

# Radio Frequency Magnetic Fields:

Effects / Volumes / Forces / Harms

Tobias Gilk - September 26, 2022

# Rules of the Road

- Everything on the screen is for you (you can copy or take photos).
- If you have questions, ask!
- If you disagree, please speak up.

# Outline

## Radio Frequency Magnetic Fields

- Intro
- Fields / Distributions
- SAR / SED /  $B_{1+RMS}$
- Levels & Labeling
- Heating & Burns
- Implant Scenarios
- Q & A

***“If you don’t know what you’re exposing a patient (or device) to, you can’t begin to perform an MR risk-assessment.”***

– Me

# Radio Frequency (RF) Magnetic Fields

## Recap & Advance

- When & Where
- Units & Measures
- Plots & Graphs

# Radio Frequency (RF) Magnetic Fields

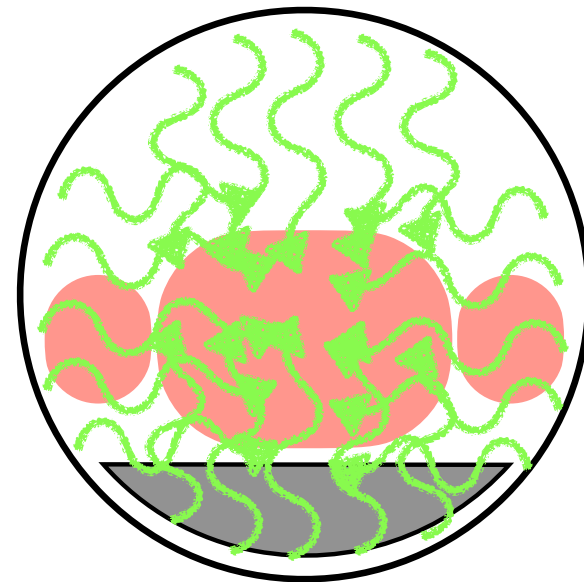
## What Are They?

- Rapidly fluctuating magnetic field
- Changing 1,000,000s of times per second (Hz)

# Radio Frequency (RF) Magnetic Fields

## Why?

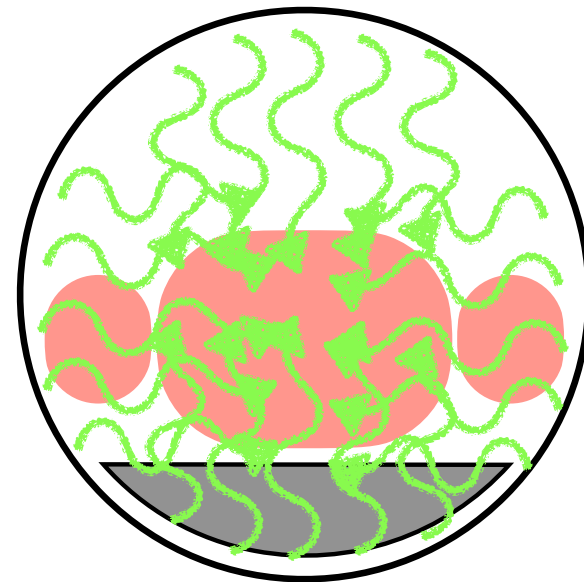
- Because we need to energize materials, first, to get signal out of them we can read
- Larmor Frequency



# Radio Frequency (RF) Magnetic Fields

## When & Where?

- Only during active imaging
- Only in the bore
- But not uniform throughout the bore





# Radio Frequency (RF) Magnetic Fields

## Modes

### Normal Mode

- $\leq 2.0$  W/kg  
Whole Body Averaged  
(WBA)  
SAR

### First Level Controlled Operating Mode\*

- $\leq 4.0$  W/kg  
Whole Body  
Averaged (WBA)  
SAR

### Second Level Controlled Operating Mode

- Whatever Your System  
Can Produce

#### **201.3.208**

#### **FIRST LEVEL CONTROLLED OPERATING MODE**

mode of operation of the MR EQUIPMENT in which one or more outputs reach a value that can cause physiological stress to PATIENTS which needs to be controlled by MEDICAL SUPERVISION

