➢1% patients are allergic to CT contrast
- ➢Can affect renal function

Costs more than radiographs
- ➢Knee radiographs (4 views): $154
- ➢Knee CT (no contrast): $1,200

Can't see structures inside joints
- ➢Knee: Menisci, Ligaments, Cartilage
- ➢Shoulder: Rotator Cuff, Labrum
- ➢Spine: Disks, Spinal Cord

MRI: Giant Leap Sideways

Radiographs
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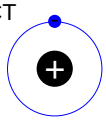
MRI doesn't rely on X-rays to see projected shadows of patients
- Unlike radiographs, tomography, CT

MRI sees tissues based upon sub-atomic characteristics
- Proton nucleus of Hydrogen

"NMR"
- "~~Nuclear~~ Magnetic Resonance"
- *"No More Radiologists"*

MRI
- "Magnetic Resonance Imaging"



MRI Scanner: 2 Components

Radiographs
CT
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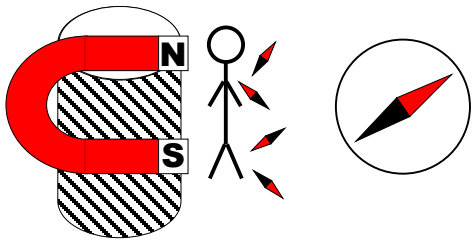
THE MAGNET



MRI Scanner: 2 Components

Radiographs
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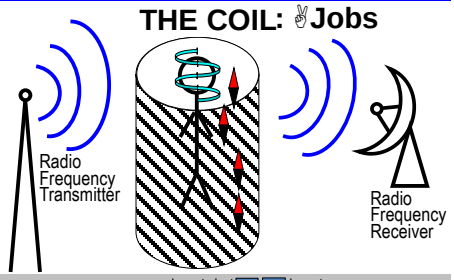
THE COIL: ✌Jobs



How MR Scanner Works

Radiographs
CT
MR
Signal
Sequences
Coils
Magnets
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Hardware

Magnet
- Aligns spins of protons in hydrogen nuclei
  - ✓Align in direction of magnetic field, B_0

Coil

1) Sends RF pulse to flip spinning protons
   - ✓After RF pulse is off, protons realign to B_0
   - ✓As protons realign, resonate RF energy
2) Measures strength of resonant RF echo
   - ✓**At a specific time, T_E, "Echo Time"**

Steps 1&2 repeated many times / image slice
- ✓**At a specific "Repetition Time", T_R**

Key to MRI

Radiographs
CT
MR
Signal
Sequences
Coils
Magnets
Safety
Hardware

Specific tissue types have specific resonant echoes (T1, T2) depending upon specified T_R & T_E

- **Fluid (Hydrogen protons in H_2O)**
  - ✓Cysts
  - ✓Joint effusions
  - ✓Edema (in soft tissues, in bone marrow)
- **Fat (Hydrogen protons in fat)**
  - ✓Sub-cutaneous fat
  - ✓Fatty yellow bone marrow
- **Dense Stuff (with few Hydrogen protons)**
  - ✓Cortical bone
  - ✓Ligaments, tendons
  - ✓Menisci

T1 Recovery Curve (T_R~500ms)

