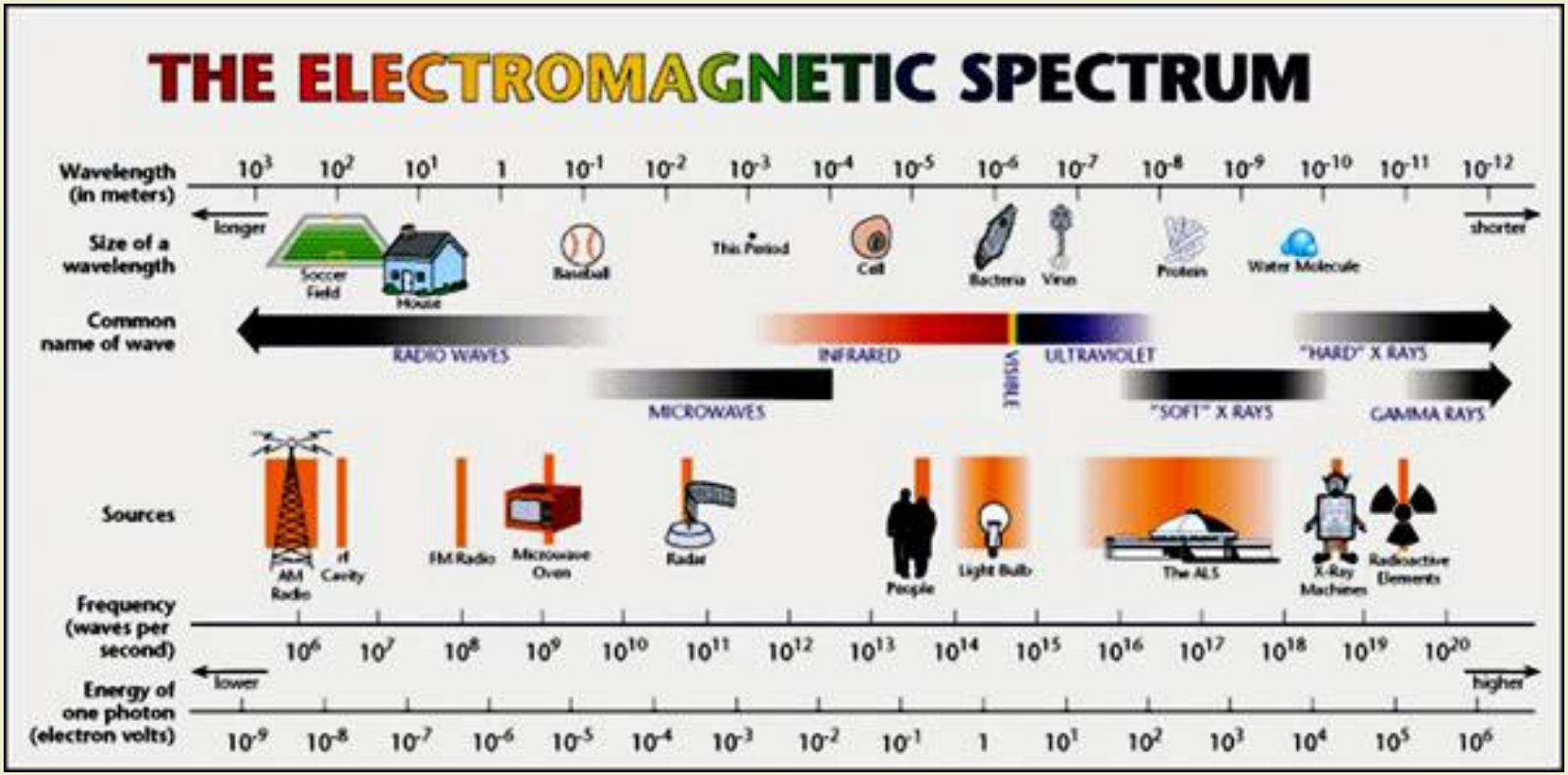
A MR Technologists' guide to Radiofrequency

Vera Kimbrell BSRT R MR FSMRT

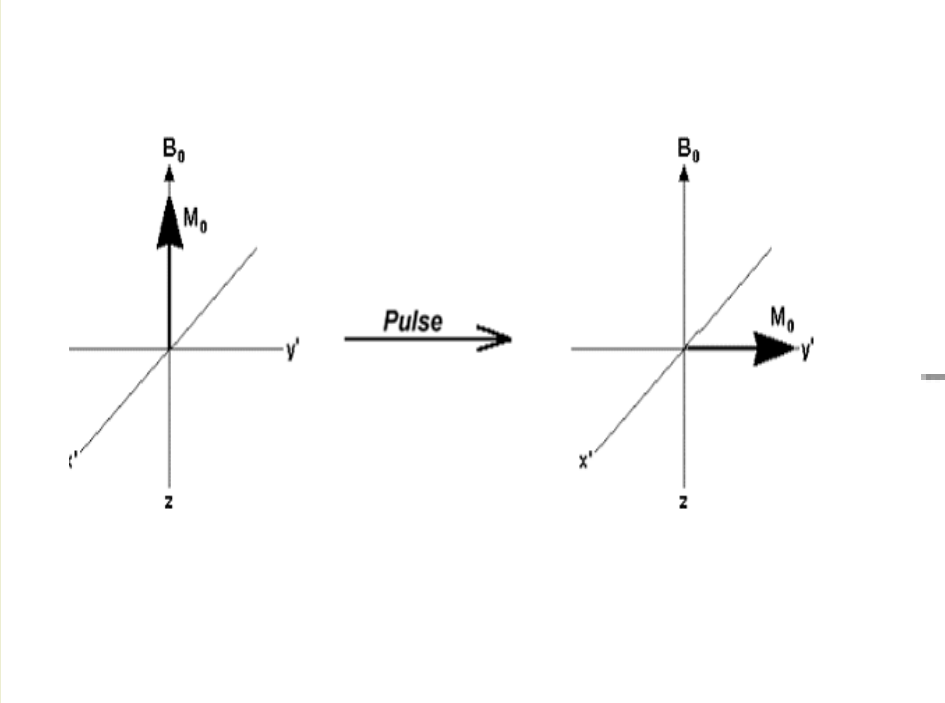
What is Radio Frequency?

- http://rifevideos.com/images/Chapter%204/radio_spectrum.jpg

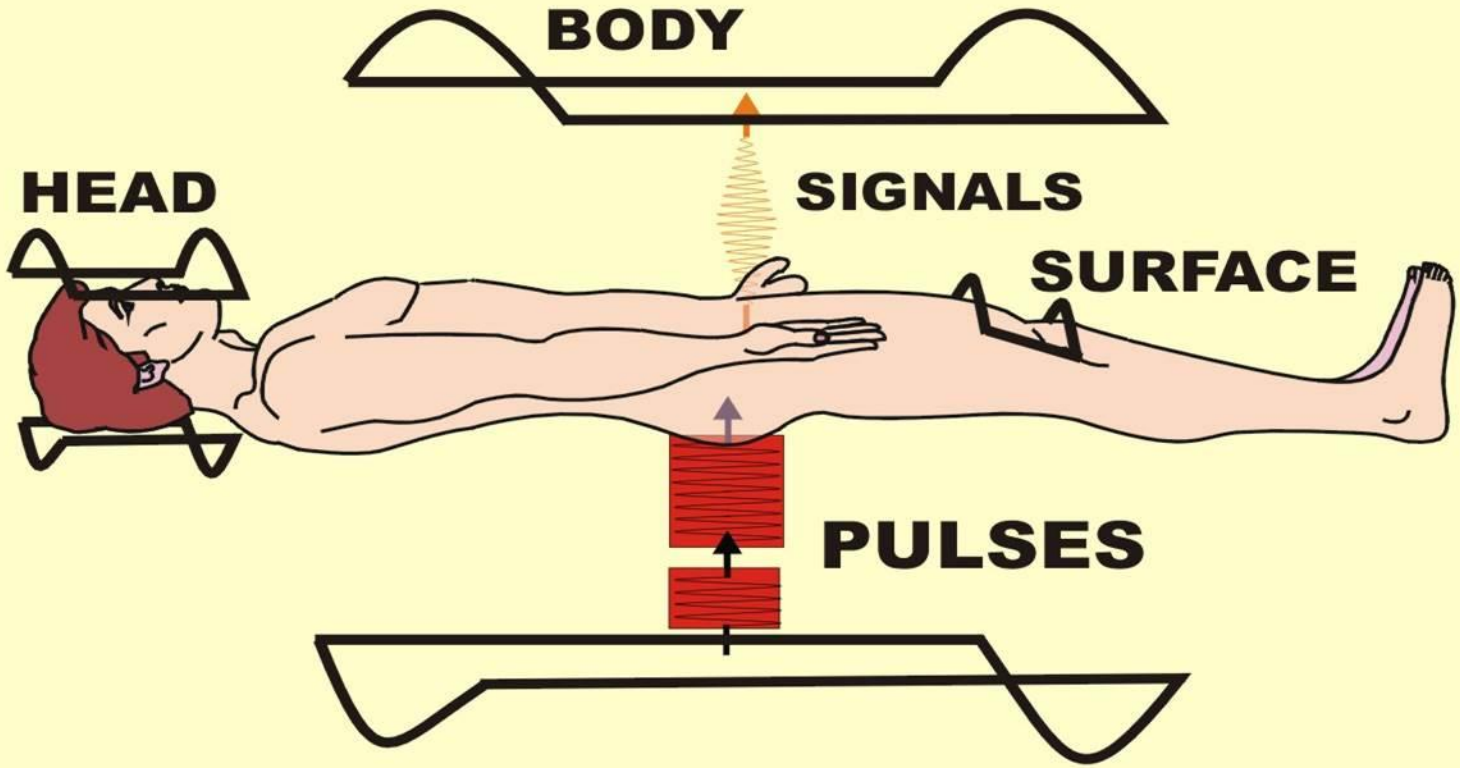


What is the RF pulse in MRI?

- An oscillating magnet field
- Electromagnetic waves switched on and off in short “bursts”
- Transmitted 90’ to the static field at the “larmour frequency”
- Referred to as the “ RF excitation”
- Generally called the B1 field



THE RF COILS



http://www.sprawls.org/mripmt/MRI02/MRI%202-6.jpg

Sprawls

How is RF produced?