# Radio Frequency (RF) Magnetic Fields

## Modes

Table 201.105 – SAR limits for volume transmit coils

Averaging time	6 min		
	WHOLE BODY SAR	PARTIAL BODY SAR	HEAD SAR
Body region →	Whole body	Exposed body part	Head
Operating mode ↓	(W/kg)	(W/kg)	(W/kg)
NORMAL	2	$2 - 10^a$	3,2
FIRST LEVEL CONTROLLED	4	$4 - 10^a$	3,2
SECOND LEVEL CONTROLLED	>4	$>(4 - 10)^a$	>3,2
MR EXAMINATION specific absorbed energy	The max. energy dose (SAR × examination time) shall be limited, subject to the RISK MANAGEMENT.		
Short duration SAR	The SAR limits over any 10 s period shall not exceed two times the stated values.		
<sup>a</sup> The limit scales dynamically with the ratio "exposed PATIENT mass / PATIENT mass": NORMAL OPERATING MODE : $\text{PARTIAL BODY SAR} = 10 \text{ W/kg} - (8 \text{ W/kg} * \text{exposed PATIENT mass} / \text{PATIENT mass})$  FIRST LEVEL CONTROLLED OPERATING MODE : $\text{PARTIAL BODY SAR} = 10 \text{ W/kg} - (6 \text{ W/kg} * \text{exposed PATIENT mass} / \text{PATIENT mass})$			

# Radio Frequency (RF) Magnetic Fields Modes

Table 201.106 – SAR limits for local transmit coils

Averaging time	6 min		
	LOCAL SAR		
Body region →	Head	Trunk	Extremities
Operating mode ↓	(W/kg)	(W/kg)	(W/kg)
NORMAL	10 <sup>a</sup>	10	20
FIRST LEVEL CONTROLLED	20 <sup>a</sup>	20	40
SECOND LEVEL CONTROLLED	>20 <sup>a</sup>	>20	>40
Short duration SAR	The SAR limits over any 10 s period shall not exceed two times the stated values		
<sup>a</sup>	NOTE In cases where the orbit is in the field of a small LOCAL RF TRANSMIT COIL, care should be taken to ensure that the temperature rise is limited to 1 °C.		

# Radio Frequency (RF) Magnetic Fields

## SAR - SED - B1<sub>+RMS</sub>

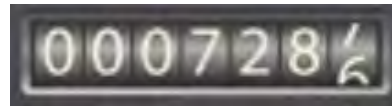
### SAR (W/kg)

- Rate of delivered RF energy
- Think of it as the RF speedometer
- Averaged across body mass



### SED (kJ/kg)

- Total quantity of delivered RF energy
- Think of it as the RF odometer
- Also averaged across body mass



### B1<sub>+RMS</sub> (μT)

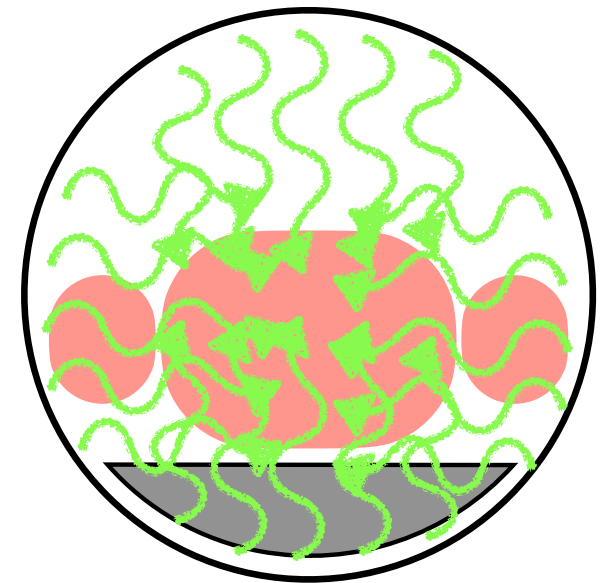
- Total delivered magnetic field energy
- **Not** averaged across body mass

