Practical MSK MRI and CT Physics and Image Optimization

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2018-2019 MSK Fellow

Lecture goals

- Review importance of understanding image optimization as an MSK radiologist
- Review relevant MRI (and CT) physics
- Cover coils and their role in image optimization
- Review common artifacts and troubleshooting
- Cover specific techniques available to optimize and customize MSK imaging
- Cover some potential future directions
- Provide resources and tips for further reading

Background

- Cross-sectional imaging (CT and MRI in particular) play a large role in our practice
- Make up a large part of RVUs
- In many private practice groups, there are limited MSK specialists and so you may be called to review/revise/create MSK protocols
- Techs may ask you to troubleshoot problems
- You may notice that your practice’s protocols are suboptimal and may want to improve them

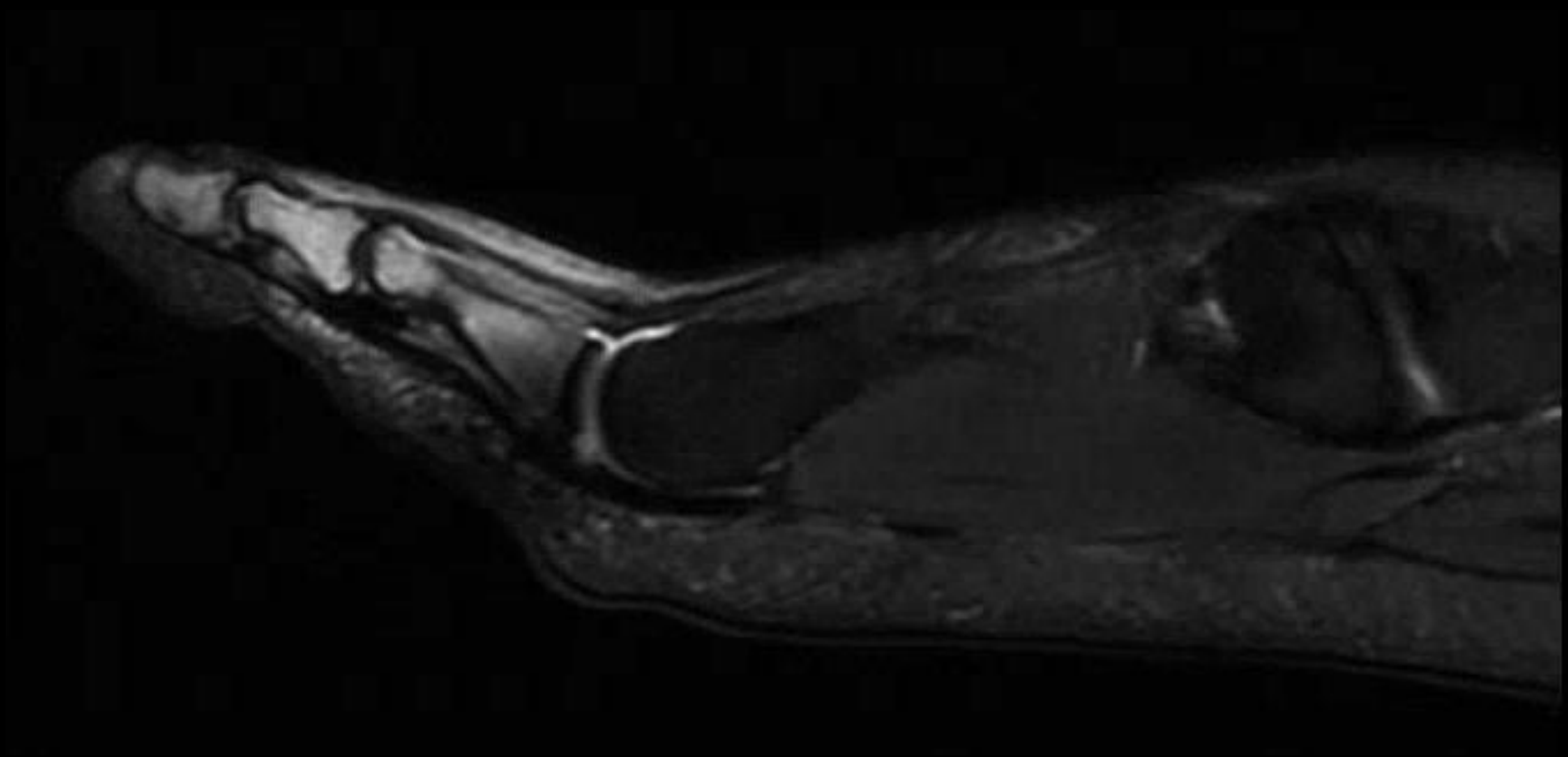
Background

- Do not want to mistake artifacts for pathology
- As MRI sequences get faster, studies will be shorter, easier to tolerate, and enable more patient throughput
- For metal implants specifically, US is expected to be doing 0.5 million hip arthroplasties per year in 2030, and 3.48 million knee arthroplasties per year by 2030 [Kurtz 2007]

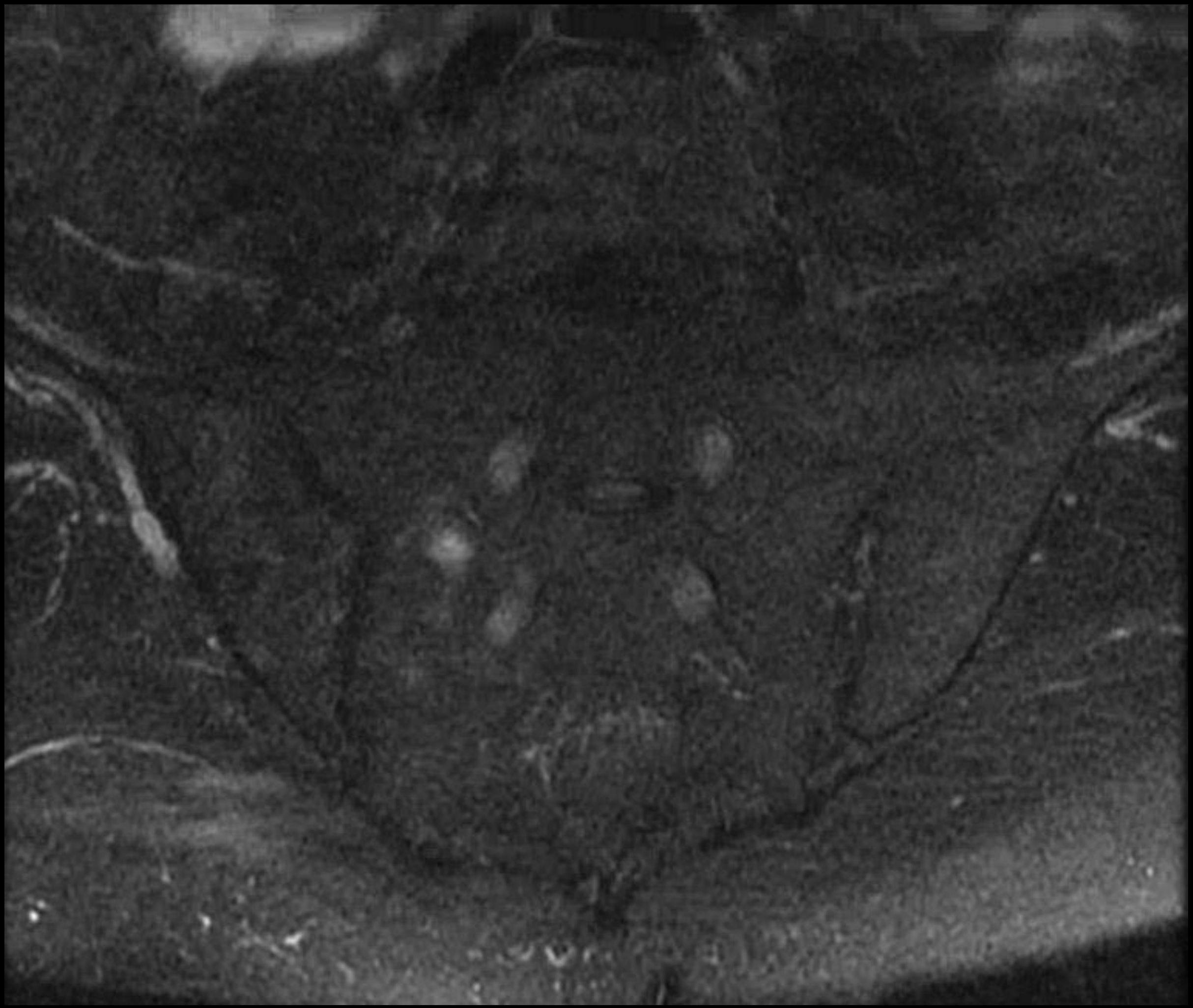
Example MSK cases/scenarios

Example Case 1: your practice wants to you to check/update the knee MRI protocol

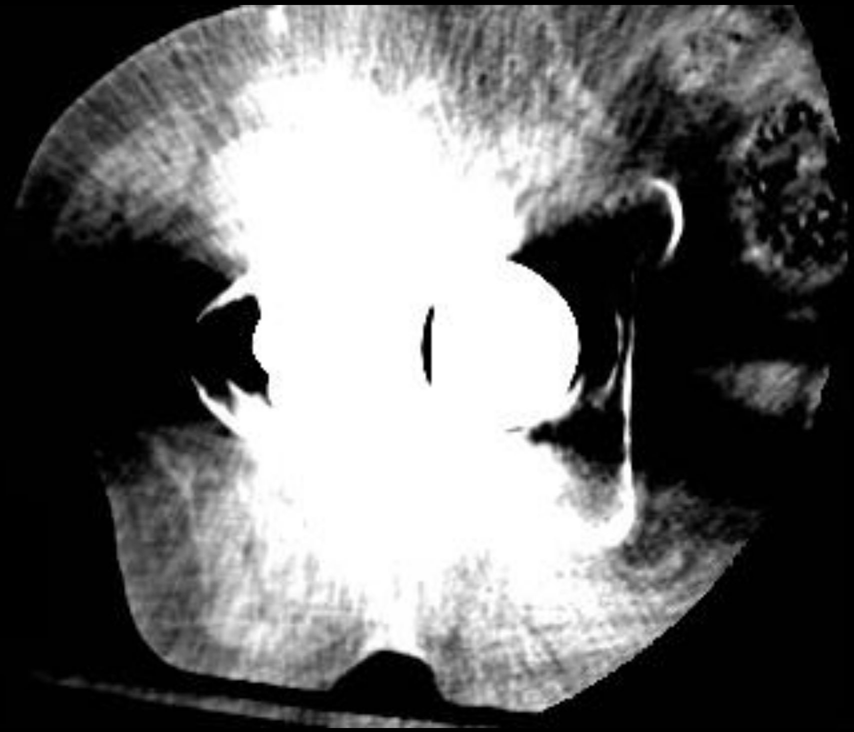
Example Case 2: poor fat saturation in a forefoot MRI

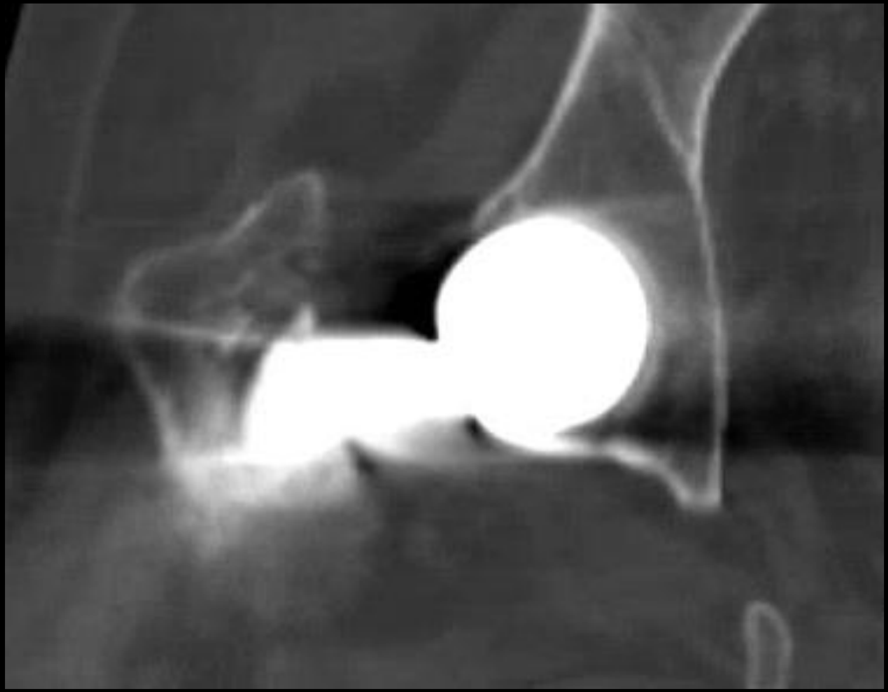


Example Case 3: atypical hemangioma or prostate metastasis?