- Frequency Synthesizer-Produces a carrier wave at the Larmour Frequency
- Modulator –Shapes the wave into “pulses” or bursts
- Amplifier- Generates large currents to drive the RF coils. This is where the gain is adjusted and the “flip angle” determined
- Quad Hybrid- Splits the output of the power amp into 2 parts 90’ out of phase with each other (in phase and quadrature)
- T/R Switch- electronic switching circuitry to ensure current delivered to the coil at correct time. Some coils are used to both transmit and receive signal. For these special T/R switch is required to isolate the two functions and make sure the powerful electric currents used for transmission do not go into and burn up the sensitive receiver circuitry

http://mriquestions.com/radiofrequency-waves.html

RF Heating in MRI

- The heating from RF in MR exams is based on the tissues resistive loss and is dependent on the amount of energy absorbed. The body loses heat by the following mechanisms:
  - Convection
  - Conduction
  - Radiation
  - Evaporation
- If the body cannot achieve thermal homeostasis it will store heat, temperature in tissue rises
  - Disease
  - Drugs
  - Ambient temperature

www.mrisafety.com

RF and Heating

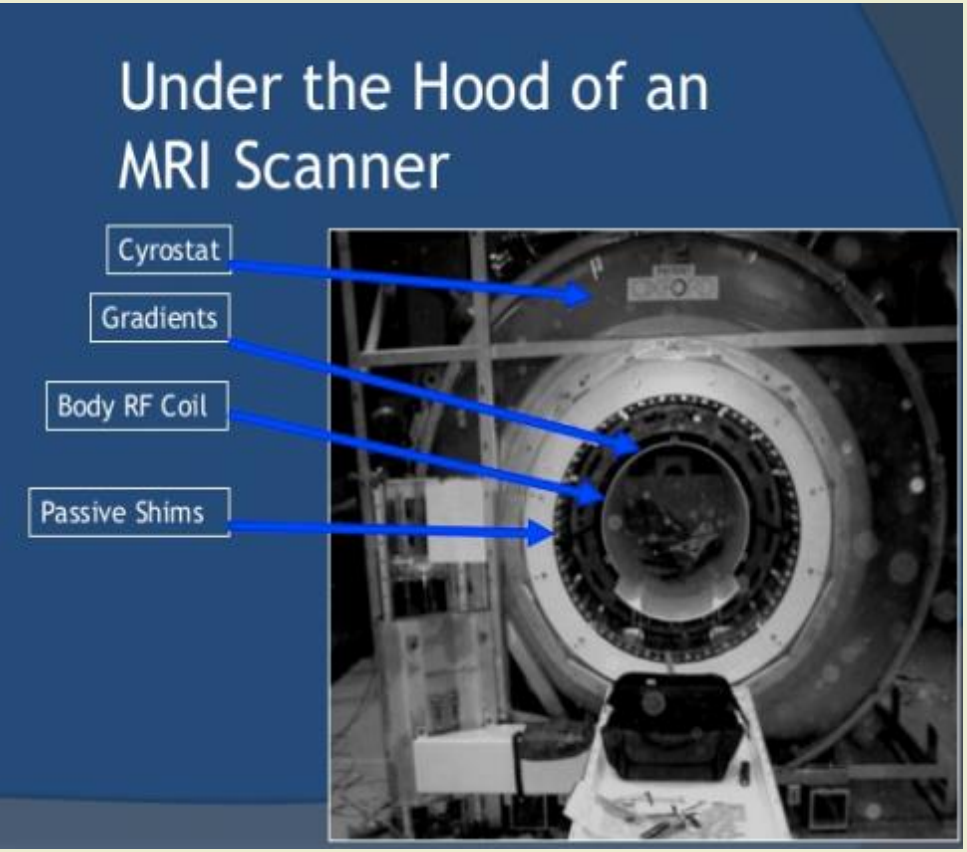
- 2 types of heating:
  - **Induction**
    - EMF causes electrical currents to be excited within the tissue. These currents heat the tissue The amount of heat generated is dependent on three factors:
      - (1) the magnitude of the induced currents,
      - (2) the resistance of the material to the flow of the currents
      - (3) the length of time the material is exposed to the field.
  - Dielectric
    - Refers to heat generated in poor electrical conductors
    - The heat results from electrical losses that occur in a material.
    - Hi Frequency alternating fields in the range of 10-100 Mhz

During the Scan

- A RF pulse (time varying magnetic field) "*induces"* a voltage (electric field) and current flows in the tissue
  - Human tissue is a poor conductor but does conduct current
- RF is absorbed in the tissue
  - Resistance causes heating
- The Pulse is turned off
  - Energy is released
  - A current is induced in the RF receive coil
  - This current becomes our FID

Transmit RF------Receive RF

MRI Hardware slide share

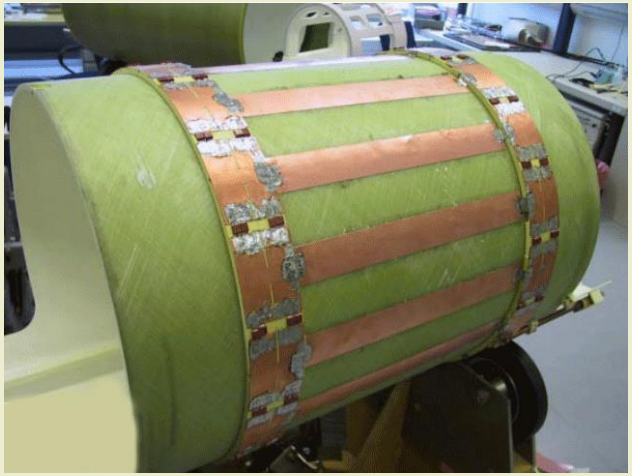


Types of RF Coils

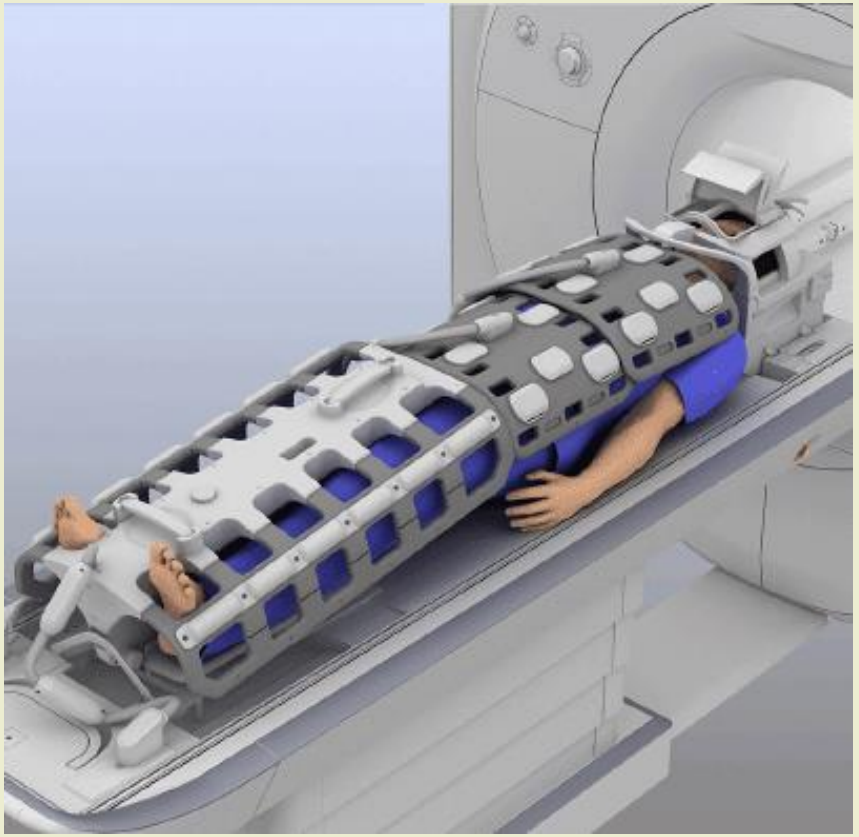
- Transmit
  - Transmits the RF pulse only
- Receive
  - Receives the RF pulse only
- Transmit & Receive
  - Transmits & Receives the RF Pulse
- Dual Transmit ** New
  - Divides the RF transmitter into independent elements that each produce a portion of the pulse
    - This should generate a more homogeneous field
    - Better distribution of magnetic and electric fields

RF coils

Transmit and Receive

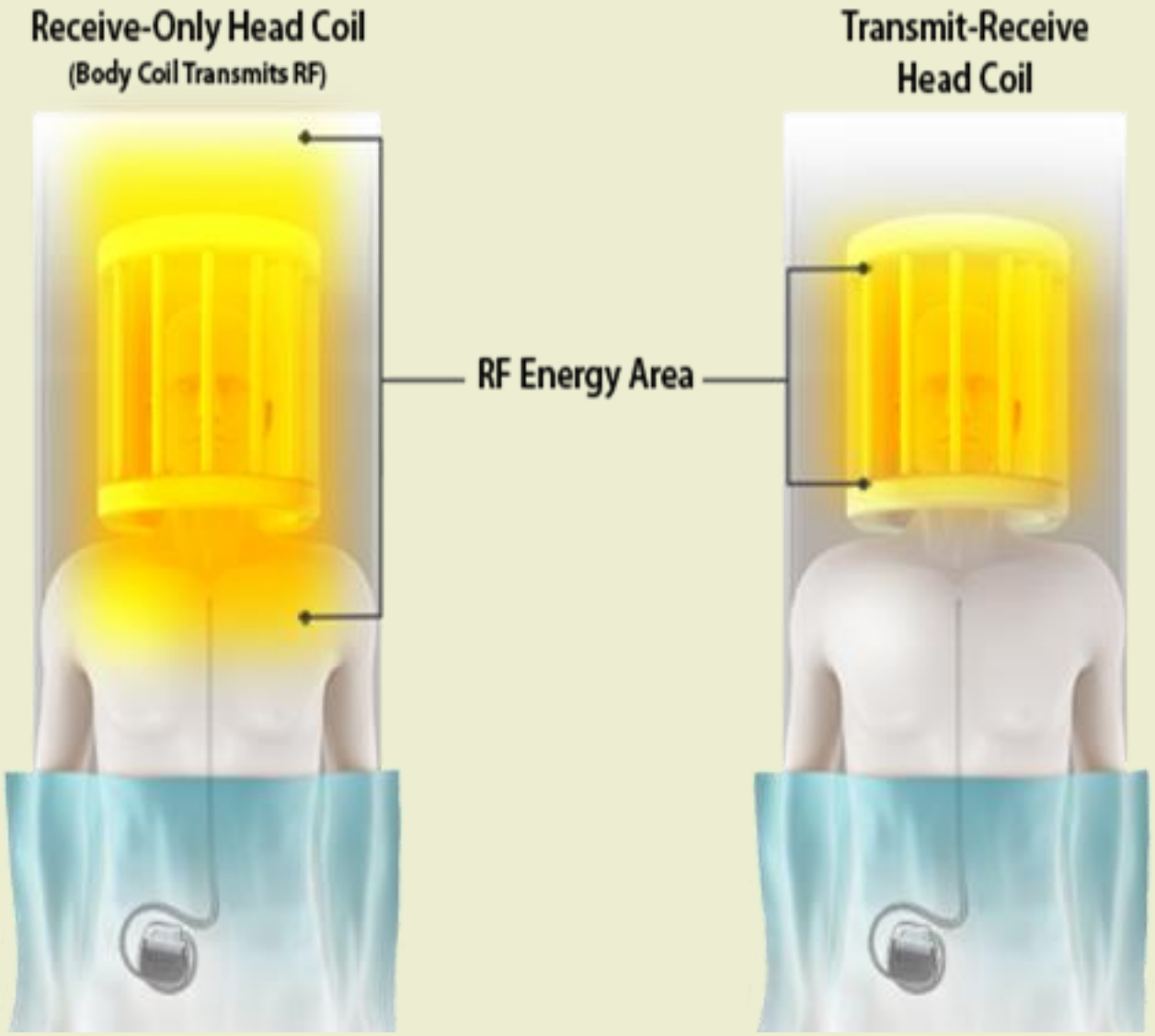


Receive only



Mriquestions.com

http://mri-q.com/uploads/3/4/5/7/34572113/3943010_orig.gif



Multi-Transmit or Parallel Transmit Coils

- Uses multiple RF channels in “parallel”
  - 2 or more sources
- Reduces SAR
- Produces a more homogenous B1 field
  - B1 shim