Radiographs
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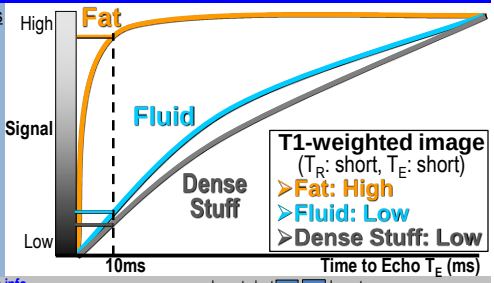
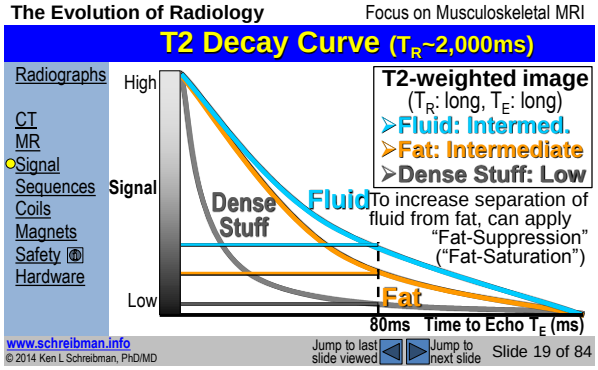
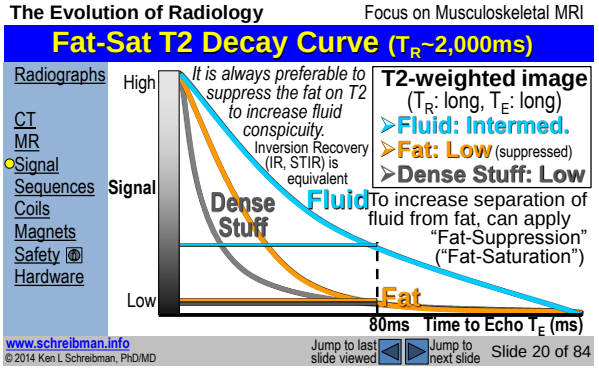
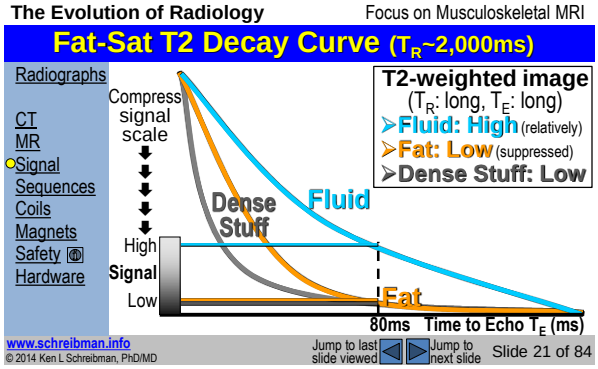
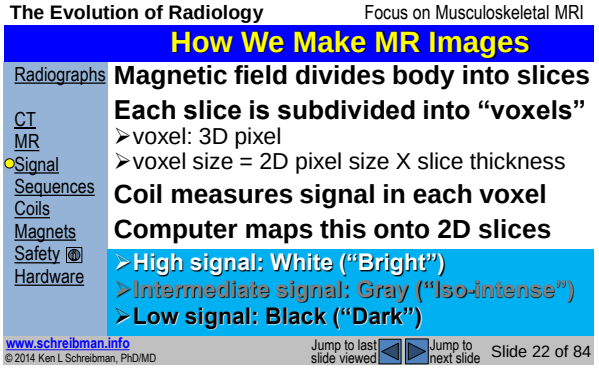


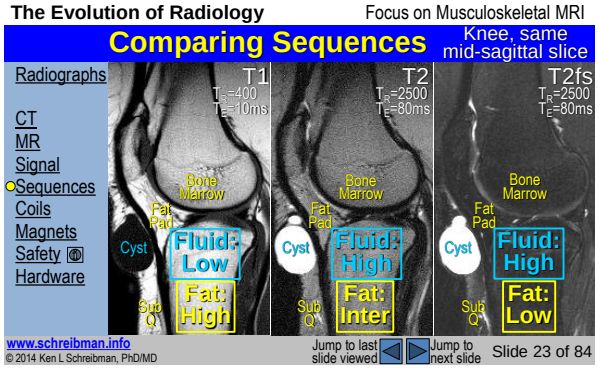
Evolution of Radiology: Focus on MSK MRI