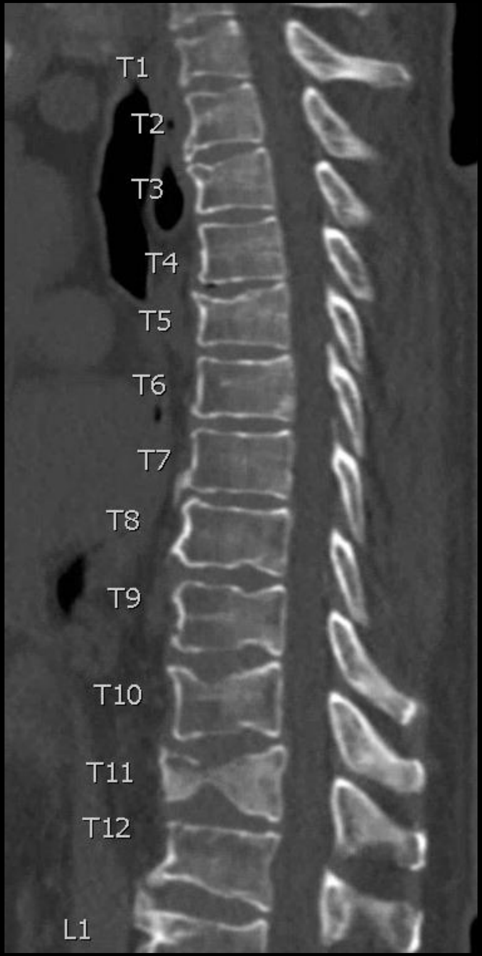


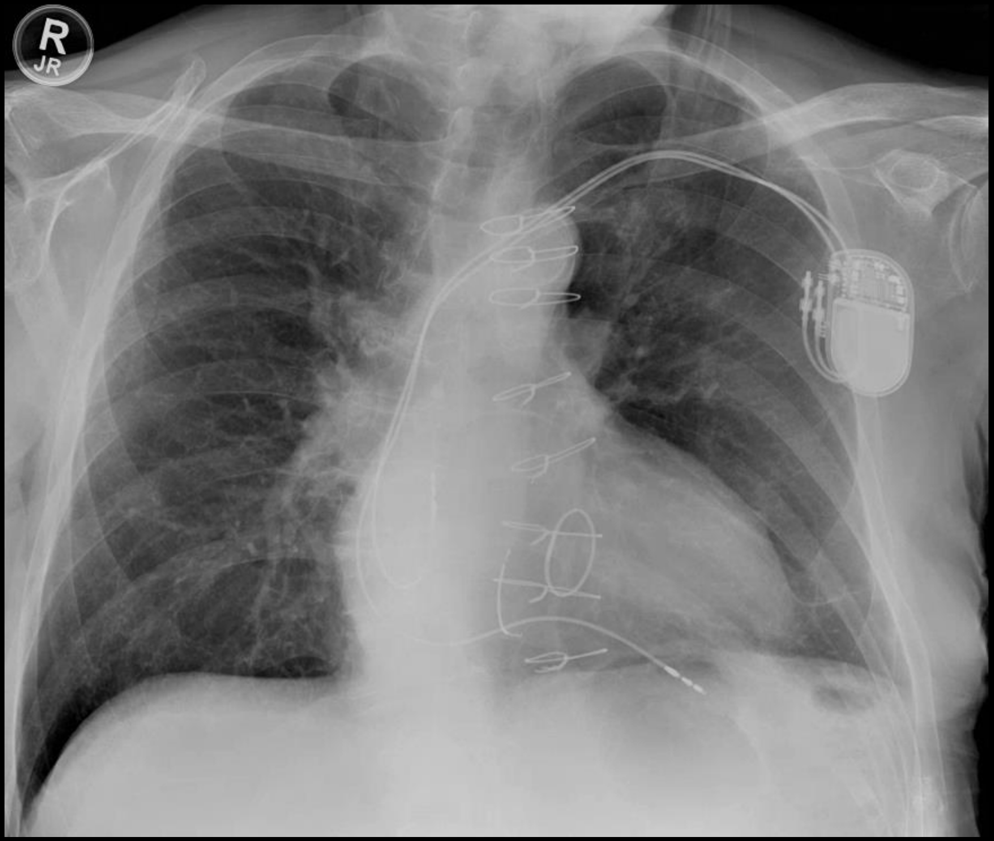
Example Case 4: concern for periprosthetic fracture with hemiarthroplasty; CT limited





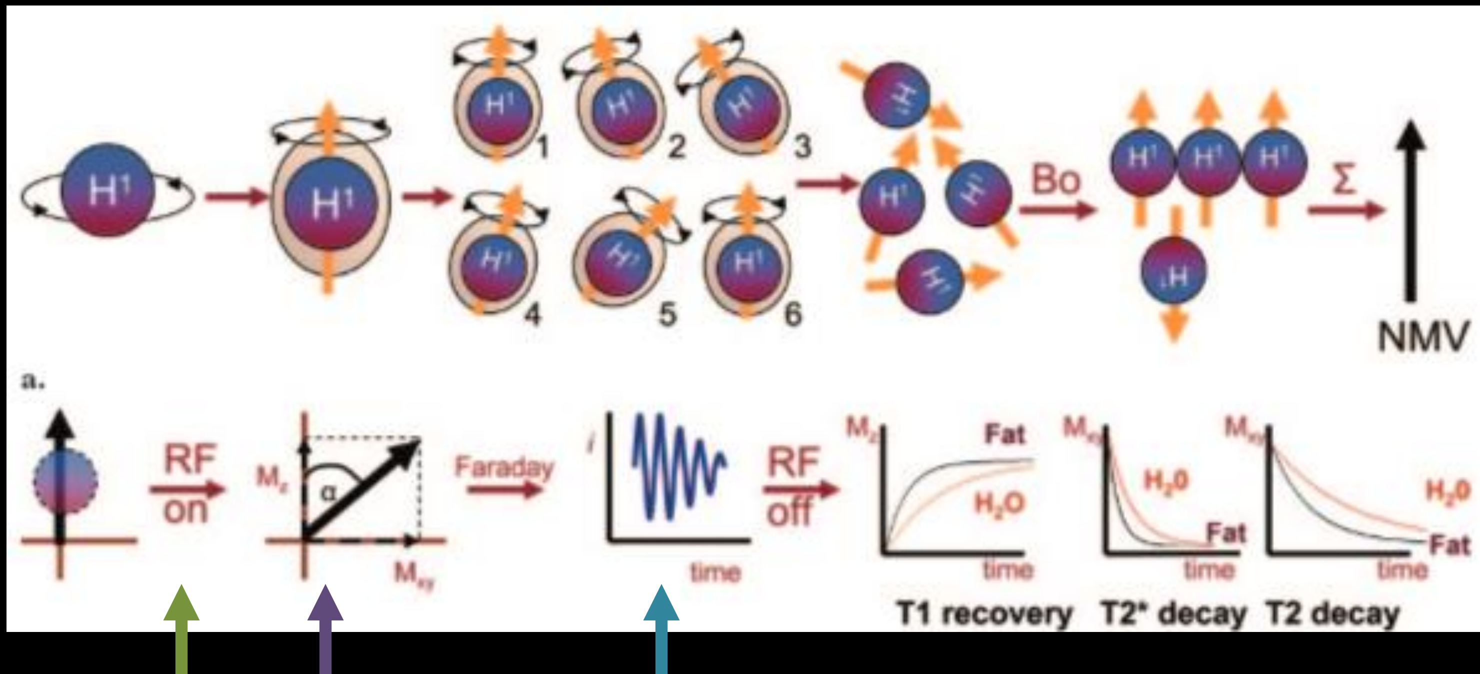
Example Case 5: age of spinal compression fractures; unknown pacer





Quick review of basic MRI physics

Quick review of basic MRI physics



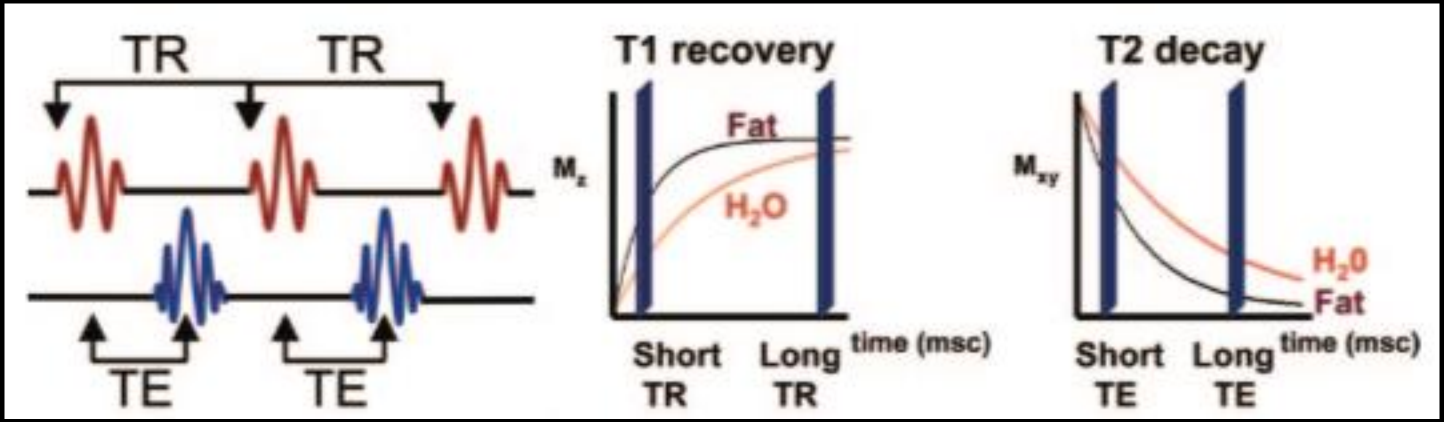
RF pulse applied to excite a specific **slice**

Specific **flip angle:** results in **transverse** & **longitudinal magnetization**