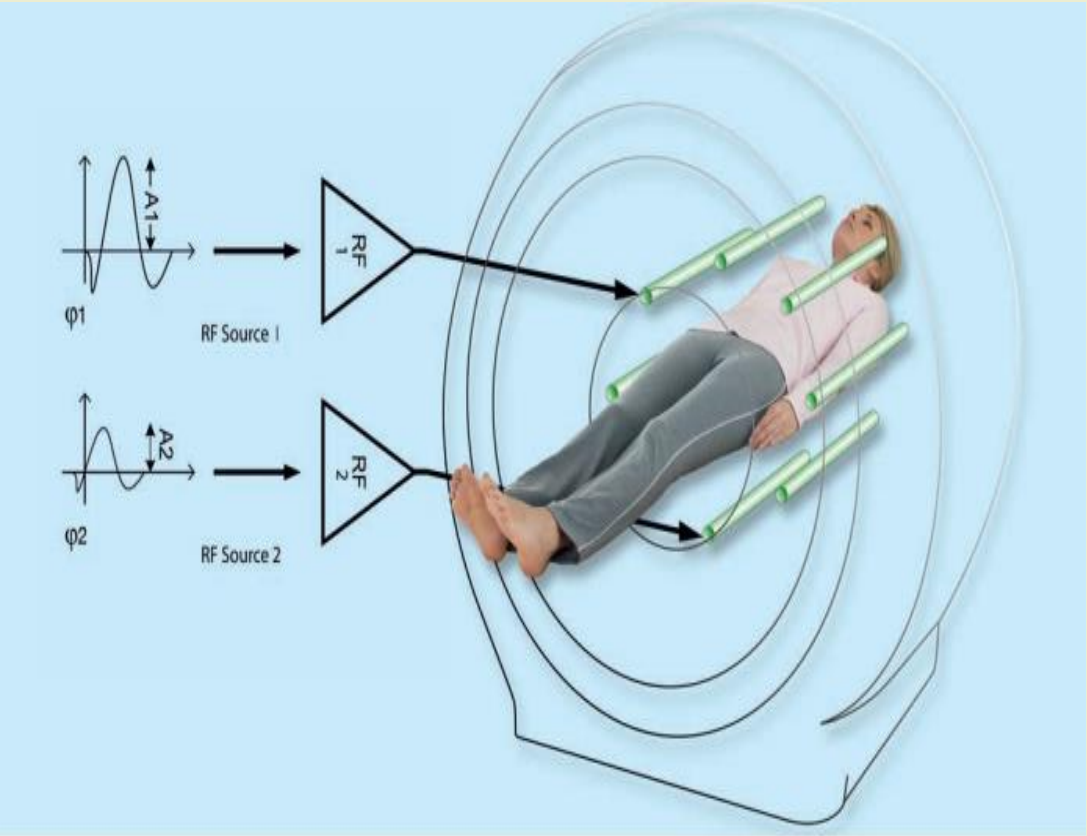


Image courtesy of Phillips healthcare

New RF Transmit workflow

- 3T and higher only
- PT/TX mode
  - Quadrature (single transmit like always)
  - Multichannel (usually 2)
  - B1 shim mode
    - Volume specific
    - Pt. specific
  - Dielectric improvements
  - Lower SAR

Components of the RF pulse

- B1+
  - The positively rotating portion of the B1 field useful for imaging
- B1-
  - Rotates opposite to the B1+ field. Does not interact with the spins but does contribute to heating

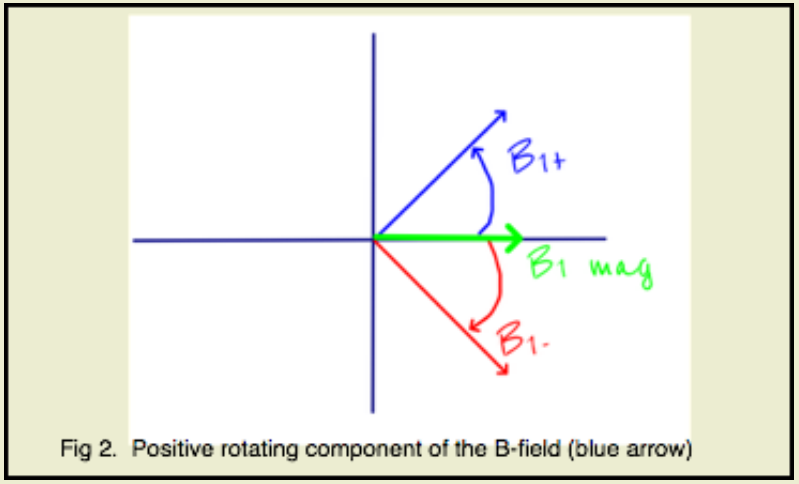


Fig 2. Positive rotating component of the B-field (blue arrow)

http://www.ismrm.org/smrt/E-Signals/2016FEBRUARY/eSig_5_1_hot_2.htm

Potential mechanisms for RF Burns

- Direct electromagnetic induction in a conductive loop*
  - Circulating currents cause current to flow in conductor causing resistance and heating
- Induction in a resonant conducting loop **(near field)
  - Occurs when the transmitted frequency matches a particular resonance frequency of a circuit
- Electric field resonant coupling with a wire (the antenna effect) ***
  - Resonance is achieved when the antenna is approximately half a wavelength long (half-wave dipole antenna). When resonance is achieved, the electrical energy remains confined to the immediate vicinity of a given antinode. Thus, the highest electric field of the antennae is at the tip.

J Magn Reson Imaging. 2001 Apr;13(4):627-31.Investigation of the factors responsible for burns during MRI Dempsey MF1, Condon B, Hadley DM

Direct Induction in a loop

Radiology. 1996 Aug;200(2):572-5.

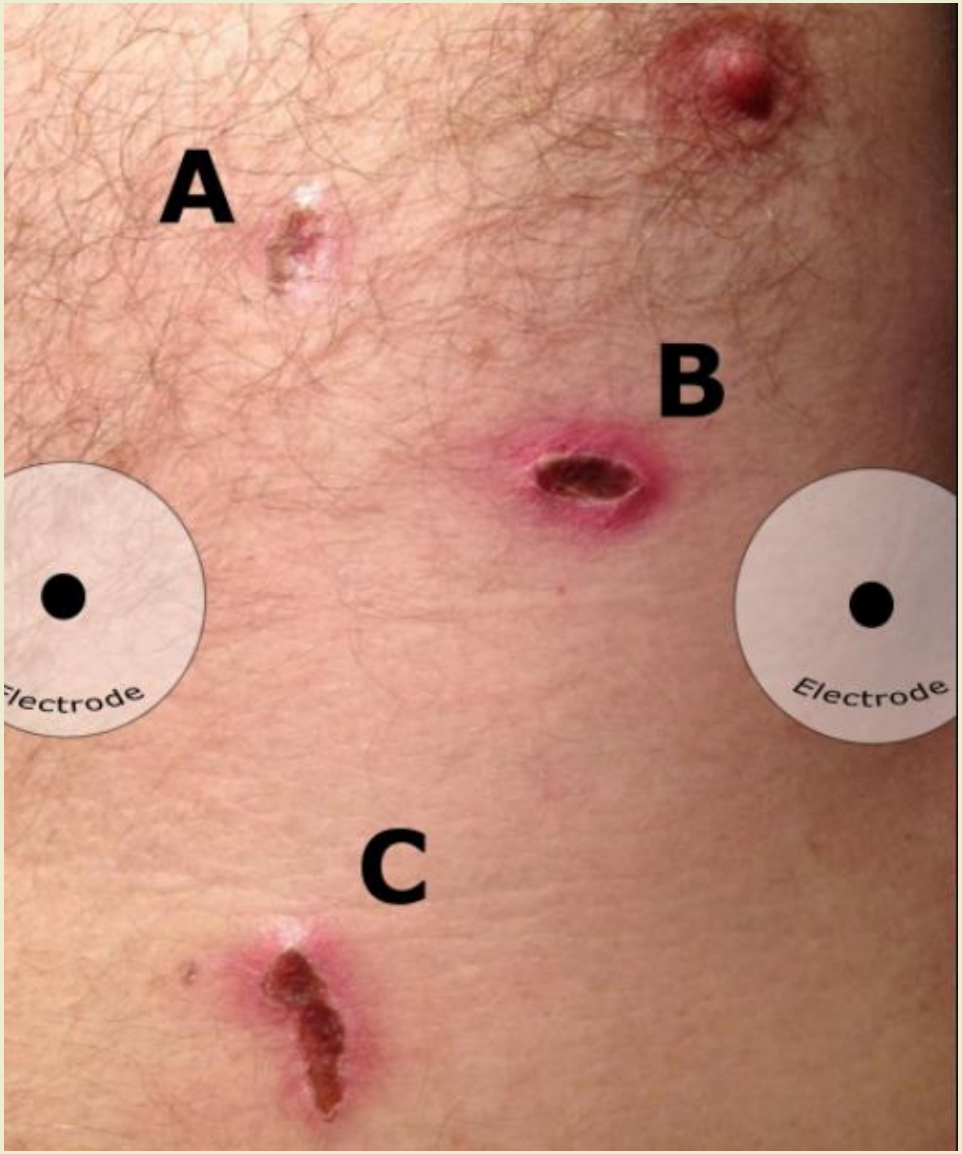
Unusual burns of the lower extremities caused by a closed conducting loop in a patient at MR imaging.

Knopp MV[1], Essig M, Debus J, Zabel HJ, van Kaick G.