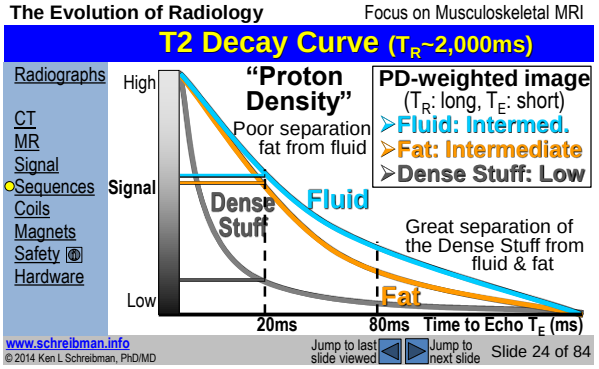








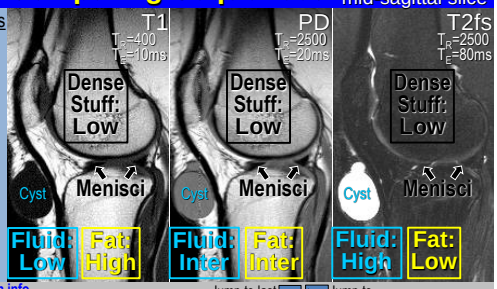




Evolution of Radiology: Focus on MSK MRI

Comparing Sequences

Knee, same mid-sagittal slice



MRI: Need Multiple Sequences

T1 shows Fat best
- Most normal anatomy surrounded by fat
- In essence, T1 shows anatomy best

T2 shows Fluid best
- Most pathology contains fluid (edema)
- In essence, T2 shows pathology best
  - ✓Fat-suppression makes fluid more conspicuous

PD shows Dense Stuff best
- Good for meniscal and tendon tears
- Used mostly for MRI of joint pain

Limitations of MRI

Limited Field of View (FOV)

Image resolution related to voxel size
- Smaller FOV = smaller voxels
- Smaller voxels = higher resolution
- To maximize resolution, try to limit FOV

Can only image inside the coil
- Requires an assortment of different coils for different body parts

Knee Coil

Knee Coil for the Ankle

Foot Coil

Evolution of Radiology: Focus on MSK MRI

Elbow Coil

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Wrist Coil

Radiographs
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Hardware

2 Part Torso Coil

Radiographs
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Many Coils are Needed

Radiographs
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Signal Sequences
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Hardware

MRI Scans are Expensive

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
Safety
Hardware

- Coils are expensive: >$25,000 EACH!
- Scanners are expensive: >$2,000,000
- Specialty trained technologists are expensive
- **MR scans take 30-60 minutes**
  - ✓Run several sequences in several planes
  - ✓Can scan only a limited number of patients per day
  - ✓Have to charge a lot per scan

Knee Radiographs (4 views): $154
Knee CT (no contrast): $1,200
Knee MR (no contrast): $2,400

Don't order MSK MR before getting Radiographs!

MR Scans are Long

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
Safety
Hardware

MR scans take 30-60 min

- Patient's need to lie still… like a statue… for the entire time.
- If the patient is ill the day of the scan and can't stop coughing or sneezing, should reschedule.
- Patients who can't lie flat, severe heart failure (CHF), can't get MRI.

Evolution of Radiology: Focus on MSK MRI

Scanners

Radiographs
CT
MR
Signal
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Hardware

A CT scanner… is a doughnut

Scanners

Radiographs
CT
MR
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Hardware

A CT scanner… is a doughnut

An MR scanner… is a cannoli

MR Scanner is a Tube

Radiographs
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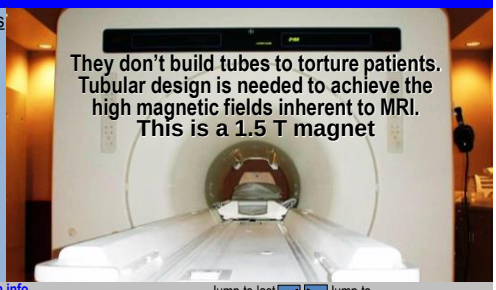

Tesla: Measure Magnetic Field Strength

Radiographs
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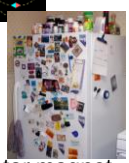
Earth's magnetic field:
- 30 μT (3×10^{-5} T)

Typical refrigerator magnet:
- 3 mT (3×10^{-3} T)



High Field MRI scanner:
- 1.5 – 3 T
- 1,000 times the strength refrigerator magnet
- 100,000 times the Earth's magnetic field

"Open" MRI = Low Field

Radiographs
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Favored by commercial stand-alone MRI sites

Our MRI scanner is open on all four sides; that's a major advantage for large people who find a tunnel too confining, for children who might become frightened inside a tunnel, and for anyone with a touch of claustrophobia.