Current induced in a **receiver coil**

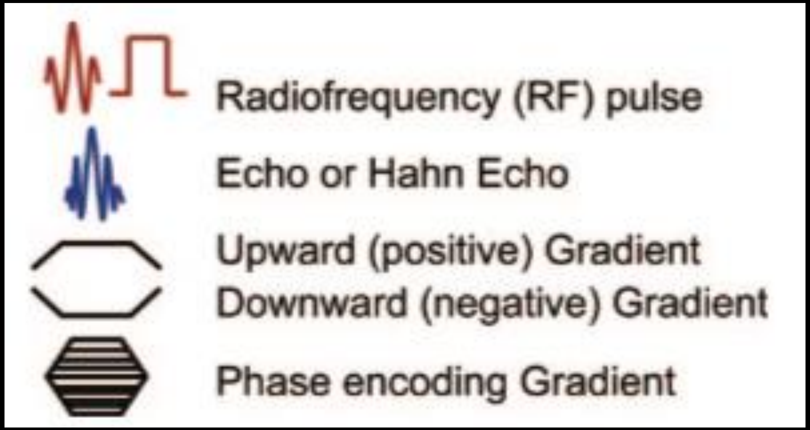
Bitar 2006

Quick review of basic MRI physics



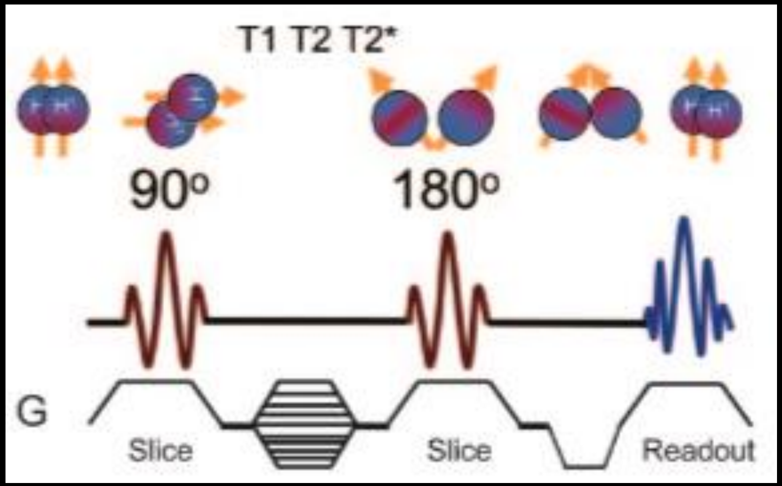
T1 contrast: TR time

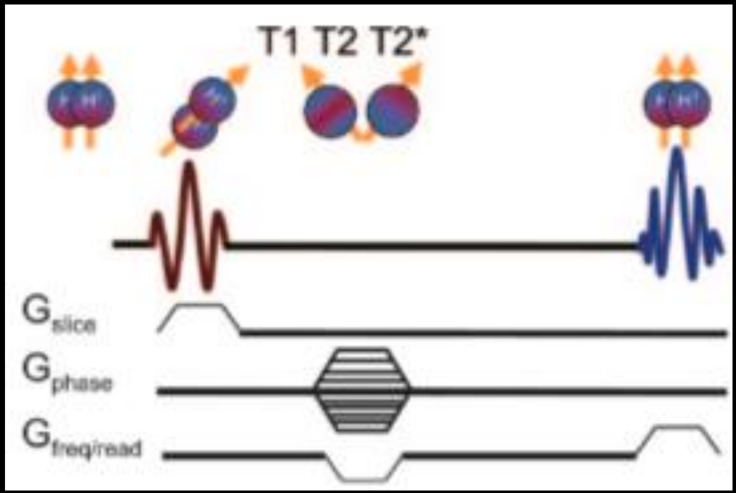
T2 contrast: TE time



Bitar 2006

Spin echo vs gradient echo





	Spin echo	Gradient echo
Rephasing	RF pulse	Variation of gradients
Flip angle	90 deg only	Variable
Eff @ decr inhomogen.	Yes, very(true T2)	Not very (T2* weighting)/susceptibility
Acquisition t	Long/very slow	Short/fast

Bitar 2006

Spin echo vs gradient echo: applications in MSK

SPIN ECHO:

-Includes fast spin echo, turbo spin echo, inversion recovery
-Workhorse in MSK

GRADIENT ECHO:

-More susceptibility
-Scouts, often post-contrast, diffusion, chemical shift

Quick review of basic MRI physics

Table 1
Effect of TR and TE on MR Image Contrast

Imaging Technique	TR	TE
T1 weighting	Short	Short
T2 weighting	Long	Long
Proton-density weighting	Long	Short

Table 2
Typical TR and TE Values for SE and GRE Sequences

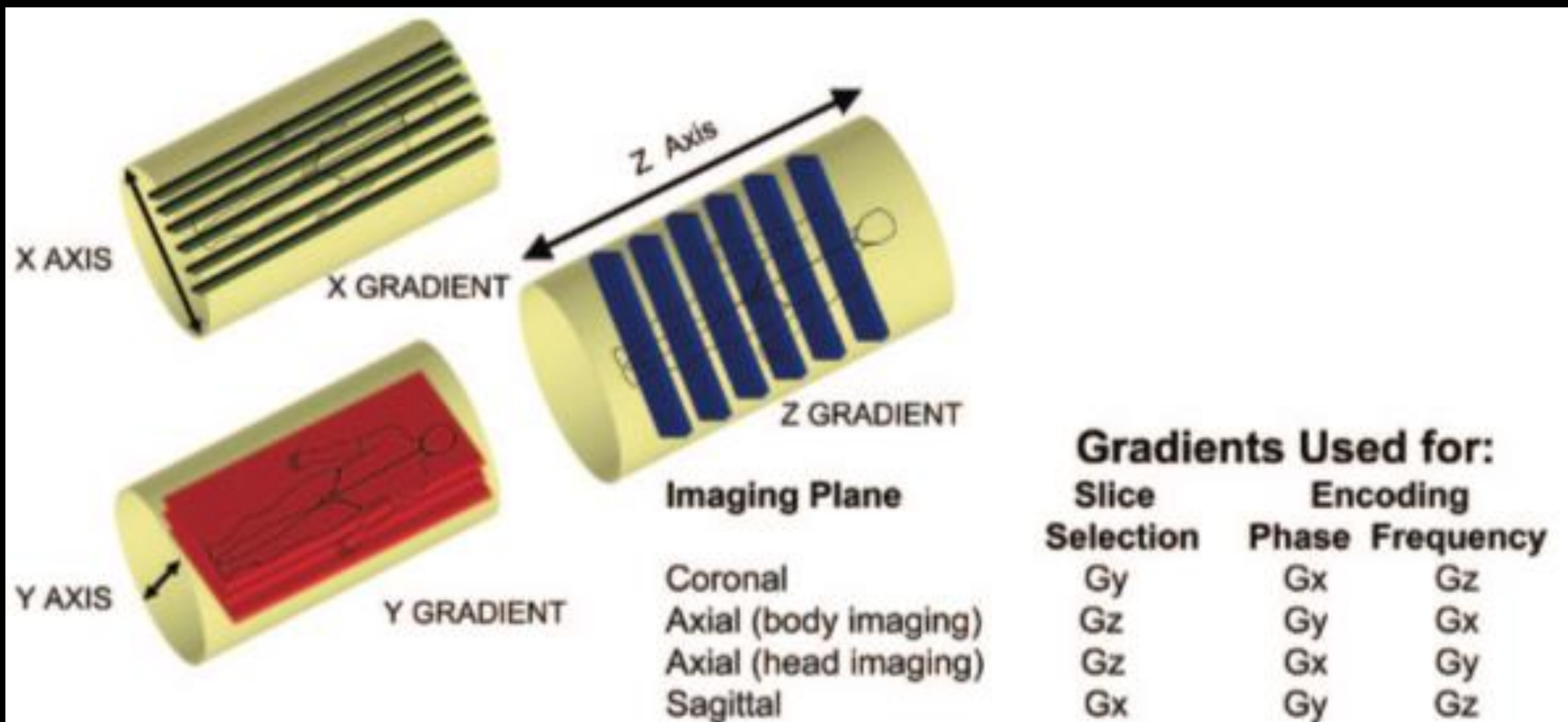
	TR		TE	
Sequence	Short	Long	Short	Long
SE	250–700	> 2000	10–25	> 60
GRE	< 50	> 100	1–5	> 10

Note.—Values are given in milliseconds.

	TR	TE	Flip angle	TI
T1	<800	<30	90	
T2	>2000	>80	90	
PD	>1000	<30	90	
MSK PD	>2000	30-70	90	
STIR	>2000	>60	180, 90	120-170
GRE T1	var	<30	70-110	
GRE T2*	var	<30	5-20	

Bitar 2006

Quick review of basic MRI physics



Imaging Plane	Gradients Used for: Slice Selection	Encoding: Phase	Encoding: Frequency
Coronal	Gy	Gx	Gz
Axial (body imaging)	Gz	Gy	Gx
Axial (head imaging)	Gz	Gx	Gy
Sagittal	Gx	Gy	Gz

Bitar 2006

Phase encoding, frequency-encoding, and slice selection gradients

- Slice selection gradient:
  - RF gradient in z axis for axial
- Phase encoding gradient:
  - before frequency, after slice
  - Induces phase variability within slice
- Frequency encoding gradient:
  - a.k.a. readout gradient; when signal is acquired
  - Perpendicular to phase gradient

Example Case 1: your practice wants to you to check/update the knee MRI protocol

1.5 T knee protocol: GE Signa Explorer

Series	Flip (deg)	Echo	TE	TI	TR	Thick/ spacing	FOV (cm)	Matrix	NEX
3-plane loc (GRE)	90	1/1	78		1163	5.0/5.0	24x24	384x256	0.53
Ax PD FSE FS	160	1/1	31		2000	4.0/1.5	15x15	384x224	4
Sag PD	160	1/1	34		2932	4.0/0.4	16x16	320x224	4
Sag T2 FS	142	1/1	70		3773	4.0/0.4	16x16	384x224	4
Cor T1 FSE	160	1/1	11.8		503	4.0/1.0	14x14	320x224	4
Cor T2 FS	142	1/1	68		3347	4.0/1.0	14x14	384x224	4

GE Signa Discovery 750 3T knee protocol

Series	Flip (deg)	Echo/ ETL	TE	rBW	TR	Thick/ spacing	FOV (cm)	Matrix	NEX
Ax PD FS FSE	110	1/10	30	50	3655	3.0/0.5	12x12	384x384	2
Ax T1 FSE	111	1/4	Min full	50	650	3.0/0.5	12x12	400x320	2
Sag PD FSE	110	1/8	35	50	2922	3.0/0.5	14x14	512x320	2
Sag T2 FS FSE	125	1/14	50	62.5	4487	3.0/0.5	14x14	400x320	2
Cor T1 FSE	110	1/4	18	50	800	3.0/0.5	14x14	512x352	2
Cor T2 FS FSE	125	1/13	50	62.5	4341	3.0/0.5	14x14	420x300	2

GE Signa Discovery 750 3T knee protocol

AX T1 FS Post

PATIENT POSITION	
Patient Entry	*Feet First*
Patient Position	*Supine*
Coil Configuration	*GEM Flex Medium Array*
Plane	*OBLIQUE*
Series Description	*AX T1 FS Post*
SCAN TIMING	
Flip Angle	*111*
TE	*Min Full*
Number of Echoes	*1*
TR	*785.0*
Echo Train Length	*3*
Receiver Bandwidth	*50.00*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
Fat/Water Saturation	*Fat Classic*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*On*

IMAGING PARAMETERS	
Imaging Mode	*2D*
Pulse Sequence	*FSE-XL*
Imaging Options	*NPW, EDR, TRF, Fast, ARC*
PSD Name	*fsenpw*
SCAN RANGE	
FOV	*12.0*
Slice Thickness	*3.0*
Slice Spacing	*0.5*
ACQ TIMING	
Freq	*400*
Phase	*300*
Freq DIR	*A/P*
Fat Shift DIR	*Normal (A)*
NEX	*2.00*
# of Acq. Before Pause	*0*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*Yes*
USER CVS	
User CV19	*0.85*
User CV22	*1.00*
TR Min	*500.0*
TR Max	*999.0*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*Yes*

AX T1 FS Post

GE Signa Discovery 750 3T knee protocol

3D Sag PD Cube FS HyperSense test for Brady

PATIENT POSITION	
Patient Entry	*Feet First*
Patient Position	*Supine*
Coil Configuration	*GEM Flex Medium Array*
Plane	*SAGITTAL*
Series Description	*3D Sag PD Cube FS HyperSense test for Brady*
SCAN TIMING	
TE	*30.0*
Number of Echoes	*1*
TR	*1200.0*
Echo Train Length	*35*
Receiver Bandwidth	*62.50*
IMAGE ENHANCE	
Filter Choice	*None*
GATING/TRIGGER	
Auto Trigger Type	*Off*
FMRI	
PSD Trigger	*Internal*
Slice Order	*Interleaved*
View Order	*Bottom/Up*
# of Repetitions REST	*0*
# of Repetitions ACTIVE	*0*
SAT	
Tag Type	*None*
Fat/Water Saturation	*Fat Classic*
TRICKS	
Pause On/Off	*On*
Auto Subtract	*0*
Auto SCIC	*Off*

IMAGING PARAMETERS	
Imaging Mode	*3D*
Pulse Sequence	*Cube*
Imaging Options	*EDR, Fast, FR, ARC, HS*
SCAN RANGE	
FOV	*14.0*
Slice Thickness	*0.6*
Location per Slab	*220*
Overlap Locations	*0*
ACQ TIMING	
Freq	*288*
Phase	*288*
Freq DIR	*S/I*
NEX	*1.00*
Phase FOV	*1.00*
Auto Shim	*Auto*
Phase Correction	*No*
USER CVS	
User CV5	*0.80*
User CV12	*70.00*
User CV22	*1.00*
MULTI-PHASE	
Seperate Series	*0*
Mask Phase	*0*
Mask Pause	*0*
DIFFUSION	
Recon All Images	*On*
CONTRAST	
Contrast Yes/No	*No*