Near Field

Facebook mri safety group

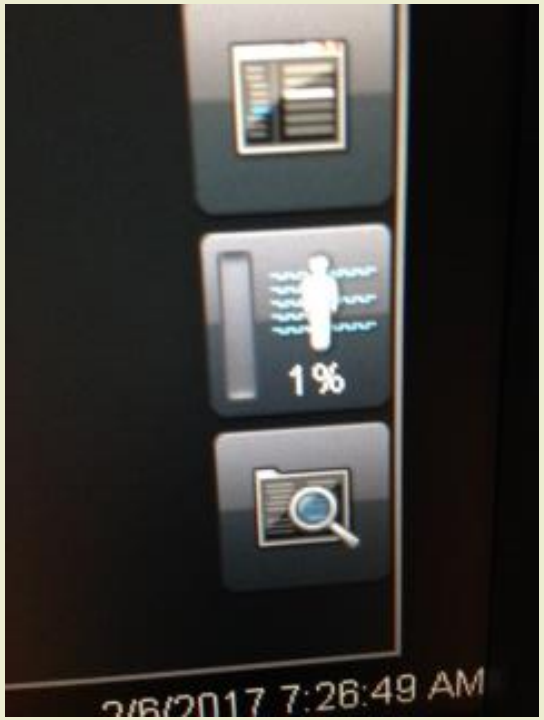
Antenna Effect



http://nobleresearch.org/

Measurements of RF in MRI

- Specific Absorption Rate-SAR
  - The amount of RF that a subject encounters
  - Average, peak, Whole body
  - Complex calculation:
    - Magnetic field/RF frequency
    - Pulse type
    - TR
    - RF coil
    - FOV
    - Size and shape of the ROI



Alternative RF Measurement

- B1 + rms
- Expressed in $_{m}T$
- The root-mean-square value of the MRI effective component of the B1 eld. Units are micro-Tesla (μT)
- Is thought to be a more precise exposure metric

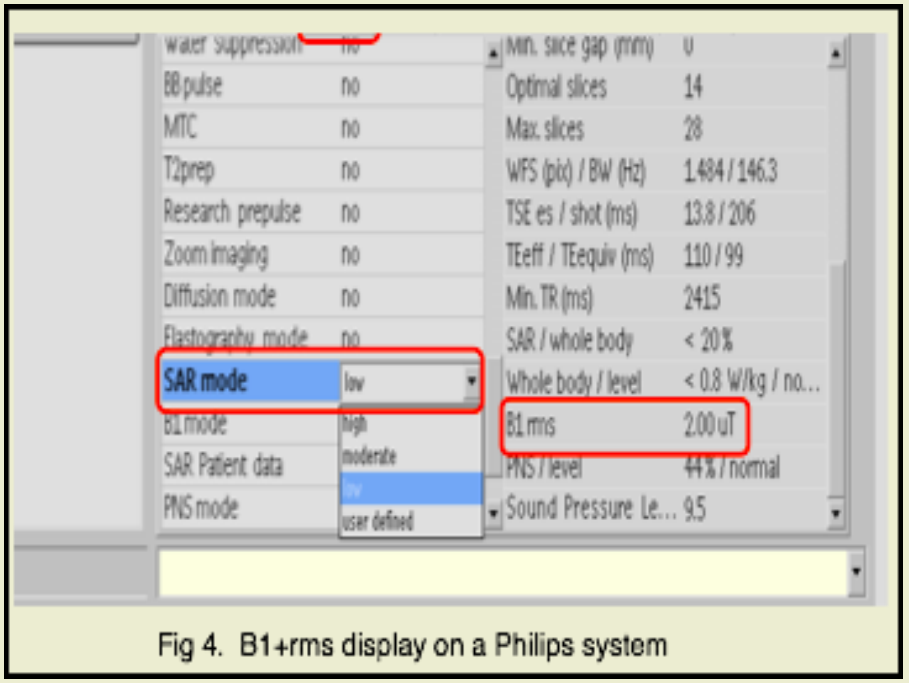
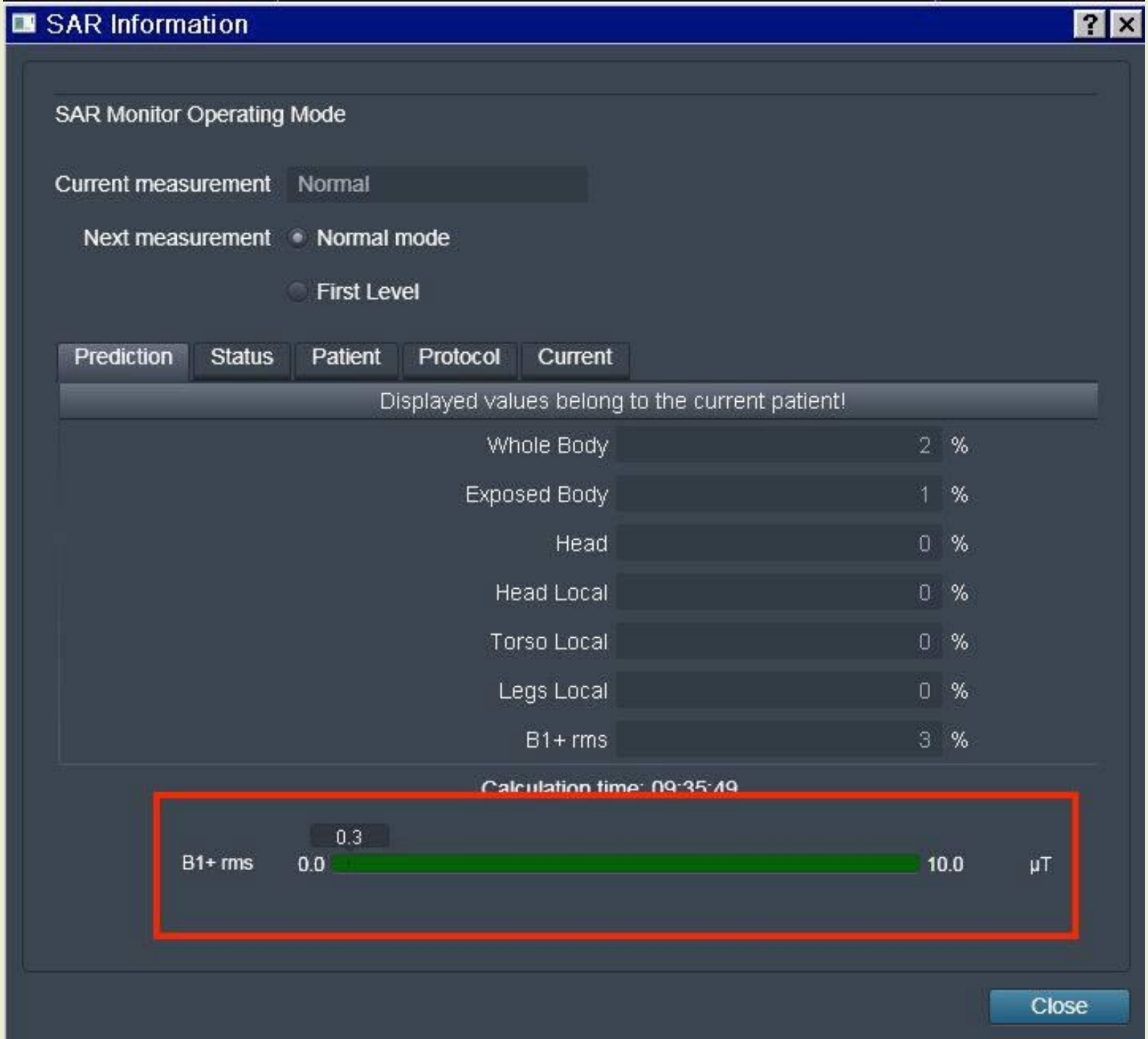
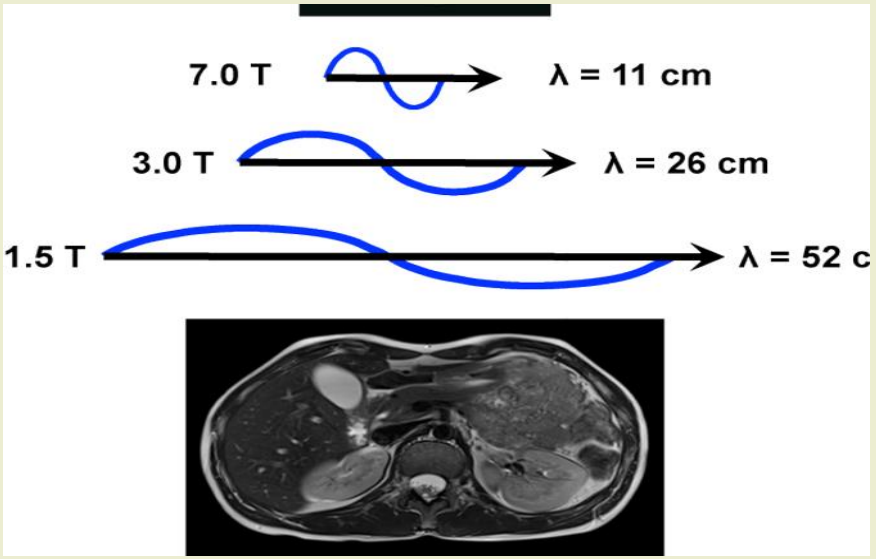


Fig 4. B1+rms display on a Philips system


SAR Information
SAR Monitor Operating Mode
Current measurement
Normal
Next measurement
Normal mode
First Level
Prediction
Status
Patient
Protocol
Current
Displayed values belong to the current patient!
Whole Body 2 %
Exposed Body 1 %
Head 0 %
Head Local 0 %
Torso Local 0 %
Legs Local 0 %
B1+ rms 3 %
Calculation time: 09:35:49
0.3
B1+ rms
0.0
10.0
µT
Close

1.5 vs 3T

- 1.5T requires a frequency of about 64mHz
- 3T requires a frequency of approx. 128mHz
- 1.5T to 3T means a 4x factor for SAR
- Dielectric Artifact



http://mriquestions.com/uploads/3/4/5/7/34572113/2610674_orig.jpg

Courtesy of Titi Owman

Fieldstrength	Frequency	Wavelength
1T	**42 MHz**	**79 cm**
1.5T	**63 MHz**	**52 cm**
3T	**128 MHz**	**26 cm**
7T	**294 MHz**	**11 cm**