"Open" MRI = Low Field

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Favored by commercial stand-alone MRI sites

- Typical open MR: 0.1-0.3T
- 1/10th strength of a high field scanner…

- 1/10th image resolution of a high field scanner.
- Costs 1/10th the price to buy low field scanner…
- They charge the same price as a high field scan.

Diagnostic value of low field MR is inferior to that of high field MR.

Evolution of Radiology: Focus on MSK MRI

UW Experience with Open MR

Radiographs
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0.7 T "Mid Field"

- This is highest field open scanner made

Our accuracy: Knee

- In 1.5 T MR: ≈ 95% ☺
- In this scanner: 75% ☹
  - ✓Same UW radiologists
  - ✓Same UW protocols

Diagnostic value of low field MR is inferior to that of high field MR.

UW Experience with Open MR

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Our surgeons refused to schedule patients in our open scanner.

- Ran it only 2 days/week
- Primarily:Obese patients
- As bad as this scanner was, it did a particularly poor job with… obese patients.
- Got rid of it for a 3 T ☺!

My Recommendations

Radiographs
CT
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For yourself or your patients:

- Don't use open low field scanners
- Always want to use at least a 1.5 T scanner
- **Go to a 3 T if available!**

What about obese patients?

- Patients who don't fit in the standard 1.5 T?
- **We now have an alternative to low field open scanners for the "Wisconsin-sized" patient…**

Wide Bore 1.5T

Radiographs
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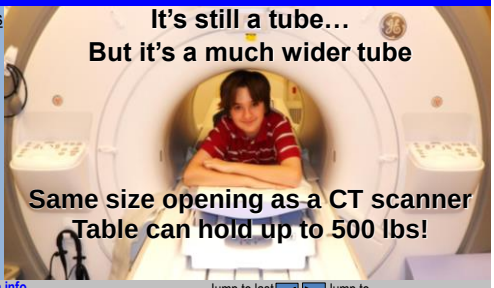

Wide Bore 1.5T, also Short Bore

Radiographs
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MR scanner is a tube

Radiographs
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Claustrophobia

Don't make patients claustrophobic

- Things I've seen clinicians write:
  - ✓*I told my patient how traumatic an MR scan is*
  - ✓*I told my patient it's like laying inside a* ***COFFIN***
  - ✓*I told my patient it's like laying in a* ***SEWER PIPE***

Evolution of Radiology: Focus on MSK MRI

MR scanner is just a tube

Radiographs
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Nothing happens inside the tube

- Nothing moves
- Nothing crushes
- Open at both ends
- Plenty of air
- No radiation
- No X-rays
- No flashing lights

If it didn't make any noise you wouldn't even know anything was happening.

MR scanners make lots of noise

Radiographs
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We protect the patient's ears

- Ear plugs
- Headphones
  - ✓Can play radio station
  - ✓or CD
  - ✓or patient's iPod

Our goal is to make patient relaxed

- We get our best pictures of people sleeping

If your patient is still anxious

Radiographs
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Can take something mild as an outpatient

- Valium (Diazepam)
- Ativan (Lorazepam)
- Cocktail? (not all 3)
- **Patient should not drive!**

If patient is really problematic

- We can provide conscience sedation at hospital
  - ✓Not at outpatient facility

If patient is *really really* problematic

- General anesthesia can be arranged (It rarely comes to that)

The Big Problem with MRI

Radiographs
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Why is it Always On?

Radiographs
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Isn't it an electromagnet?

- Can't we just flick a switch and turn it off?
- It's not that simple…
- Yes, it's an electromagnet.
- Yes, it works by passing current through wire

To achieve 1.5T, need to pass A LOT of current through wire

- Requires low resistance wire…
- …super-conducting wire
- Super-conducting materials operate at CRYOGENIC TEMPERATURES!
- Can't turn off magnet with venting cryogens.

Occasionally Replenish Cryogens

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Evolution of Radiology: Focus on MSK MRI

MRI Safety

Radiographs
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Everyone in the entire medical center needs to respect MRI safety

Can't bring into the scanner room anything that is:

- Ferromagnetic
- Electronic

that is not certified MRI compatible.