3D Sag PD Cube FS HyperSense test for Brady

An aside about k-space/NEX

- Will not go into k-space in detail in this talk
- Analogy: k-space = chest of drawers [Westbrook 2005]; storage device
  - # drawers = # lines k space to fill
  - # drawers = # phase encoding steps
  - Slice encoding g: which chest of drawers
    - 1 chest per slice
  - Phase encoding g: which drawer to open
  - Frequency encoding g: where to put sock in the drawer

Westbrook 2005

An aside about k-space/NEX

- NEX (# excitations), a.k.a. NSA (# signal averages or acquisitions) = # times each line of k-space is filled
  - Sampled at same slope of phase gradient
  - Slope constant over multiple TRs instead of changing at each TR
- Higher NEX
  - Higher SNR
  - Longer scan time

Westbrook 2005

Getting parameter information

- Image annotations
- DICOM dump
- Scanner console – be nice to your technologist

2	slice_thickness	DS	1	"3"
4	repetition_time	DS	1	"4425"
6	echo_time	DS	1	"46.08"
2	number_of_averages	DS	1	"1"
10	imaging_frequency	DS	1	"127.790758"
2	imaged_nucleus	SH	1	"1H"
2	echo_numbers	IS	1-n	"1"
2	magnetic_field_strength	DS	1	"3"
4	spacing_between_slices	DS	1	"3.5"
2	echo_train_length	IS	1	"13"
4	percent_sampling	DS	1	"100"
2	percent_phase_field_of_view	DS	1	"95"
8	pixel_bandwidth	DS	1	"244.141"
16	device_serial_number	LO	1	"0000000858657MR6"
44	software_versions	LO	1-n	"27\LX\MR Software re
10	protocol_name	LO	1	"-52. KNEE"
2	beat_rejection_flag	CS	1	"Y"
2	heart_rate	IS	1	"0"
2	cardiac_number_of_images	IS	1	"0"
2	trigger_window	IS	1	"0"
4	reconstruction_diameter	DS	1	"140"
16	receiving_coil	SH	1	"GEM Flex LG Full"
8	acquisition_matrix	US	4	0x0000 0 ...
4	phase_encoding_direction	CS	1	"ROW"
4	flip_angle	DS	1	"125"
2	variable_flip_angle_flag	CS	1	"N"
6	sar	DS	1	"2.5924"

Building and analyzing MR protocols

- Different opinions and priorities exist
- Parameters may be pathology dependent and some institutions/practices have specific parameters for different indications
  - ?Chondrocalcinosis or PVNS? Add a GRE sequence
  - ?ACL tear? Add a small FOV coronal oblique
  - ?Infection? Triplanar T1 and STIR; many knee protocols only include 1 true T1

Note on specific modifications

- To maximize SNR on PD FSE FS sequences
  - Beware of using TE >50; may decrease SNR (35-45 optimal
  - Beware of using TR < 3000; may obscure SNR at cartilage-fluid interfaces
- Adjust FOV by patient size and pathology
  - Increase sag/coronal FOV especially if concerned for MCL injury
  - Decrease FOV (to 12 cm or less) in children to increase spatial resolution

Stoller 2007

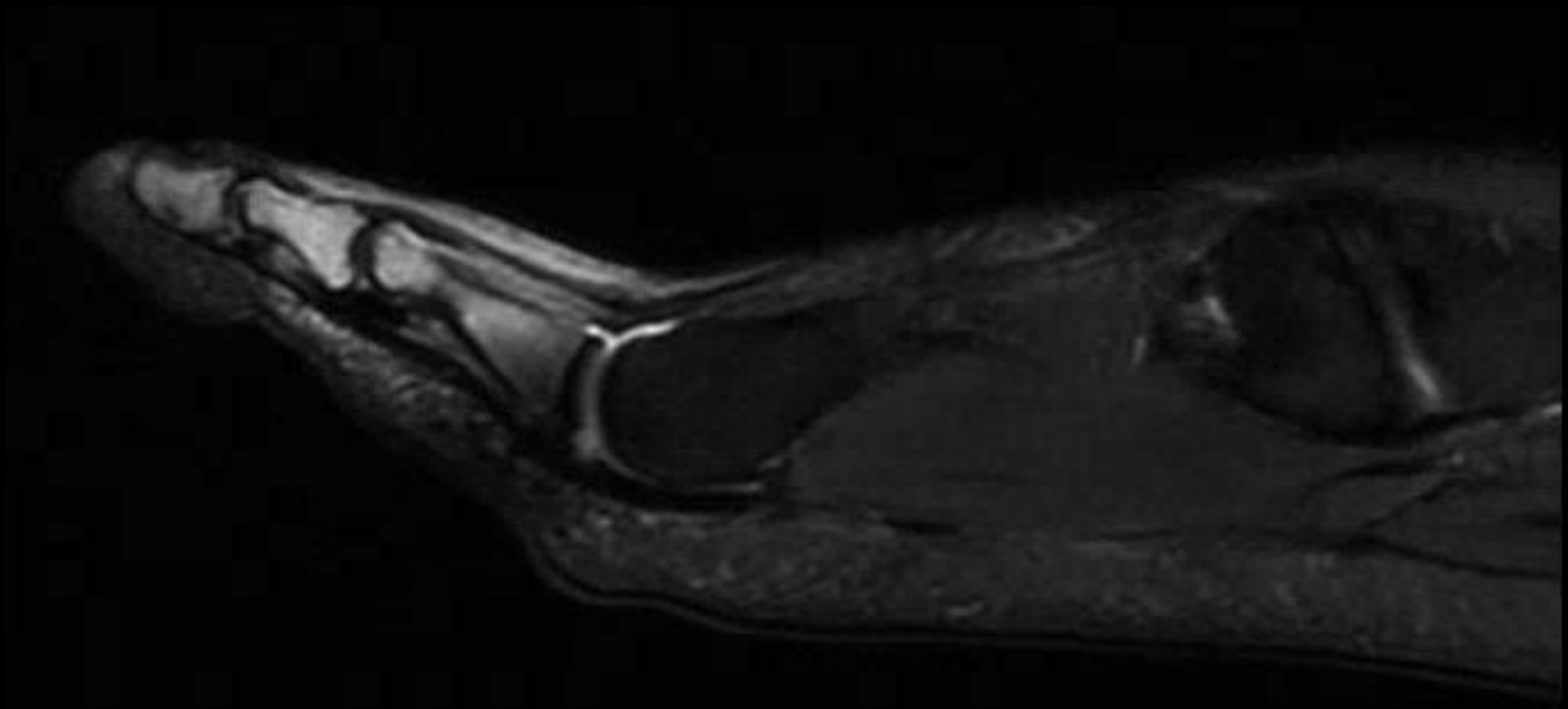
Role of vendors

- Get in touch/get to know with local sales representative
- Meet with industry representatives at national meetings
- Have reps come out for troubleshooting or when rolling out new software/protocols/updates

Tailoring to the customer

- Remember that you're on the same team as your referrers; discuss their wishes/input in any protocol changes
- Remember that patient satisfaction is important and optimization of protocols will decrease wait-times and decrease motion

Example Case 2: poor fat saturation in a forefoot MRI



Artifacts/troubleshooting

- Poor fat-sat
- Wrap
- Pulsation
- Magic angle
- Motion
- 3D artifacts

RadioGraphics

TEACHING

AAPM/RSNA Physics Tutorial for Residents

MR Artifacts, Safety, and Quality Control[1]

Jiachen Zhuo, MS • Rao P. Gullapalli, PhD

More on matrices and frequency vs phase encoding directions

- K-space is filled as a matrix through phase-encoding and frequency-encoding steps
- Frequency-encoding, or readout, adds no extra time (where the socks go in the drawer)
  - Is the equal or larger number in the matrix (usually listed first)
  - Chemical shift artifact in this direction
- Phase encoding steps add time (number of drawers)
  - Small number in the matrix
  - Most artifacts in this direction

Runge 2014

Coil selection

- A.K.A. surface coils, receiver coils, RF coils, RF antennas, array coils
- Coils can be optimized due to patient size (“load”) but this makes them less reliable
  - Now, designed with a specific patient size/habitus in mind
  - Thus, may not perfectly match impedance of a specific patient, leading to loss in coil performance
- Basic types
  - Built in coil (used for spine, brachial plexus, etc.)
  - Dedicated coil

Stoller 2007

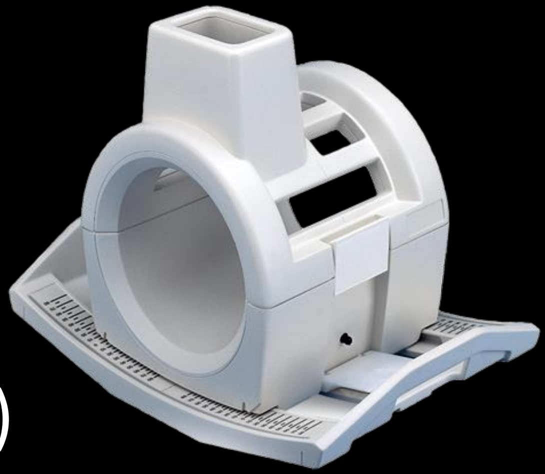
Coil selection

- Smaller coils = smaller FOV, limited patient generalizability but improved images
  - Coil diameter smaller = higher SNR
  - Coil diameter smaller = lower noise
- Coils can be general (body coil, cardiac coil) or contoured

Stoller 2007

Coil selection

- Receive only vs transmit/receive
  - Receive-only subject to artifact from adjacent tissues also excited by RF pulse (think wrist imaged in supine)
  - Transmit/receive (example: some knee coils)
    - Improves patient comfort because only AOI is excited
    - Allows higher power locally and overall less energy deposited in patient
    - Enables higher resolution, higher strength imaging while observing SAR limitations



Stoller 2007

Fat saturation

- CHESS (chemical shift (spectral) selective) or chemical fat-sat: Most common in MSK
- STIR
- Hybrid sequences (example: SPAIR)
- Spatial-spectral (example: water excitation)
- Dixon

Del Grande 2014

CHESS or chemical fat-sat

- Fast, high SNR
- Better at high field strengths
- Good pre-/post- contrast option
- Requires B_o homogeneity
  - Bad in larger FOV
  - Bad with metal
  - Bad with irregular contours and more air-skin surface area (toes/forefoot)
  - Bad with off-center imaging

Del Grande 2014

CHESS or chemical fat-sat

- Basic physics
  - Apply RF pulse then immediate spoiler to null fat's longitudinal magnetization
    - No signal contribution from fat
- Tips/troubleshooting
  - Use smallest coil possible in isocenter; minimize air
  - Increase spectral bandwidth
  - Shorter RF pulse

Del Grande 2014

STIR

- Basic physics
  - Extra 180 degree pulse before conventional SE 90 degree pulse
  - Wait time till 90 degree pulse is “TI” or inversion time which is based on T1 relaxation time of specific tissue
  - TI for fat is approximately 140 msec at 1.5T (100-200) and 205-225 msec at 3T
- Applications
  - Good for the foot
  - Good for edema
  - Good with metal

Del Grande 2014

Dixon

- Created by WT Dixon in 1984
- Exploits the resonance frequencies of water and fat (fat is 220 Hz lower at 1.5T; they will cycle out-of-phase at 2.2 msec and in-phase at 4.4 msec)
- Basic physics for “2-point Dixon”
  - Acquire 2 images: IP and OP
  - Sum then average to get pure water(fat-suppressed)
  - Subtract OP from IP then average to get pure fat (water-suppressed)
- Insensitive to B_o when you do 3- or 4-point Dixon

Summary: fat-sat

Table 1: Advantages and Disadvantages of Different Fat-Suppression Techniques in Musculoskeletal MR Imaging

Technique	Imaging Time	SNR	SAR	Effect of Metal	B_0 Sensitivity	B_1 Sensitivity	Preferred Field Strength
Chemical fat saturation	Short*	High	Medium	Strong	Sensitive	Sensitive	High
STIR	Long	Low	High	Minimal	Insensitive	Insensitive	Indifferent
SPIR	Long	High	High	Strong	Sensitive	Sensitive	High
SPAIR	Long	High	High	Strong	Sensitive	Insensitive	High
Water excitation	Short	High	Low	Strong	Sensitive	Insensitive	Medium†
Dixon	Long	High	Low	Mini-malw	Insensitive (three- or four-point Dixon)	Insensitive	Medium†

Source.—Reference 2.
Note.—All other MR imaging parameters should be considered equal. SPIR = spectral presaturation with inversion recovery.
*Depends on the pulse sequence.
†There are advantages and disadvantages at both high and low magnetic field strengths.