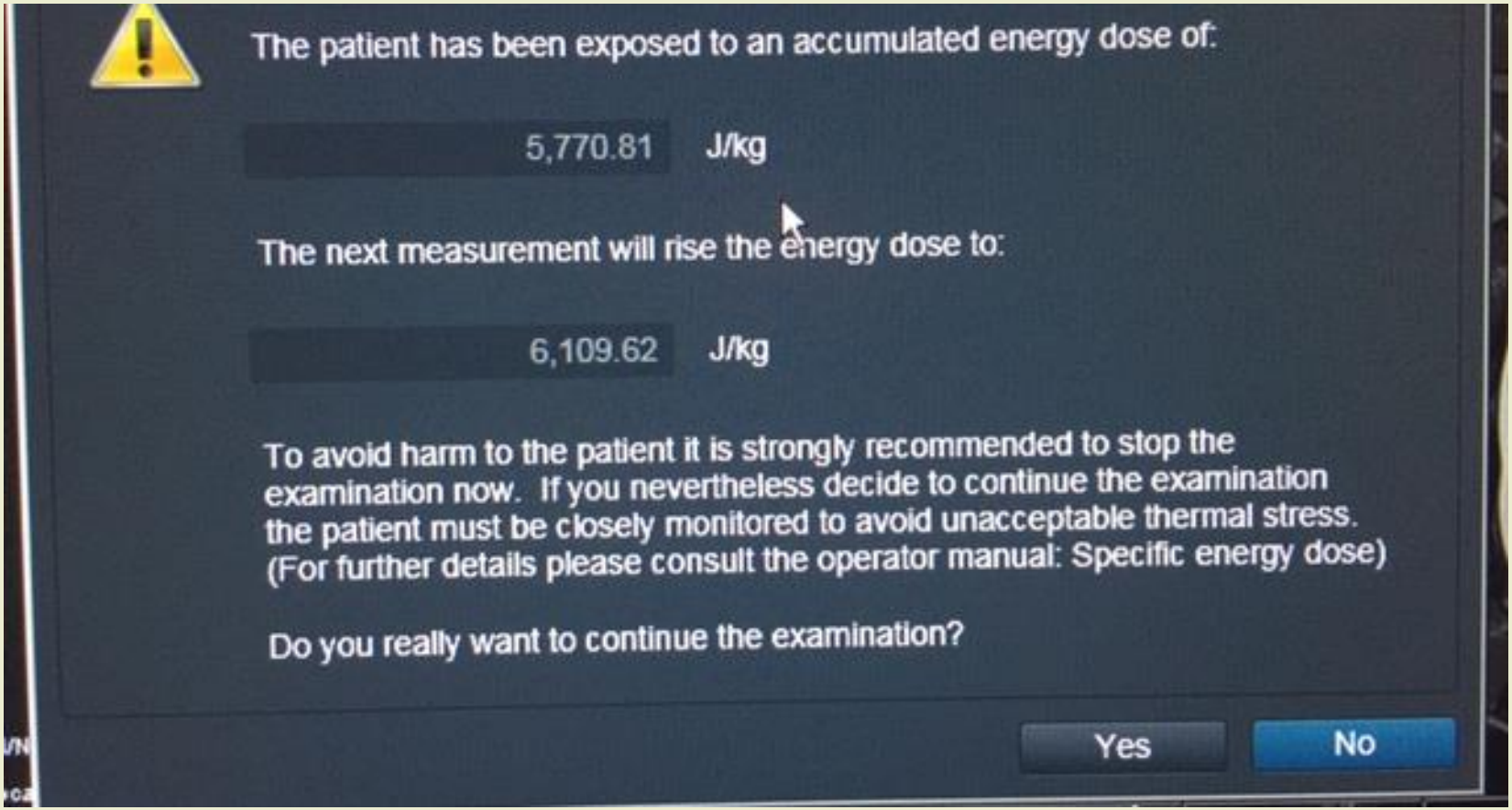
Calculating SAR

- Factors:
  - The Induced electrical field
  - Duty cycle (exposure time)
  - Tissue density and conductivity
  - Patient size
- Actual calculation=
  - Radius of the sphere^2 x B0^2 x Flip Angle^2 x Density
- Expressed in Watts per kg (Wkg)
- Assumption that 1 Wkg for 1 hour elevate the body temp 1’ C

10sec and 6min SAR calculations

SAE/SED Limits on SAR

- Long term SAR (SAE/SED) limits:
  - SED = Specific Energy Dose
  - SAE = Specific Absorbed Energy
- Some scans can be very long….
  - FDA has a report of 3rd degree burn requiring amputation below elbow
- Historical limit of 60 min. at 4 W/kg. It may seem high but think of those pt. who get a total spine and brain scan….
- SAE/SED limits are now set by MR Vendor and vary in time


The patient has been exposed to an accumulated energy dose of:
5,770.81 J/kg
The next measurement will rise the energy dose to:
6,109.62 J/kg
To avoid harm to the patient it is strongly recommended to stop the examination now. If you nevertheless decide to continue the examination the patient must be closely monitored to avoid unacceptable thermal stress. (For further details please consult the operator manual: Specific energy dose)
Do you really want to continue the examination?
Yes
No

Siemens Manual on SED

- SED limit - 400 J/kg.
- Equivalent to a continuous SAR level of 2 W/kg for 2 hours or 4 W/kg for 1 hour.
- Siemens risk management warning threshold: 6000 J/kg
- Equivalent to a continuous SAR level of 2 W/kg for 50 minutes or 4 W/kg for 25 minutes
- Below warning threshold, patients with normal thermal regulation are considered safe
- Above warning threshold, patient may suffer physiological stress or tissue damage
- Effects depend on applied SAR and patient's condition
- Adapt examination duration to the described times for normal and first level modes
- SED level: reset to zero when new patient registration is initialized

New RF Transmit terms

- Dual or parallel transmit-meaning there are multiple sources of RF transmission in the Body coil
  - You will begin to see this in implant literature-Still deciding what is the "recommended" language
    - Quadrature-CP (circularly polarized)
    - Multi coil transmit
    - TxPx(pTx-N)
    - B1 Shim and B1 mapping
      - Pt specific
      - Slice specific
      - Volume specific

What happens at the console

- The patient is registered
  - Weight and possibly height is entered
- A pulse sequence is set up for imaging
- The scanner calculates what is necessary to perform the sequence
  - The machine initiates a “pre-scan” thereby selecting necessary RF needed for the sequence
- Scan is acquired with the parameters desired
  - As long as the chosen sequence meets the threshold mode

Choosing the Transmit and Receive RF Coils

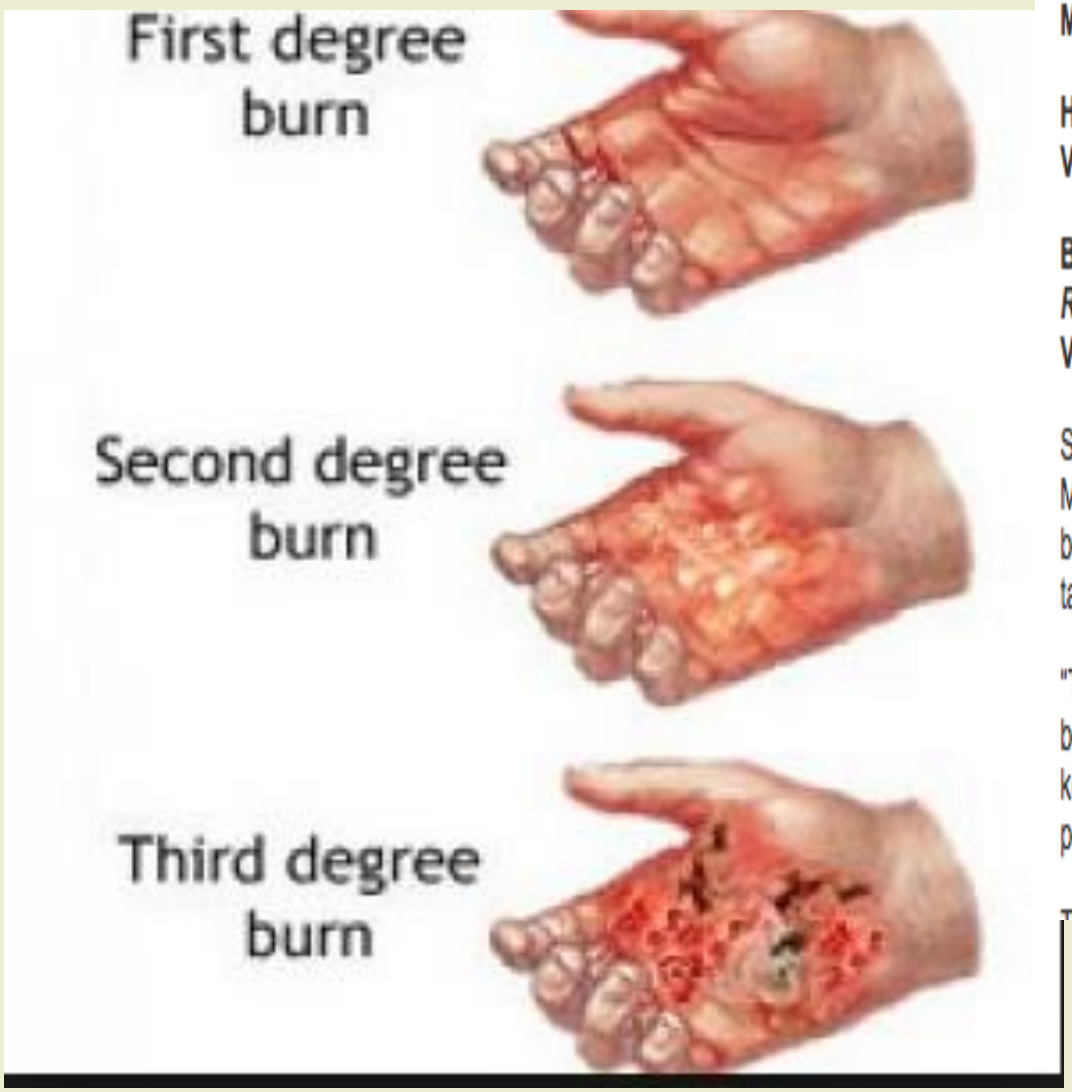
- Usually done based on body part and protocol
  - You use a knee coil when scanning a pts knee
- What are your options?
  - For Transmit?
    - Usually the internal Body coil does the Transmit
    - Some local coils are capable of both
  - For Receive?
    - The coil with the best SNR!
- What controls those decisions?
  - What's available in your facility at the moment
  - Patients body habitus
  - Implants?
  - Protocol

Choosing SAR limits

- 3-4 thresholds available on the scanner:
  - Normal
    - 2 W/kg
  - First level
    - 4 W/kg
  - 2nd level or research level
  - For some there is a “low” or implant level
    - Usually 1.5 W/kg

FDA Guidelines for SAR

- Whole body: 4W/kg/15-minute exposure averaged;
- Head: 3W/kg/10-minute exposure averaged;
- Head or torso: 8W/kg/5 minute exposure per gram of tissue;
- Extremities: 12W/kg/5 minute exposure per gram of tissue.