Safety Videos

Radiographs
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Things Stuck in Magnets: Floor Buffer

Radiographs
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MR
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Things Stuck in Magnets: Gas Tank

Radiographs
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Things Stuck in Magnets: ICU Bed

Radiographs
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Things Stuck in Magnets: Chair

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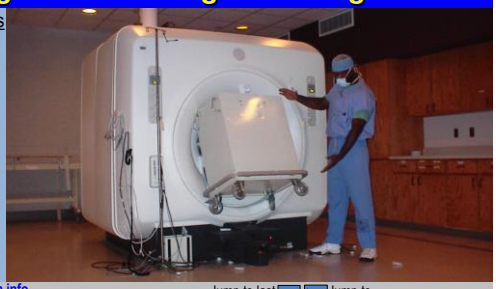
Things Stuck in Magnets: Drug Cart



Warning Signs

Warning Signs

Metal Objects May Become Airborne

MRI Safety in China

MRI Safety in China

Limit Access to MR Suite

Radiographs
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A True Tragedy

Radiographs
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New York Daily News Online **Tuesday, July 31, 2001**

Freak MRI Accident Kills Westchester Boy

Magnet send canister flying into him

Michael Colombini

6-year-old boy undergoing an MRI exam at a Westchester hospital died after the machine's powerful 10-ton magnet turned an oxygen canister into a missile that smashed his skull, officials said yesterday.

MRI Safety

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that is not certified MRI compatible.

No Implanted Electronics

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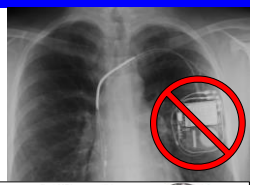
No pacemakers

- ➢Magnet won't suck pacer out of chest
- ➢But magnet may…
  - ✓Drain the battery
  - ✓Make pacer fire erratically
  - ✓Scramble electronics
  - ✓May even *reprogram* pacer



No Implanted Electronics

Radiographs
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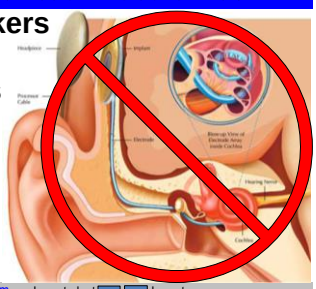
No pacemakers

No cochlea implants



No Implanted Electronics

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
Safety
Hardware

No pacemakers

No cochlea implants

No neuro-stimulators

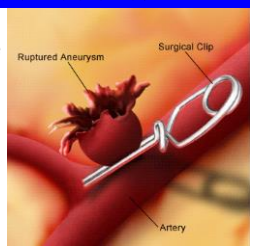
Evolution of Radiology: Focus on MSK MRI

Metal Inside Patients

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
Safety
Hardware

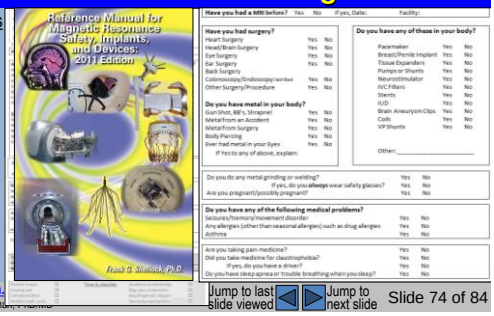
Safety Issues

- Metal that can't move is not a safety issue
  - ✓Fillings in the teeth
  - ✓Orthopedic hardware
- Need to worry about metal that CAN move
  - ✓**Metal in/around eyes**
    - ❖Welding equipment
    - ❖Grinding equipment
    - ❖Fire guns w/o protection
    - ❖*People who've been shot*
  - ✓Old aneurysm clips



New UW Screening Sheet

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
Safety
Hardware



An actual case…

Radiographs
CT
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We're screening the patient to see if he's MR compatible.

We ask the patient if he has any metal in his body.

He replies, "… yeah… I think I was shot in the head once."

Is this patient MR compatible?

Maybe yes, maybe no.

We get a skull radiograph…

What do you say now?