Del Grande 2014

Other artifacts/troubleshooting

- Magic angle
  - Tendons at 55 degrees to B_o lose augmented dephasing
  - Because structural anisotropy accelerates T2 signal loss at all other angles making it dark
  - Short TE sequences like GRE, T1 and PD; not seen on true T2 or T2FS
  - Less prominent at 3T
- Pulsation
  - Moving blood in vessels creates ghosting in phase encoding direction
  - Pre-sat bands in adjacent slices
  - Switch phase- and frequency-encoding directions

Westbrook 2008

Other artifacts/troubleshooting

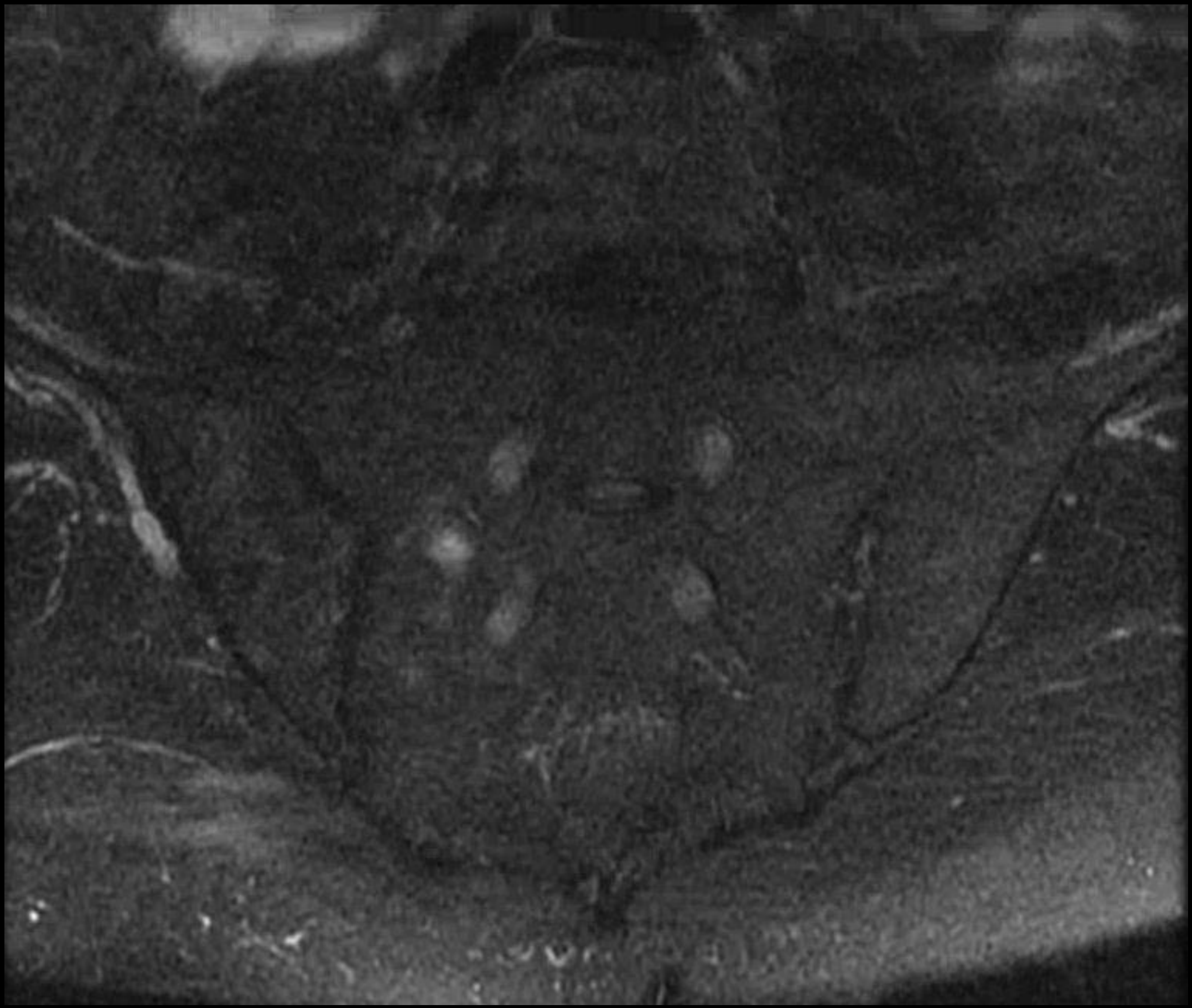
- Motion – same class as pulsation
  - Phase-encoding direction
  - Scan prone for anything ventral (lipoma in chest wall, SC joints, clavicle)
  - Blade/propeller sequences
    - K space sampled in rotational, overlapping pattern rather than rectilinear
    - Needs echo-train so standard spin echo sequences don't work

Westbrook 2008

Other artifacts/troubleshooting

- Wrap/aliasing
  - Phase-encoding (frequency already oversampled)
  - Smaller FOV than AOI; excited tissues wraps to other side of image
  - Tips:
    - Increase oversampling or FOV in phase-encoding
    - Switch phase- and frequency- directions

Example Case 3: atypical hemangioma or prostate metastasis?



Tumor imaging beyond T1 and contrast

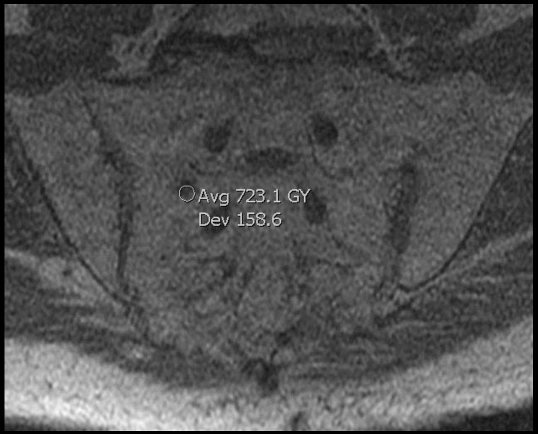
- Consider adding additional sequences
  - Functional imaging
    - Dynamic contrast
    - Diffusion
  - Extra sequences
    - In phase/out-of-phase
    - Subtraction images (especially useful in cases w/ metal)
- Troubleshooting vs standard protocols (institution dependent) - adds a lot of time

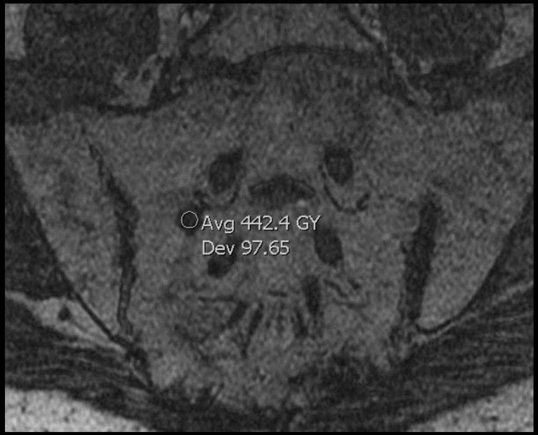
Chemical shift imaging

- Exploits the resonance frequencies of water and fat
  - 1.5T: out-of-phase at 2.2/6.6/11.0 msec and in-phase at 4.4/8.8/13.2 msec
  - 3T: out-of-phase at 1.1/3.3/5.5 msec and in-phase at 2.2/4.4/6.6 msec
- Out-of-phase has India ink artifact
- Single voxels containing both microscopic fat and water
  - Will synergize with higher signal in IP
  - “Cancel-out” signal in OOP
  - Tumors replace marrow/fat so will have no signal drop

Chemical shift imaging

- Benign entities such as hemangioma, marrow edema, red marrow will lose signal
  - Threshhold: 20% drop
  - ROI average in IP image x 0.8 must be less than or equal to OOP: microscopic fat is present
  - Must have water and fat in same voxel (ex: not lipoma)
  - Example: 723*0.8=578 578>442 Micro fat ✔





Dynamic contrast-enhanced MRI

- Fast GRE sequences after IV gad
- Often volumetric acquisition
- Tradeoff between temporal and spatial resolution
  - Ex: TWIST uses k-space undersampling in the periphery to focus on contrast and sacrifice spatial resolution (10 sec resolution for 5 min total)
- Malignant lesions show early arterial enhancement (first pass kinetics); not very specific

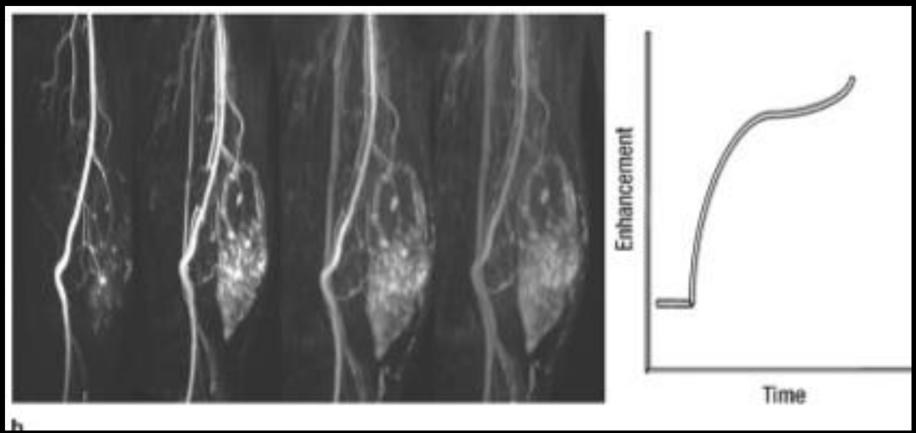
Fayad 2012

Diffusion-weighted imaging

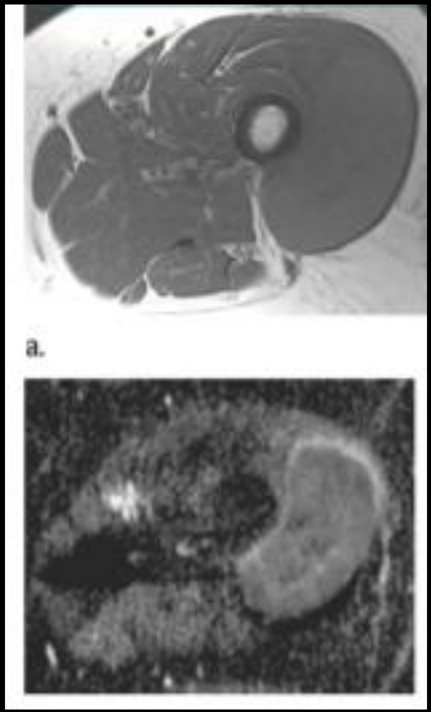
- Use ADC maps rather than DW imaging to avoid T2-shine-through
- Measures impedance to diffusivity, a surrogate for cellularity within a tumor
- Helpful with treatment change (less cellular if necrotic)
- Shi et al. showed ADC values
  - Cutoff of $\geq 0.89 \times 10^{-3}$ mm^2/sec for typical hemangiomas vs mets had 67% sensitivity, 66 % specificity