March 2010

Hidden Risk — Recent Incidents Highlight Need for Safety Vigilance in the MRI Suite

By Beth W. Orenstein
Radiology Today
Vol. 11 No. 3 P. 24

Several recent incidents involving patients receiving burns while in an MRI tube highlight the risk of presuming something can safely be brought near an MRI magnet. Maintaining a safe MR environment takes continual vigilance, noted MRI safety expert Tobias Gilk.

"There is no master list of things not to bring into the MR suite in part because it would take a team of people to develop such a list and treme keep it current," said Gilk, president and MR safety director for Mednovu products and services, including ferromagnetic detection systems for MF

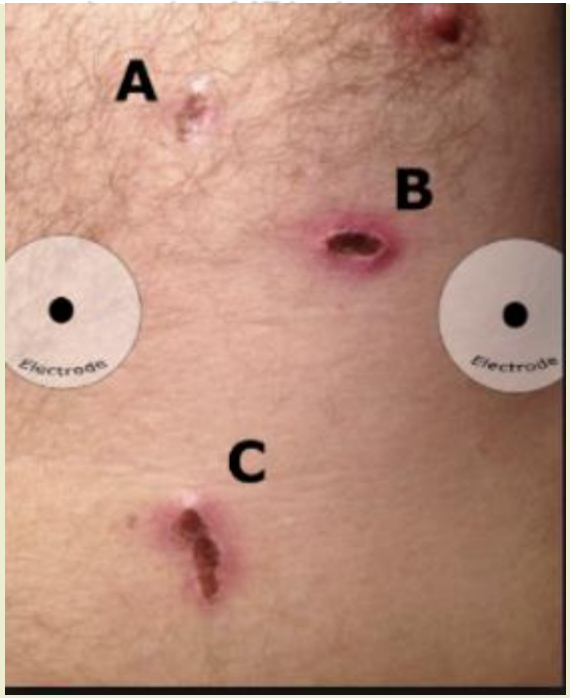
http://www.nyalihealthcare.com/burns/

Battling Burns in MR

Sep 11, 2014 | Anna Steere

According to a Joint Commission Sentinel Event Alert which cited the Manufacture and User Facility Device Experience data base of the FDA, 70 percent of MRI complications are related to thermal burns.

"The single most common adverse event in the MR environment reported to the FDA is that of MRI burns," says Emmanuel Kanal, MD, FACR, FISMRM, AANG, of the University of Pittsburgh Medical Center in Pennsylvania.



http://nobleresearch.org/Doi/10.14312/JRI-2016013

External Factors that affect Heating

- Room Temperature-Vendor usually recommend a scan room to be about 62’F
- Fan inside the bore
- Patient clothing, blankets, etc.
- The patients physical condition
- External metallic device
- Wires, cables, etc.
- Positioning within the bore

Minimizing Burn Risks

- Screening pts for external metallic devices
- Positioning in the bore of the magnet
  - Remember the pts position can change
- MR safe and conditional accessories
  - Leads
  - Monitoring and gating equipment
  - Changing into proper attire

AJNR
AMERICAN JOURNAL OF NEURORA

TECHNICAL NOTE

Invisible Metallic Microfiber in Clothing Presents Unrecognized MRI Risk for Cutaneous Burn

J.A. Pietryga[a], M.A. Fonder[b], J.M. Rogg[a], D.L. North[c] and L.G. Bercovitch[b]

+ Author Affiliations

Please address correspondence to Jeffrey M. Rogg, MD, Department of Diagnostic Imaging, Rhode Island Hospital, 593 Eddy St, Providence, RI 02903; e-mail: jrogg@lifespan.org

Abstract

SUMMARY: We report a case of a thermal burn that occurred during MR imaging likely caused by invisible silver-embedded microfibers in the fabric of an undershirt. As the prevalence of fabric containing nondetectable metallic microfiber increases in athletic and "tech"

Parameters that affect Heating

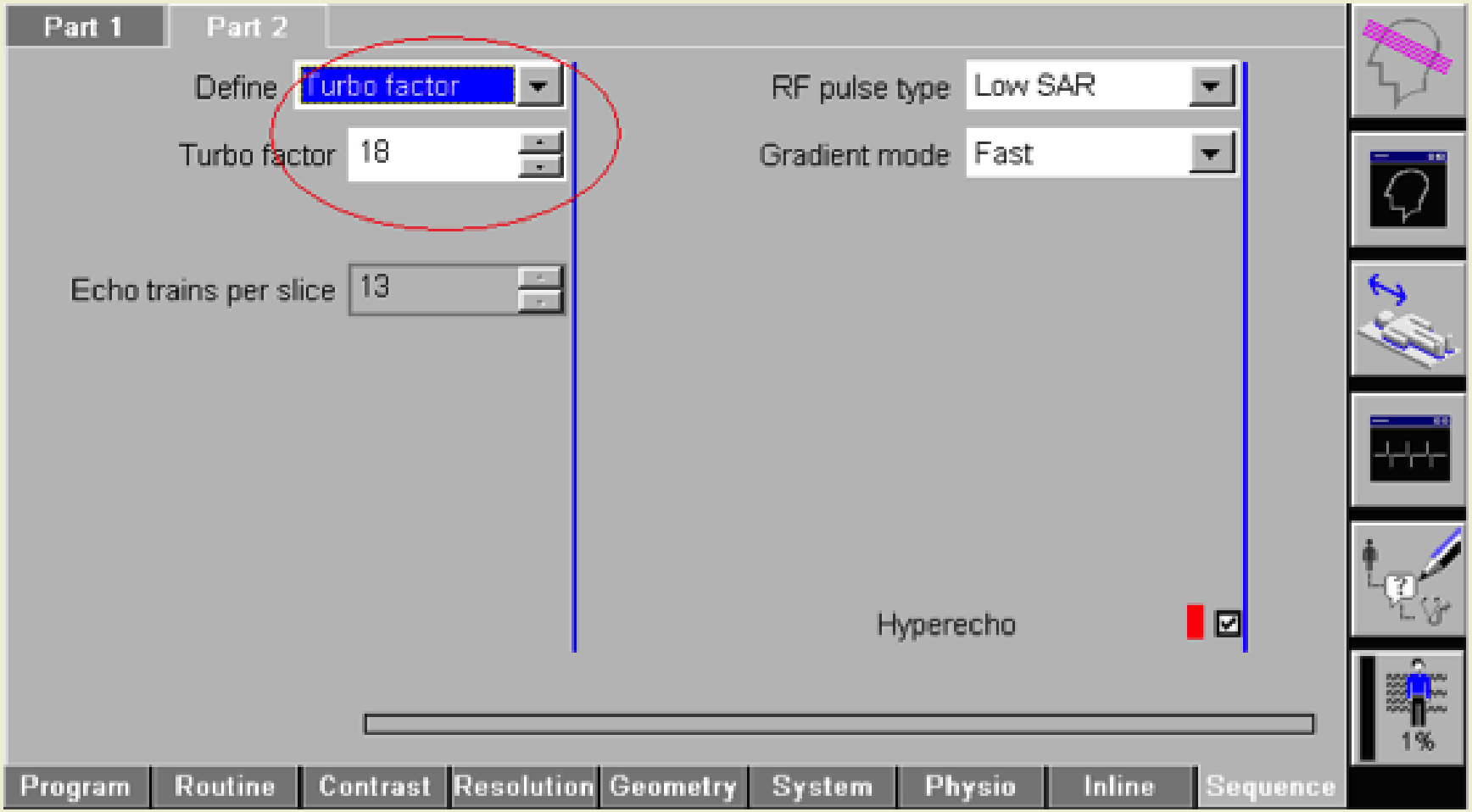
- Slices (amount of coverage)
  - Decreasing volume (V) will decrease SAR
  - Open bore magnets seem to have less SAR
- RF mode (if available)
- SAT bands (Rf pulses)
- Transmit Flip angle-
  - SAR is proportional to the square of the FA
- TR-
  - Increased TR prolongs the duty cycle
- Echo train or Turbo Factor
  - Less RF pulses=Less SAR
- To a less degree Parallel imaging-
  - Shortens imaging time and less RF excitation

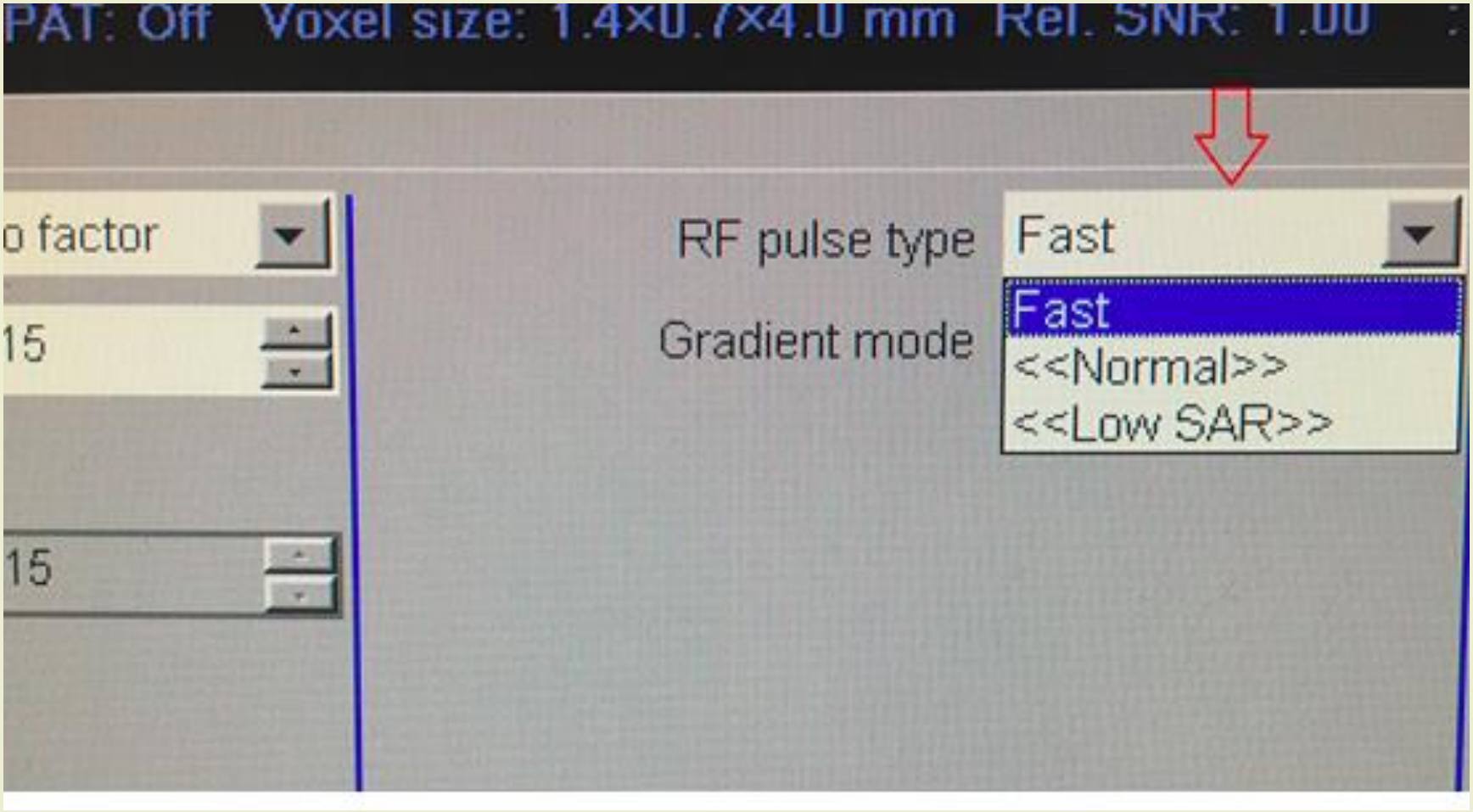
What can I do to stay in “Normal” mode?