"One view = no views"

Need to have Multiple Views

Radiographs
CT
MR
Signal Sequences
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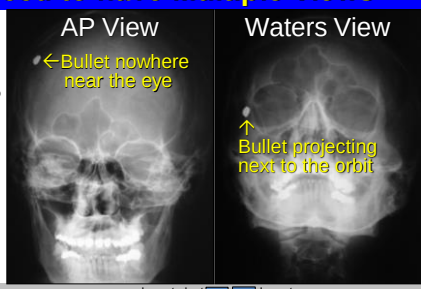
Safety
Hardware

What's the answer?



Need to have Multiple Views

Radiographs
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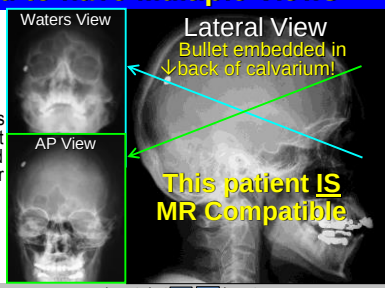
Here's the answer on the lateral view!

On the Waters view the bullet just happened to project over the eye.



This Patient is NOT MR Compatible

Radiographs
CT
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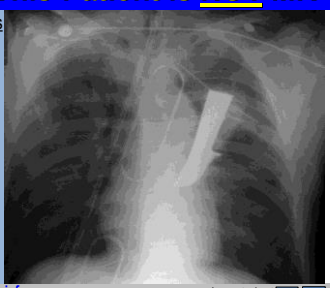

Don't want this knife blade to move from its current position.

History?

"Stabbing Chest Pain"

Evolution of Radiology: Focus on MSK MRI

Metal Inside Patients

Radiographs
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Signal Sequences
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Hardware

Safety Issues

- No implanted electronics
- No metal that can move
- OK: Orthopedic hardware
- OK: Modern aneurysm clips
- OK: Modern heart valves
- OK: Vascular stents
- OK: IVC filters

Imaging Issues

- Metal can affect the magnetic field
  - ✓"Susceptibility artifact"
- May limit diagnostic value of the scan…
- But often the scans come out just fine.
  - ✓As long as the patient is MR safe, we're willing to try.
  - ✓If we can't get useful images, cancel all charges

Metal Example: Femoral Rod

Radiographs
CT
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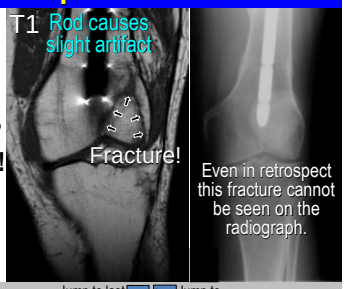
Patient with lots of metal

Is it unsafe to put this patient in the magnet?

Of course not!

Patient has unexplained knee pain.



Metal Example: Interference Screws

Radiographs
CT
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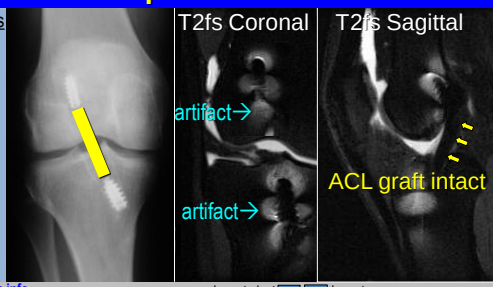

Metal Example: Interference Screws

Radiographs
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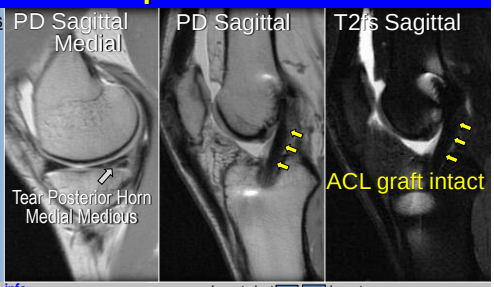

What to Order When (WOW)

Radiographs
CT
MR
Signal Sequences
Coils
Magnets
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Hardware

Should always start with radiographs

- Least expensive study
- May show the answer
- Needed for planning other studies

CT (MSK)

- Used in ER for fracture detection (spine)
- Used for surgical planning of known fractures
- Best ordered by treating specialist

MRI

- Used for tears, occult fractures, infections, …
- Best ordered by treating specialist

Any questions about anything?

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