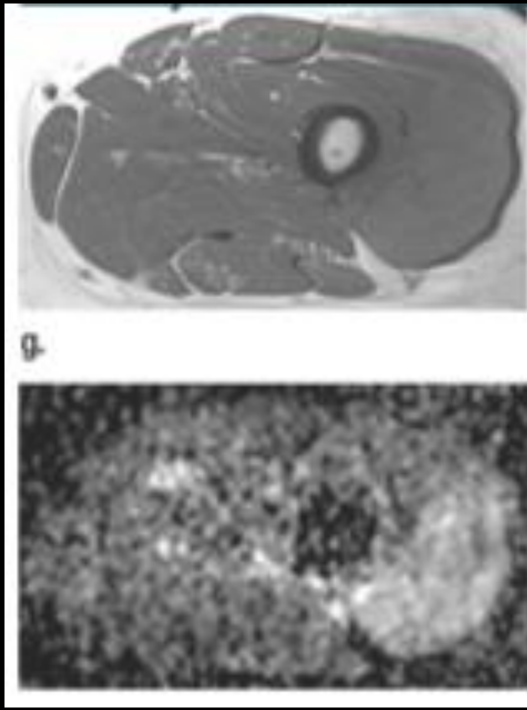
Shi 2017

DCE and DWI



Early arterial enhancement



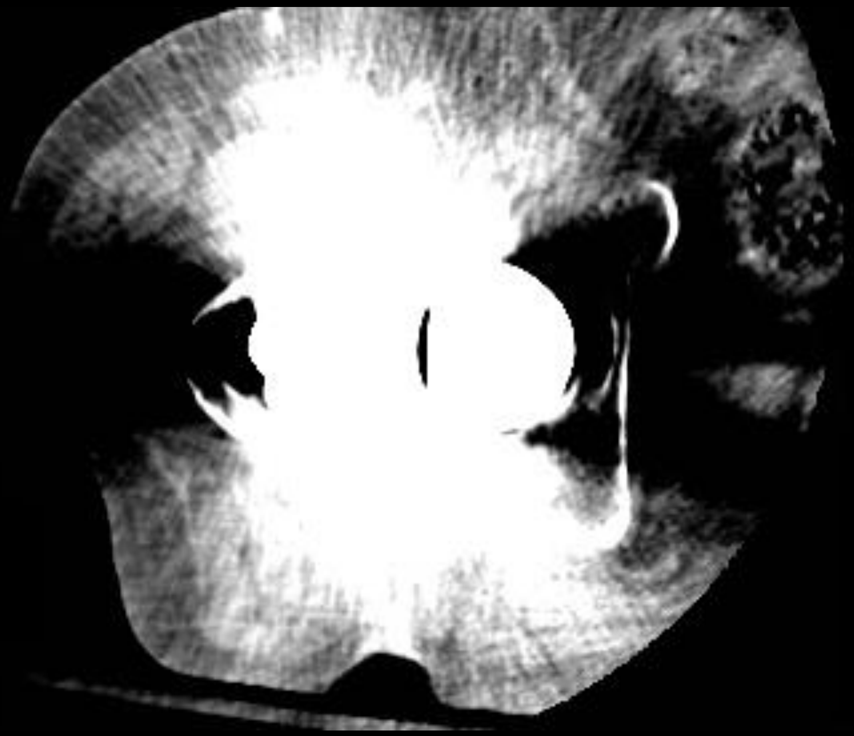


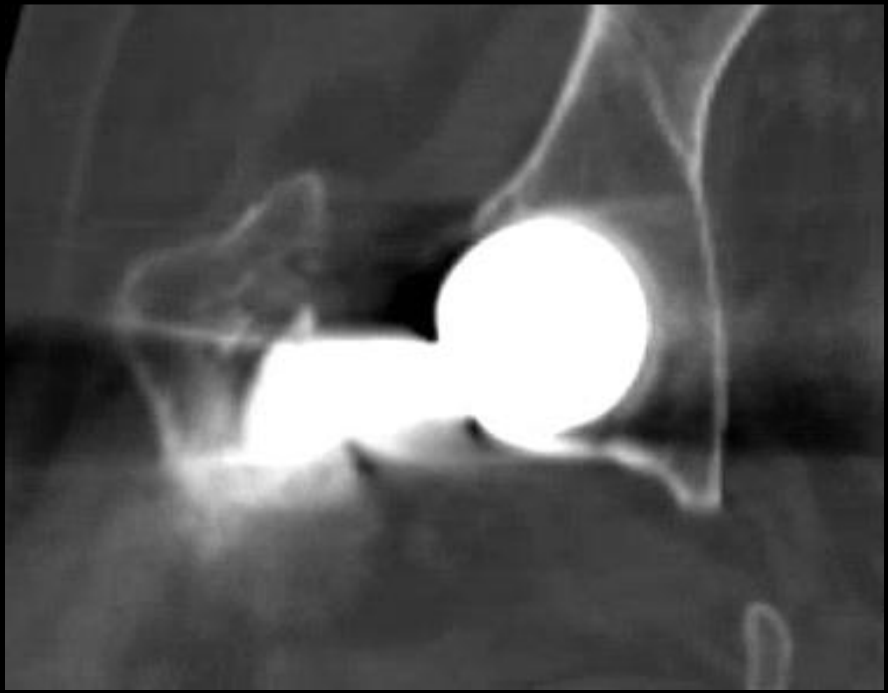
Pre-tx ADC
$0.9\text{-}1.1 \times 10^{-3}$ mm^2/sec

Post-tx ADC
$0.9\text{-}1.1 \times 10^{-3}$ mm^2/sec

Fayad 2012

Example Case 4: concern for periprosthetic fracture with hemiarthroplasty; CT limited





Transmitter vs. receiver bandwidth

- Bandwidth: range of frequencies (Hz)
- Transmitter(tBW): related to RF pulse
- Receiver (rBW): more commonly discussed; signal reception

Receiver bandwidth

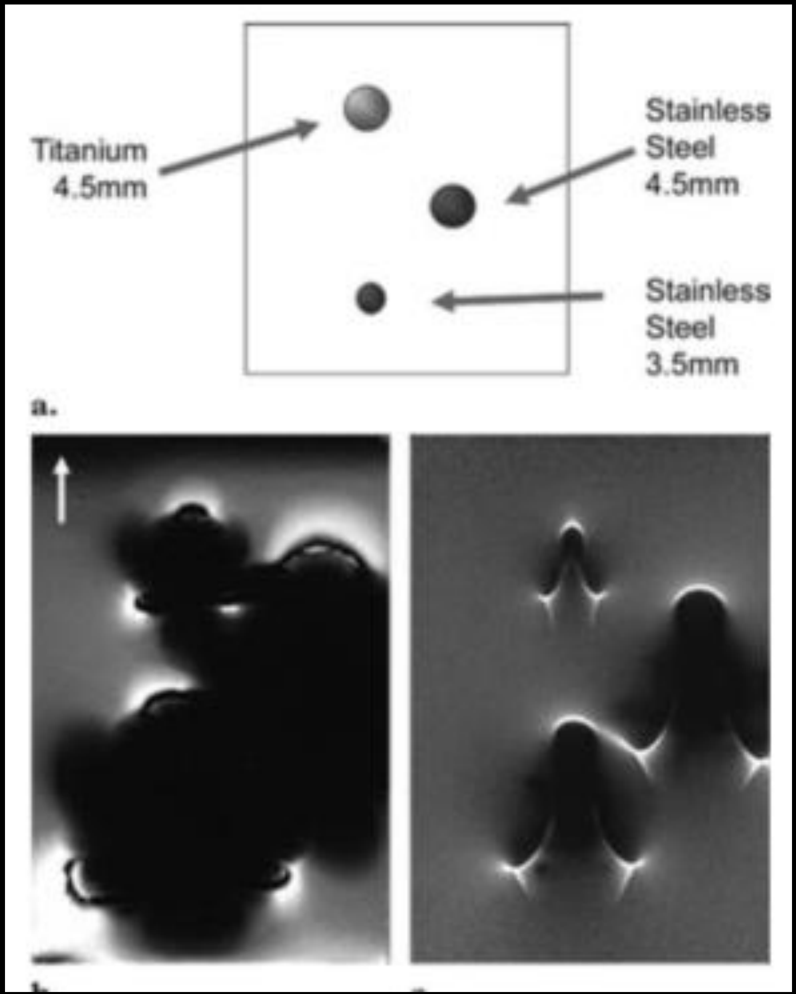
- rBW selected by operator
- Refers to range in frequency-encoding direction
- Usually range from 5-100 kHz (typical 50 kHz)
  - GE reports as total BW
  - Siemens/Toshiba report BW per pixel (ie. Divided by N_f)
    - Ex: 50,000 Hz/256 pixels = 196 Hz/pixel
- BW spread out among pixels. Pixel width = FOV (frequency direction)/N_f (# frequency encoding steps)

Metal implants and MRI

- Metal has no protons
- Alters local magnetic field in all planes
- At the site of metal, causes:
  - Higher spin frequency in adjacent protons
  - Local magnetic field “coded” as if it were higher gradient than it should be and displaces
  - Causes signal loss (void on the image) and displacement
- Displaced signal stacks with adjacent signal, becomes hyperintense in these areas as “pileup”

Metal implants and MRI

- Different types of metal and size of metal affects degree of artifact
- Stainless steel and cobalt chromium (often in hemiarthroplasty) are worse than titanium
- Ceramic usually has among lowest artifact
- Would help to know type of metal prior to protocoling but usually not known/too time intensive



Lee 2007

MARS MRI step 1

- Can use STIR or Dixon for fat sat
- Can increase rBW- larger region excited and while signal displacement is the same, less pixels are displaced
  - 500-600 Hz/pixel at 1.5T
  - 700-800 Hz/pixel at 3T
- MARS vendor sequences (e.g. WARP by Siemens) have optimized RF pulses, high rBW, better STIR sequences
- Image on 1.5T
- Smaller FOV, higher resolution matrix, thinner sections, increased echo train length,

MARS MRI step 2: VAT

- VAT = View Angle Tilting
- Different, oblique readout (freq-encoding plane) that incorporates a component that is in slice selection plane
- Result: re-registers off-resonant (distorted) spins by metal to correct location in readout direction
- Because: if both readout and slice selecting gradient active at same time, it will align off-resonant spin to slice-selecting frequency
- OVERALL: addresses in-plane distortion
- STILL have through-plane distortion

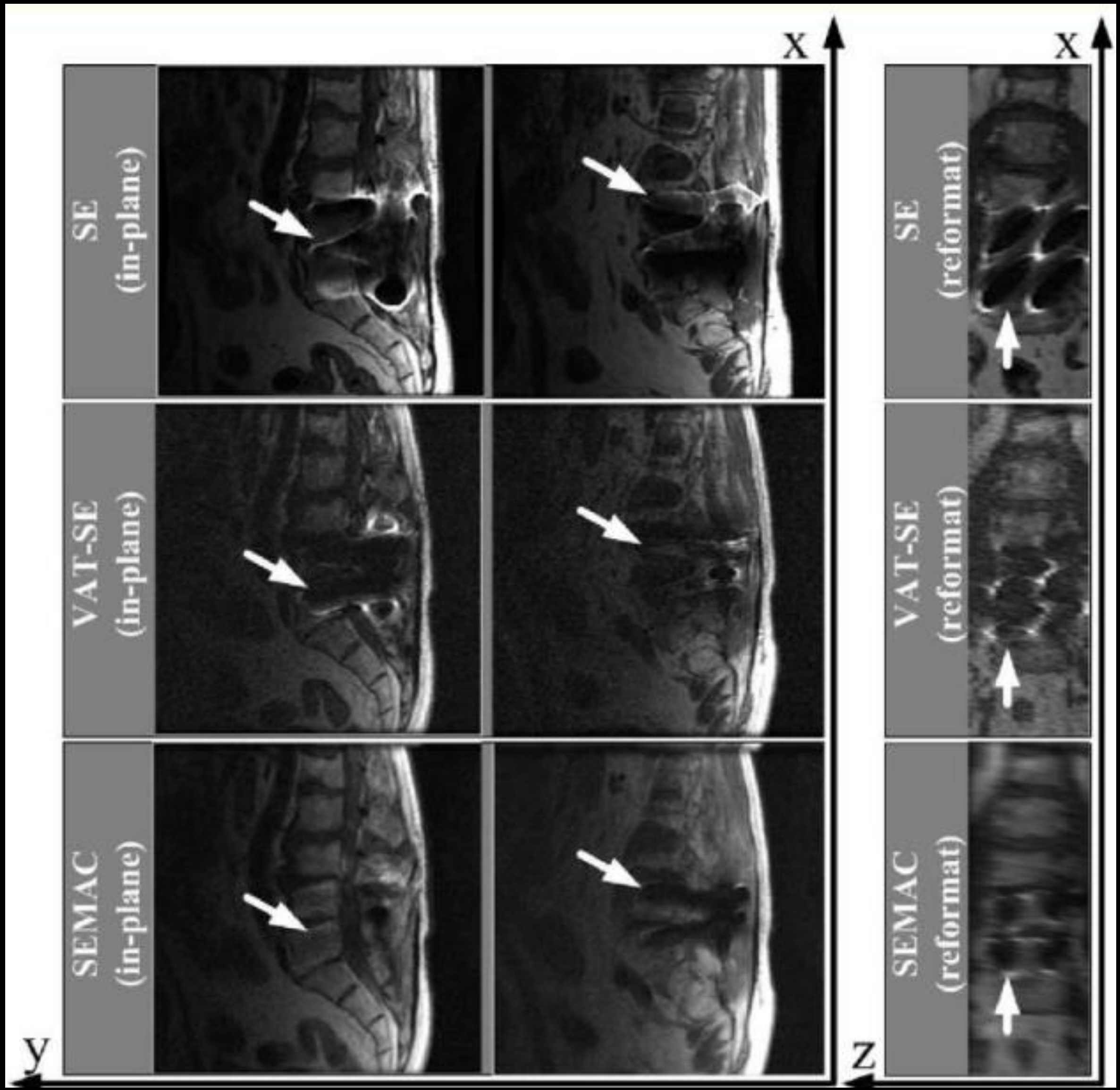
MARS MRI step 3: SEMAC

- Still have artifact? Need to see more detail? Have a stainless steel or cobalt-chromium implant?
- SEMAC (Slice encoding for metal artifact correction)
- Longer (2x scan time), FDA-approved sequence created by Stanford (Dr. Brian Hargreaves)
- Need specific software