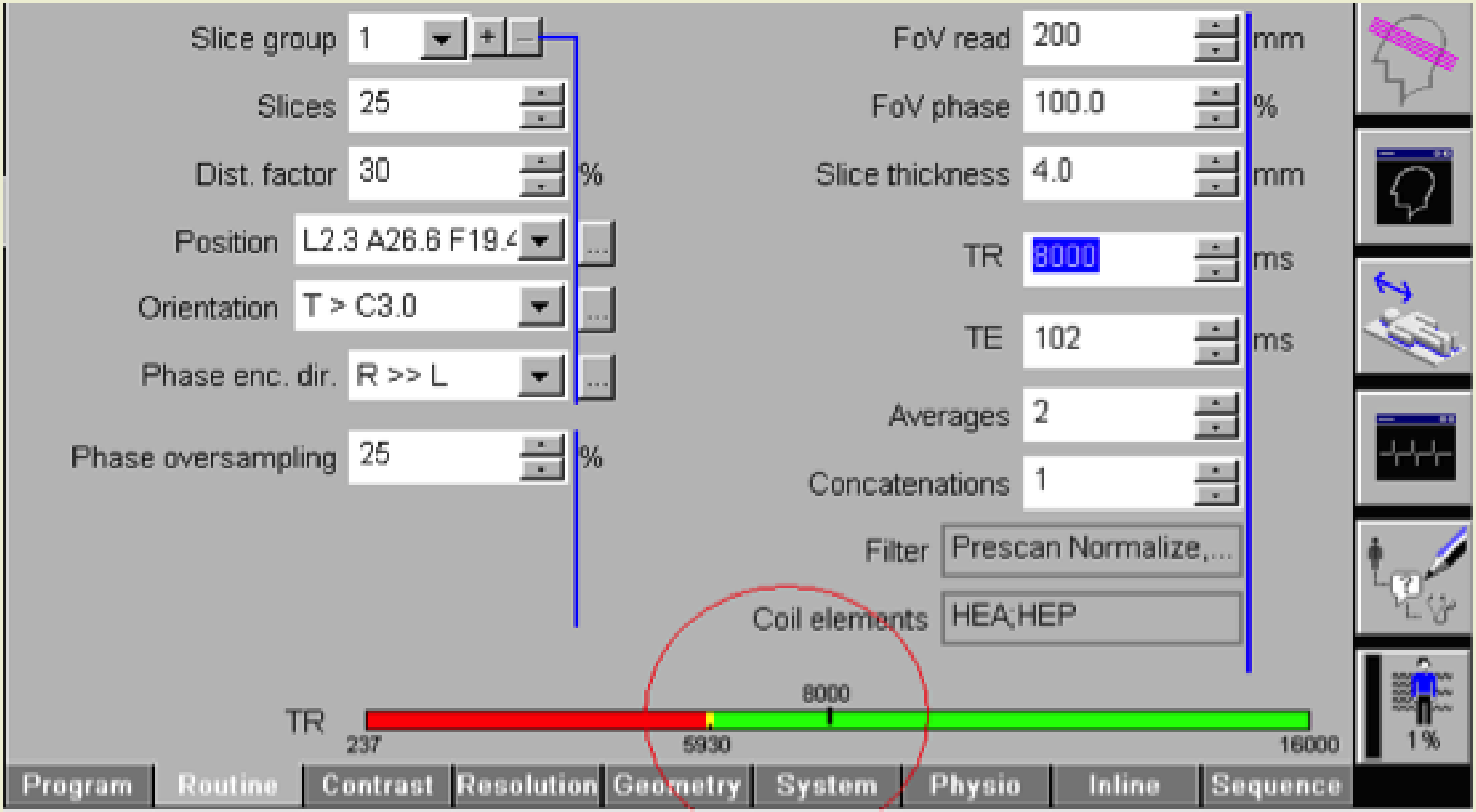
- Build protocols that are not “maxed” out with min TR, Fast RF mode
- Place your higher SAR sequences between lower ones
- Insert pauses between your sequences to allow cooling time
- Manipulate the ETL or Turbo Factor down a bit and play with other parameters to keep scan time down
- Think about 2 concats instead of 1
- Can you live without a SAT band?

What if I need to go to 1st Level?

- The single biggest reason to need 1st level scanning is time
  - As the pt heating increases the “SAR level” is reached
  - The need to elevate parameters that affect the scan time
    - TR/# slices/flip angle
  - As long as there in no conditional implant and the pt. has normal thermoregulatory function going to 1st level is fine!

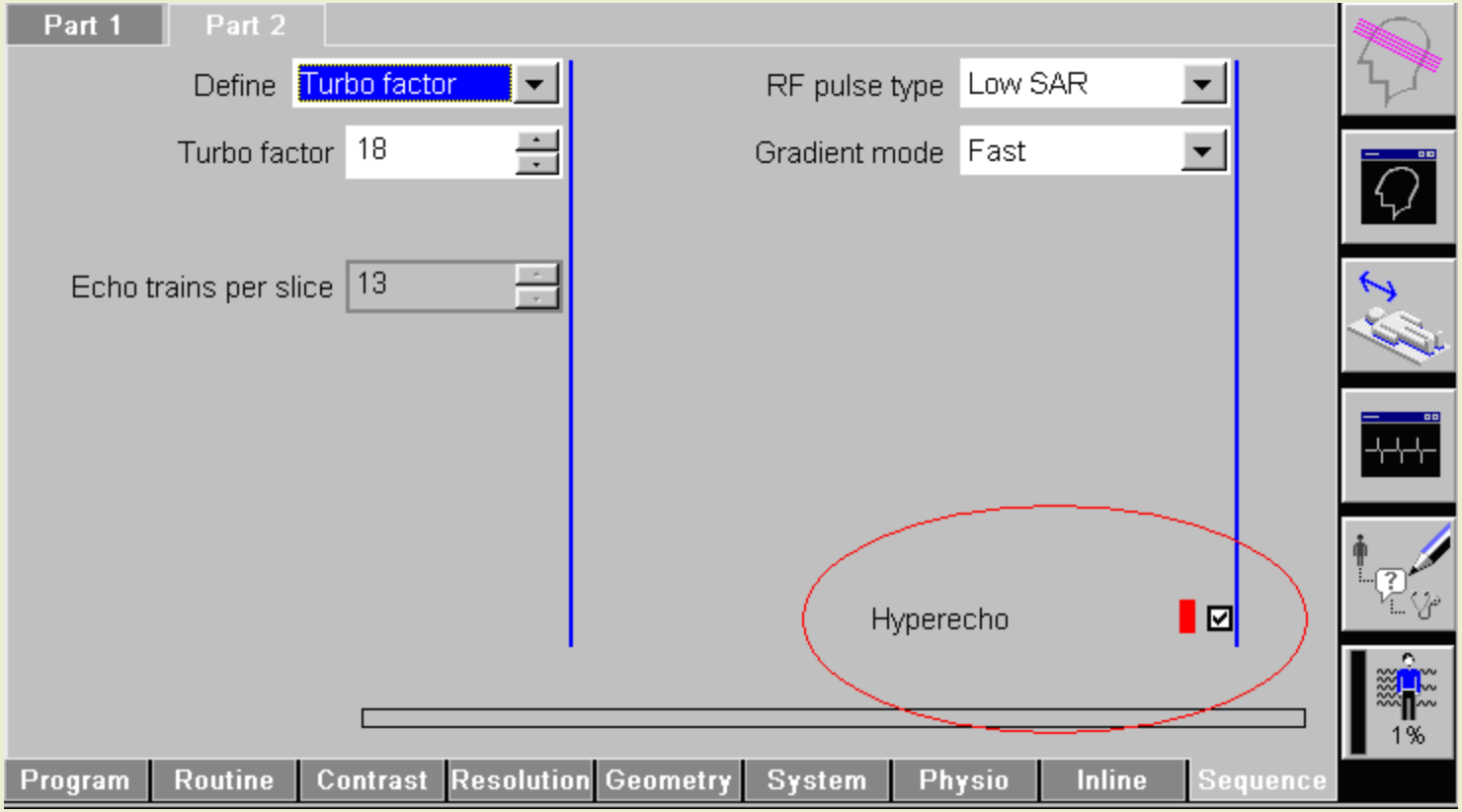

Part 1
Part 2
Define
Turbo factor
Turbo factor
18
Echo trains per slice
13
RF pulse type
Low SAR
Gradient mode
Fast
Hyperecho
1%
Program
Routine
Contrast
Resolution
Geometry
System
Physio
Inline
Sequence


PAT: Off Voxel size: 1.4×0.7×4.0 mm Rel. SNR: 1.00
o factor
15
15
RF pulse type
Fast
Gradient mode
Fast
<<Normal>>
<<Low SAR>>


Slice group 1
Slices 25
Dist. factor 30 %
Position L2.3 A26.6 F19.4
Orientation T > C3.0
Phase enc. dir. R >> L
Phase oversampling 25 %
FoV read 200 mm
FoV phase 100.0 %
Slice thickness 4.0 mm
TR 8000 ms
TE 102 ms
Averages 2
Concatenations 1
Filter Prescan Normalize,...
Coil elements HEA;HEP
TR
237
5930
8000
16000
1 %
Program
Routine
Contrast
Resolution
Geometry
System
Physio
Inline
Sequence