MARS MRI step 3: SEMAC

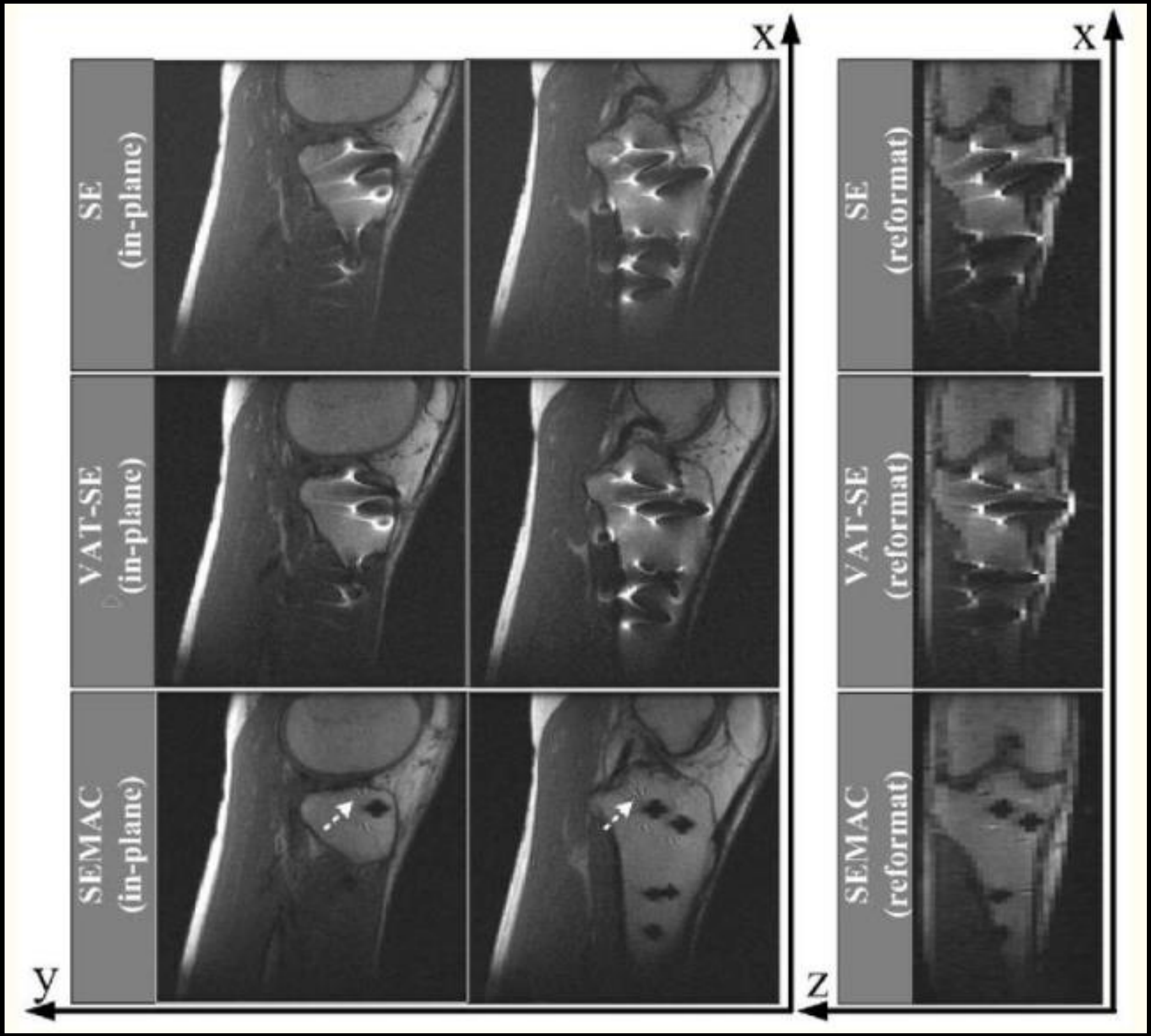
- Essentially, is VAT *plus* extra phase encoding gradients in multiple directions to figure out phase of off-resonant spins
  - Number of SEMAC steps (phase encoding steps) is adjustable; more = better image quality
- Makes 3T viable for MARS; very similar between 1.5 and 3T, except longer scan time with 3T

MARS MRI comparison



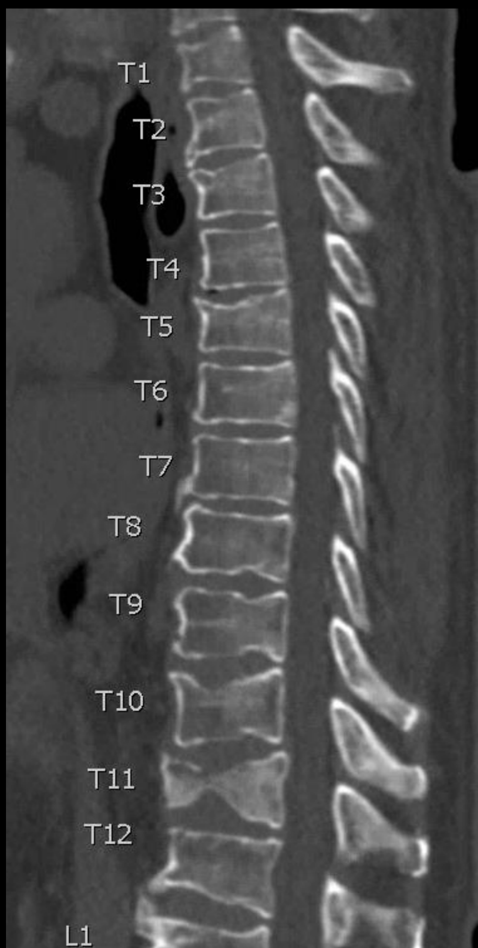
Lu 2010

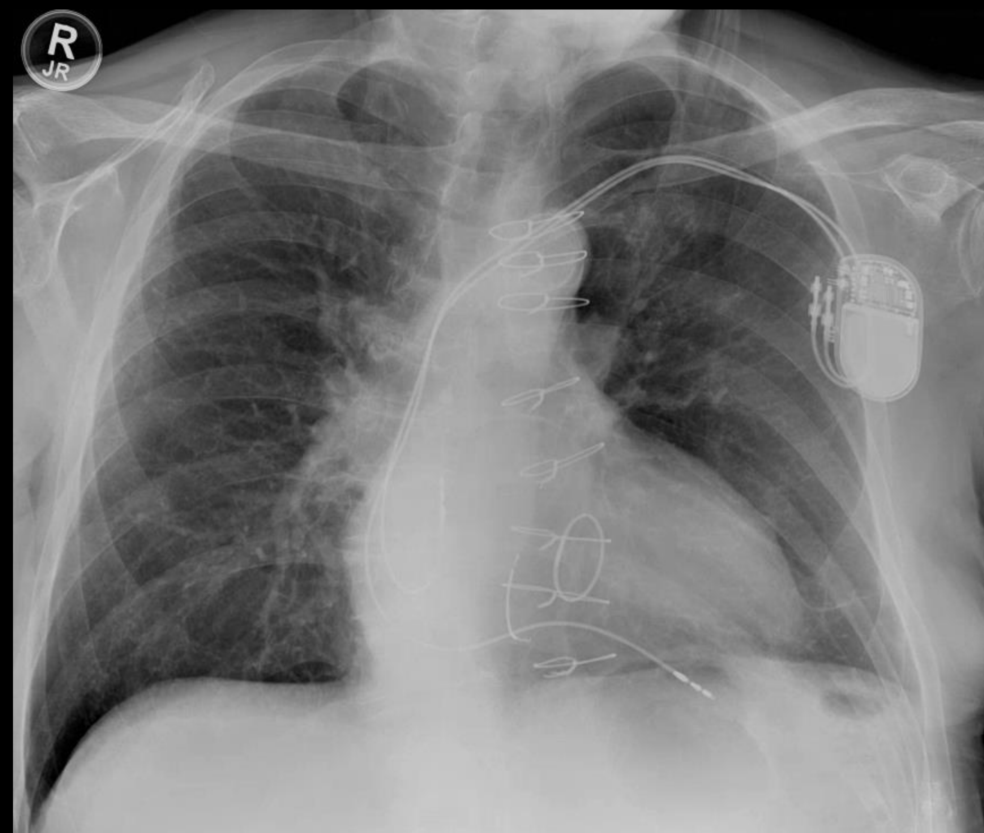
MARS MRI comparison



Lu 2010

Example Case 5: age of spinal compression fractures; unknown pacer

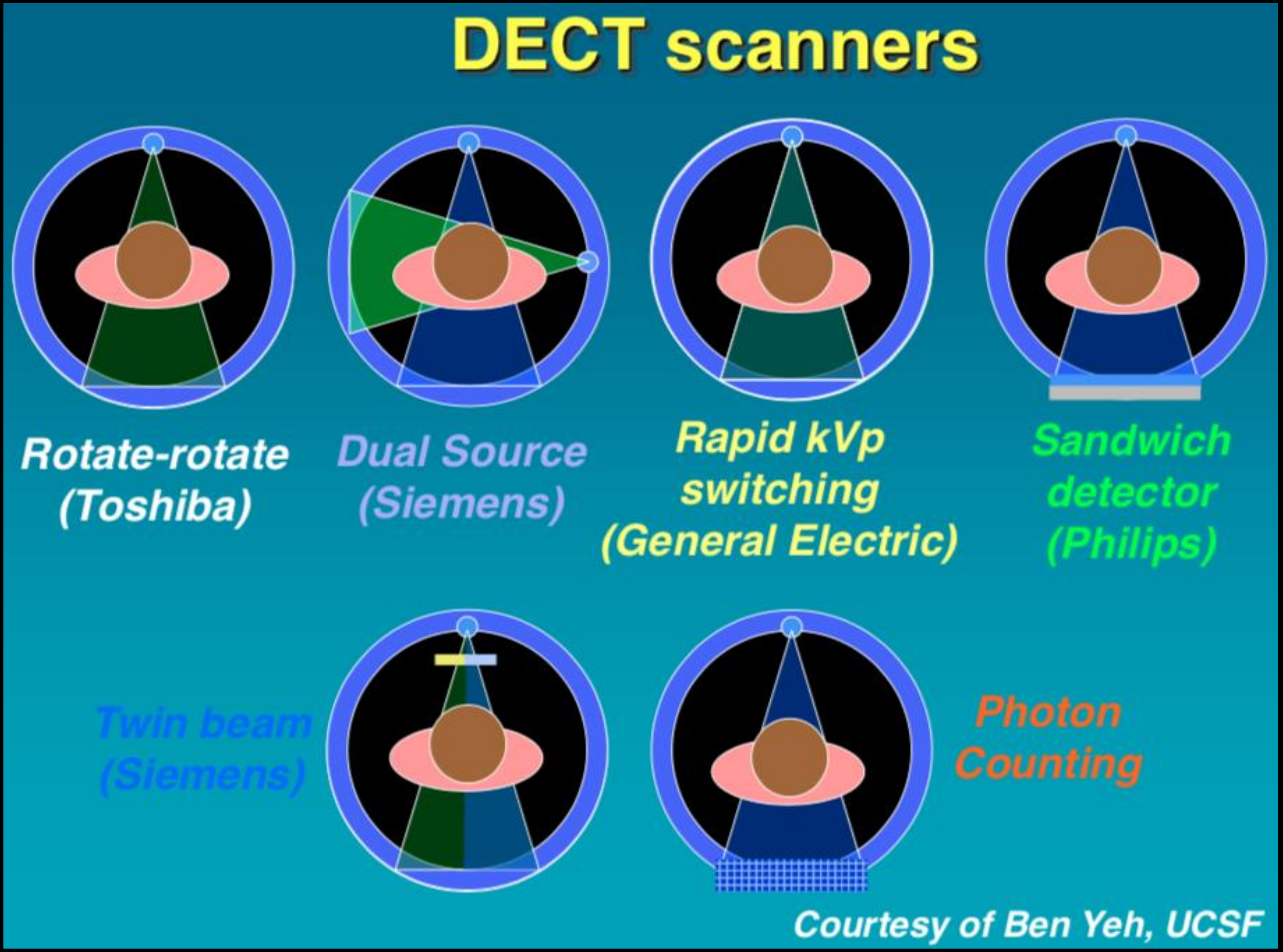




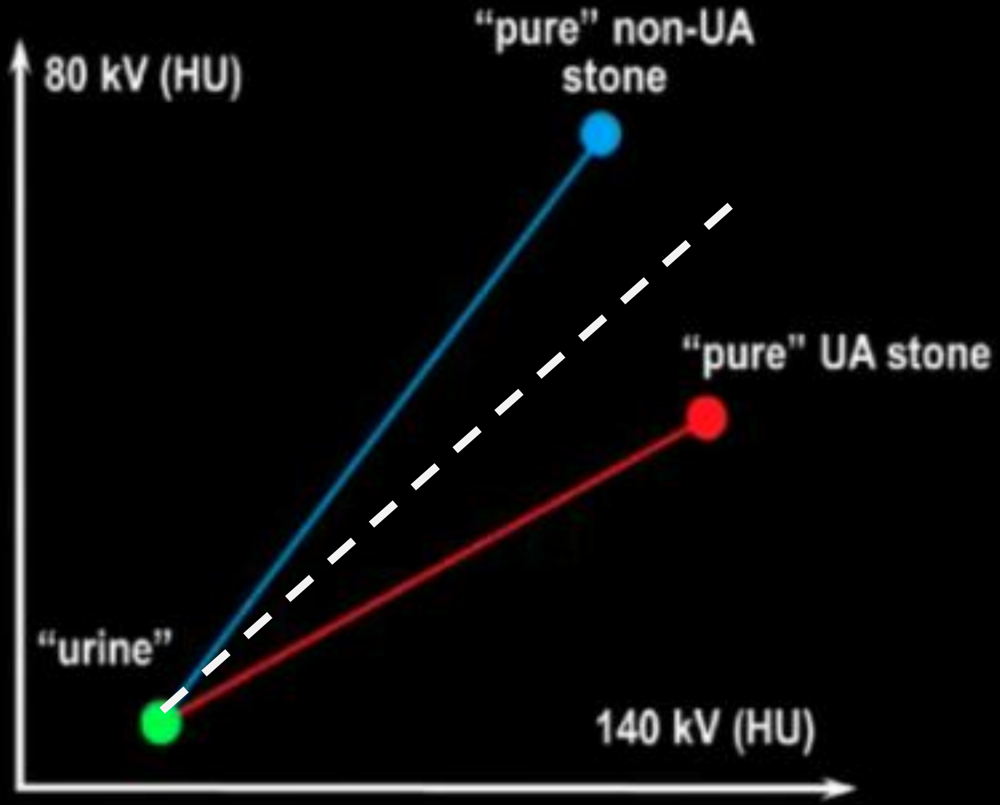
Dual energy CT (DECT)

- Sometimes called spectral CT (though this is now more appropriate for multi-energy (>2 energies) CT)
- Standard CT utilizes 1 polychromatic beam (tube max = kVp), typically around 120 kVP with 1 source tube, 1 detector, 1 scintillator at the detector
- DECT exploits property that different beam energies will be attenuated differently in the same material based on how much the photon energy exceeds k-edge (inner shell e- binding energy)

Dual energy CT (DECT)



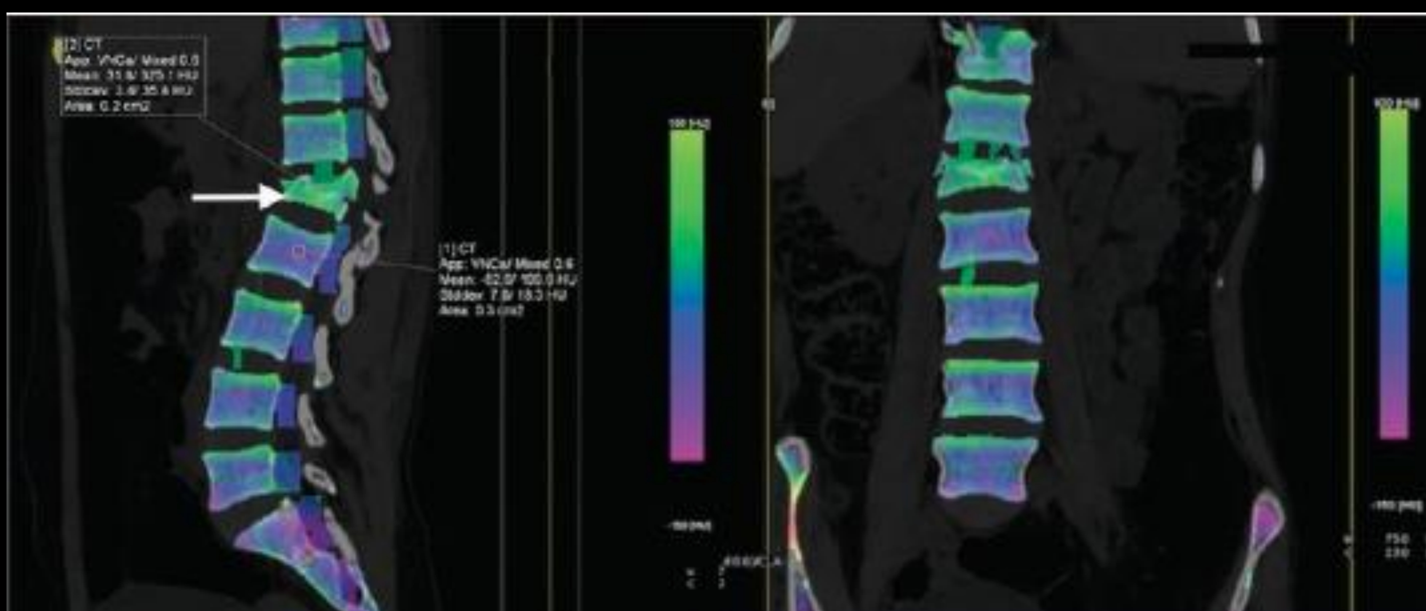
DECT



Leng

VNC (virtual non calcium) DECT for marrow edema

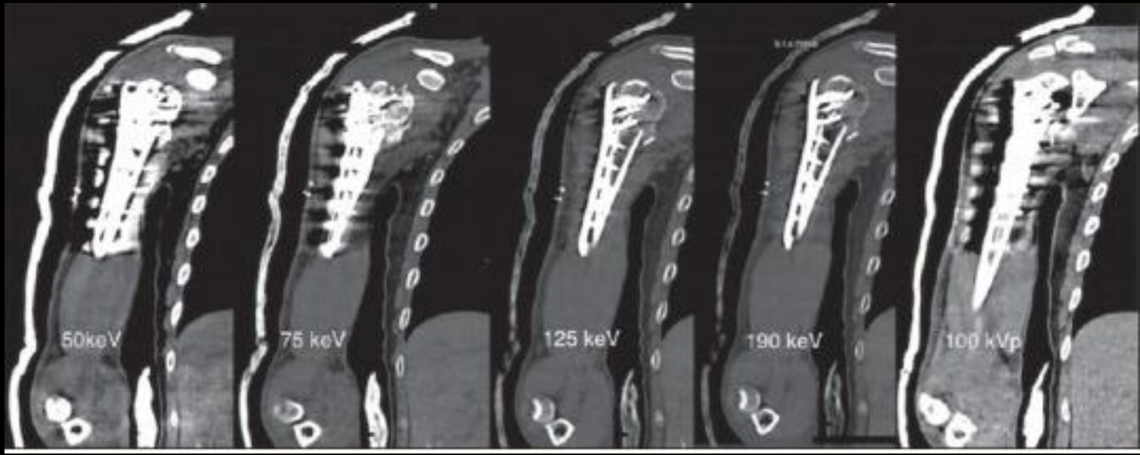
- Sensitivity 96%, specificity 98% for BME in spine in one study (Wang 2013)
- Reader-dependent sens 72%, spec 70% for BME in spine in recent study (Diekhoff 2019)

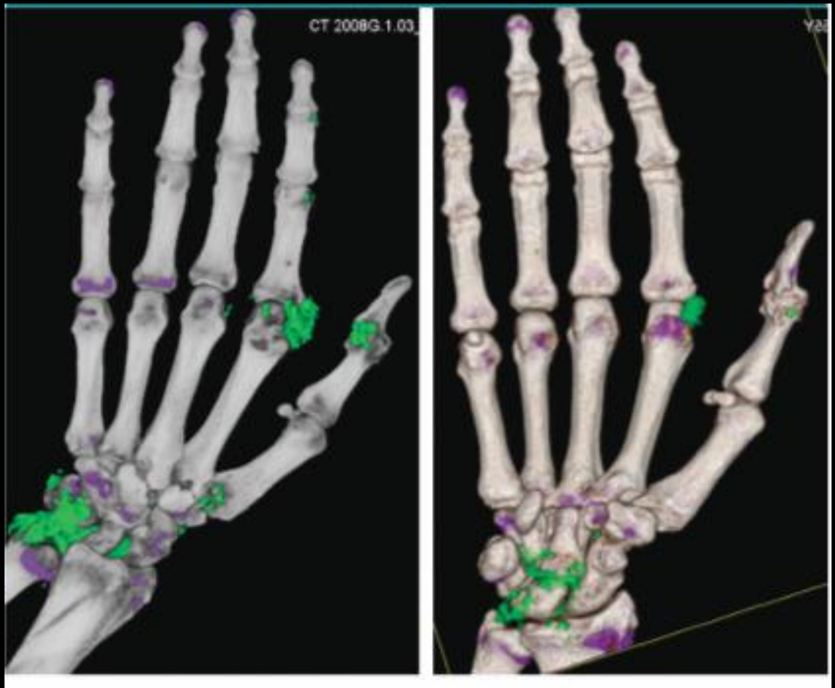


Khanduri 2017

Other applications: MARS CT, gout

- Reconstructed monoenergetic spectrum images for MARS (Khanduri 2017)
- Quantification/ identification of uric acid and treatment response (Glazebrook 2011)





DECT challenges

- Need premium scanner equipment
- No extra reimbursement
- CT techs need additional training
- More data-storage vs sent to PACs
  - Expensive storage – how long
  - More images for radiologist to review
- Usually need separate viewer (e.g. SyngoVia) and software packages for post-processing
- Poor 3rd party integration/transferability to outside PACs

Summary

- Understanding some practical MRI physics will help you be a better radiologist and asset to your practice/patients
- It takes work to understand the physics but it is achievable and many resources are available
- The more you know, the more interesting it will be!

https://en.wiktionary.org/wiki/tip_of_the_iceberg

Additional tools

- ISMRM: https://www.ismrm.org/resources/mr-sites/
- RSNA
- Great on-demand webcasts with detailed talks on DECT and MARS MRI: https://appliedradiology.com/Webcasts/on-demand-webcasts
- Dr. Brian Hargreaves (recommended by Dr. Chung!): Basic MRI: http://med.stanford.edu/bmrgroup/education/mri-physics.html
- Dr. Brian Hargreaves (recommended by Dr. Chung!): More focused topics including SEMAC: http://med.stanford.edu/bmrgroup/education.html
- Ctisus.com – dual energy CT protocols and short educational lectures, but greater emphasis on body/chest general protocols and 3D CT techniques
- Basic and in-depth common Q&A of radiologists from MIR professor: http://mriquestions.com/index.html
- Protocol pages from individual institutions (e.g. Jefferson, U Wisconsin-Madison, Hopkins CT)

Recommended readings

- AAPM/RSNA physics tutorials for residents in Radiographics
  - Example: MRI imaging brief overview/emerging applications by Jacobs in 2007
- Intro text: Hashemi's *MRI: The Basics*
- Comprehensive (also available in electronic version at UCSD library): Brown's *MRI: Physical Principles and Sequence Design*
- Bernstein's *Handbook of MRI Pulse Sequences* (also available in electronic version at UCSD library)

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