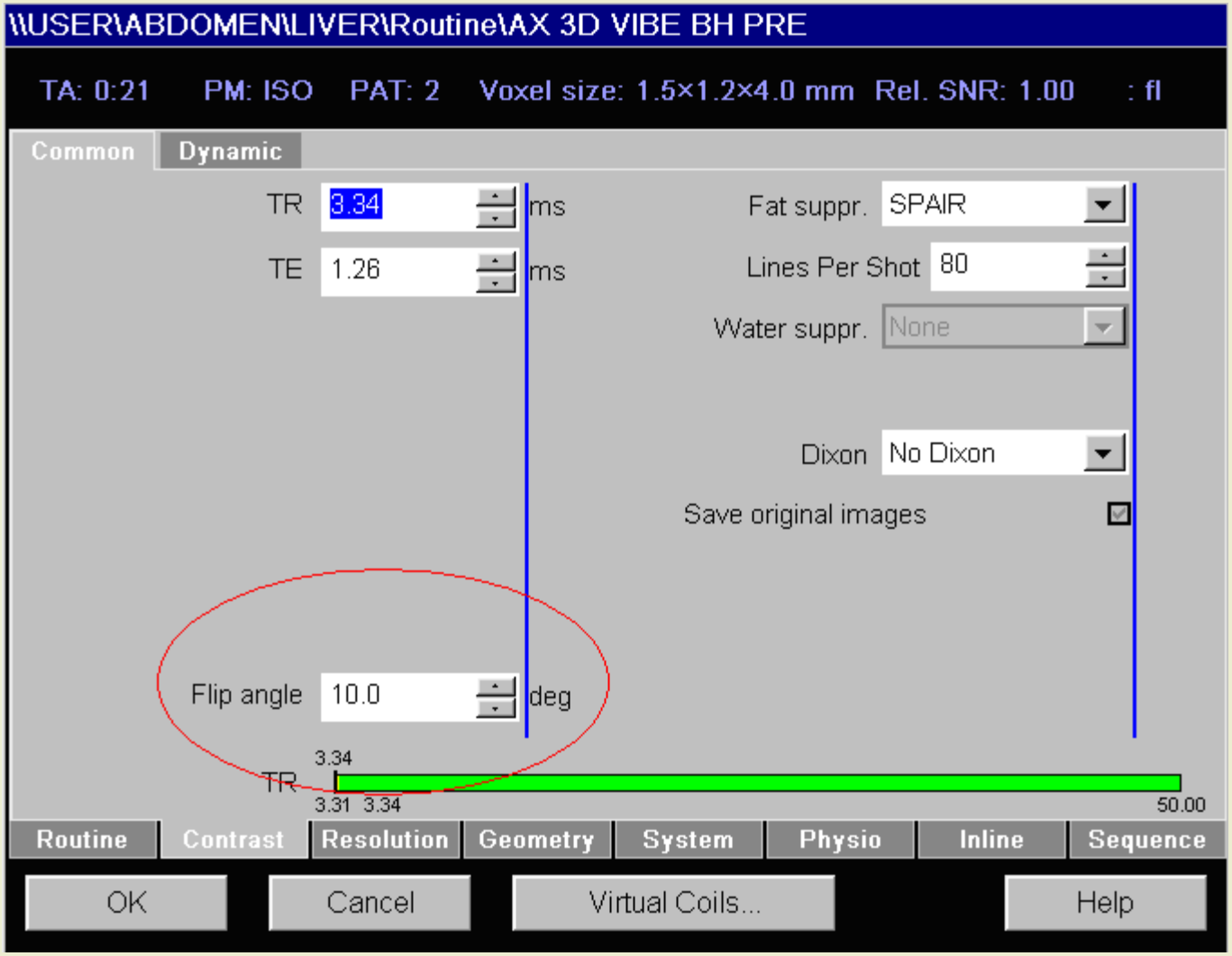
SAR Workflow Considerations

- Hyper echo- Variable flip angle for long echo train length imaging (T2)
- 180 degree refocusing pulse is at the center of the echo train length with 150 and 120 on either side



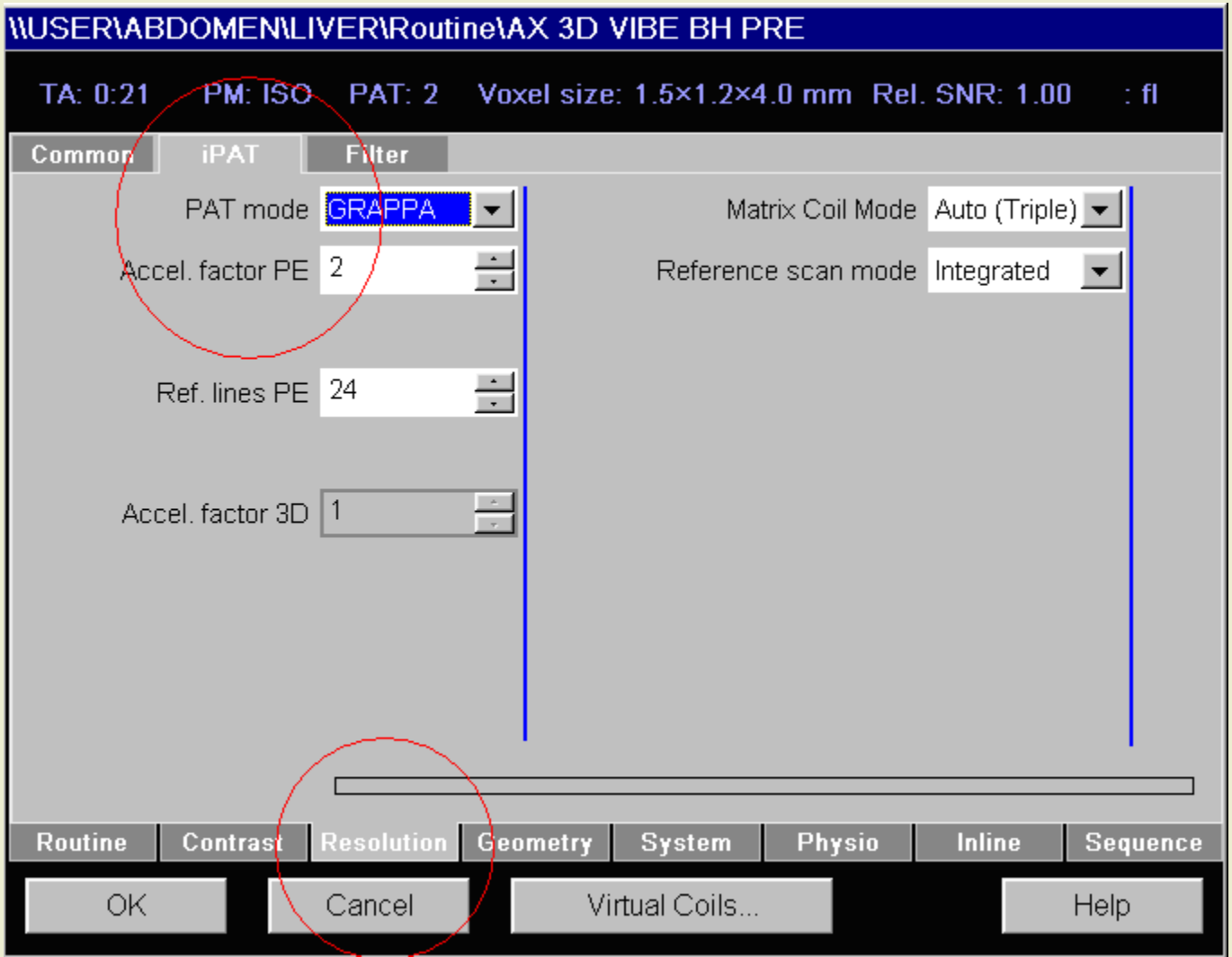
SAR Workflow Considerations

- Decreasing flip angle decreases SAR



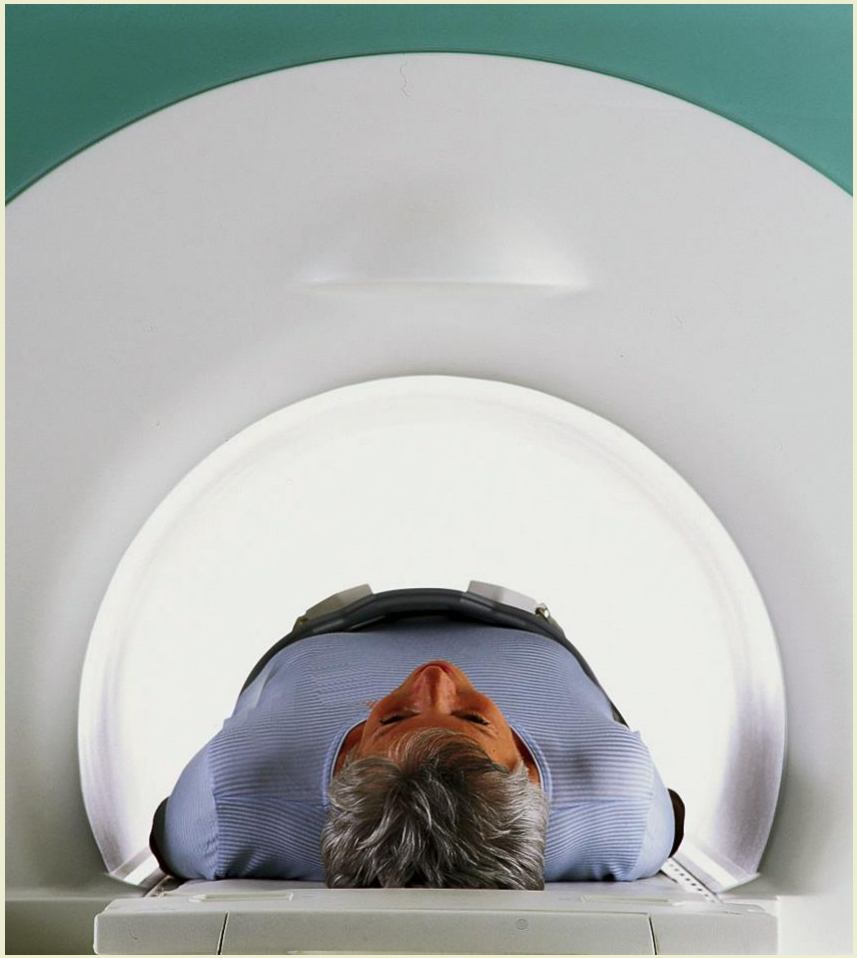
SAR Workflow Considerations

- IPAT-Phase encoding lines are skipped depending on PAT Factor utilized-reducing SAR and Scan Time
- Utilize IPAT-parallel imaging-Resolution Card IPAT



MRI and pt size

- Wt limit on MR machines varies (350-550lbs)
  - However the height of the pt and physical make-up can influence the way they fit inside the scanner
- The “bore” or opening of scanners vary (55-70cm)
  - But again it matters how the weight is distributed
- There is a risk of heating and burn if we cannot put at least a 1” pad or ¼ in of air between the pt and the bore of the magnet



Wrap up and Questions

- Understand the nature of RF and heating
- Screen and evaluate your patients
- Keep your environment cool
- Pad, pad and pad some more
- Careful with the blankets
- Watch for leads, patches, external devices
- Set the scanner for proper body wt.
- Try….to stay at Normal operating mode
- Communicate with your pt. often