# Radio Frequency (RF) Magnetic Fields

## Quadrature / Circularly Polarized (CP)

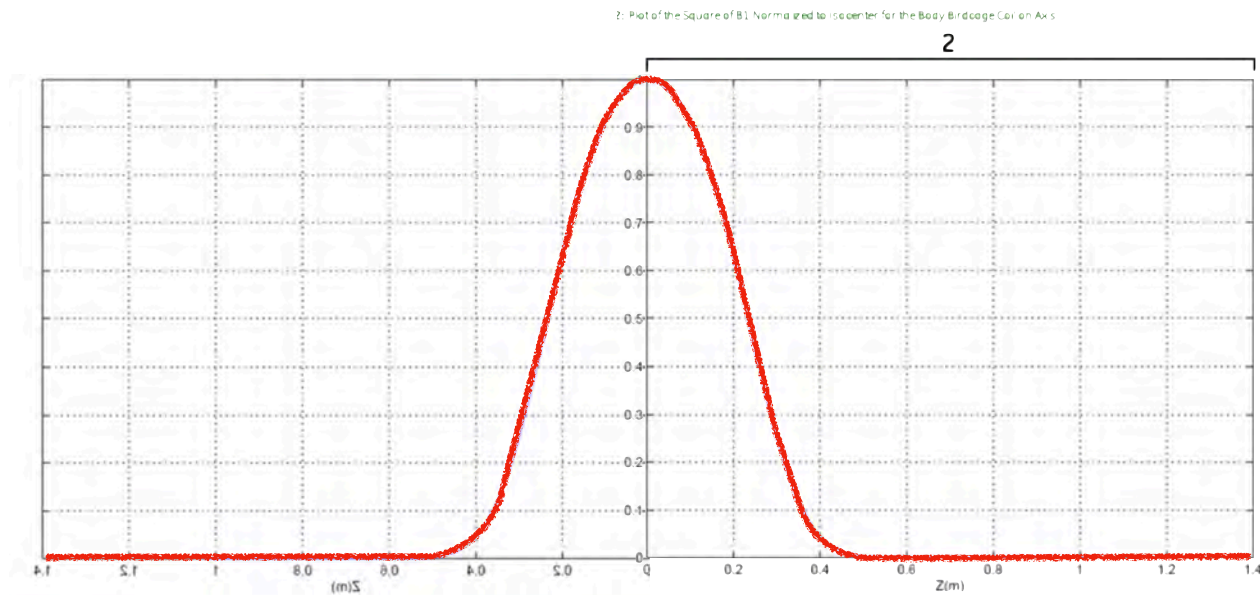
### Quadrature = Circularly Polarized

- Method of delivering RF energy by energizing RF transmit coil elements one at a time (typically following a four-step circular path)
- Linearly Polarized or RF Shimming are **not** Quadrature or CP



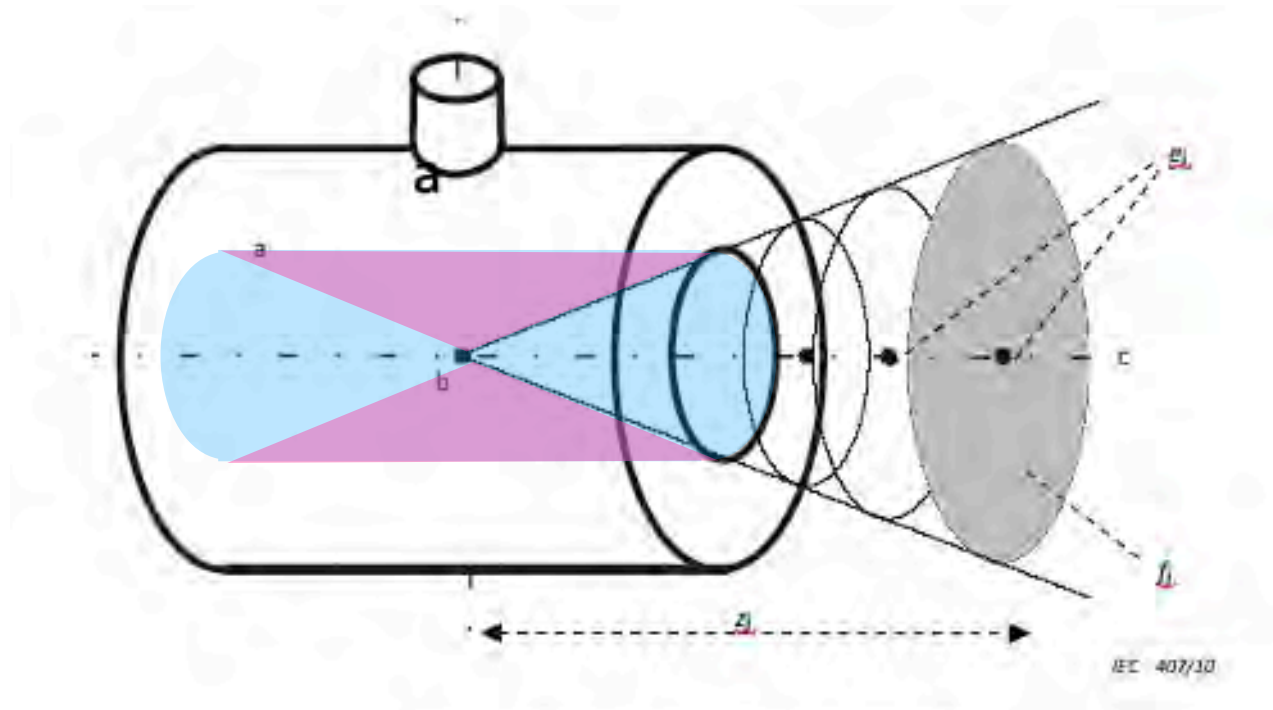
# Radio Frequency (RF) Magnetic Fields

## Plots & Graphs



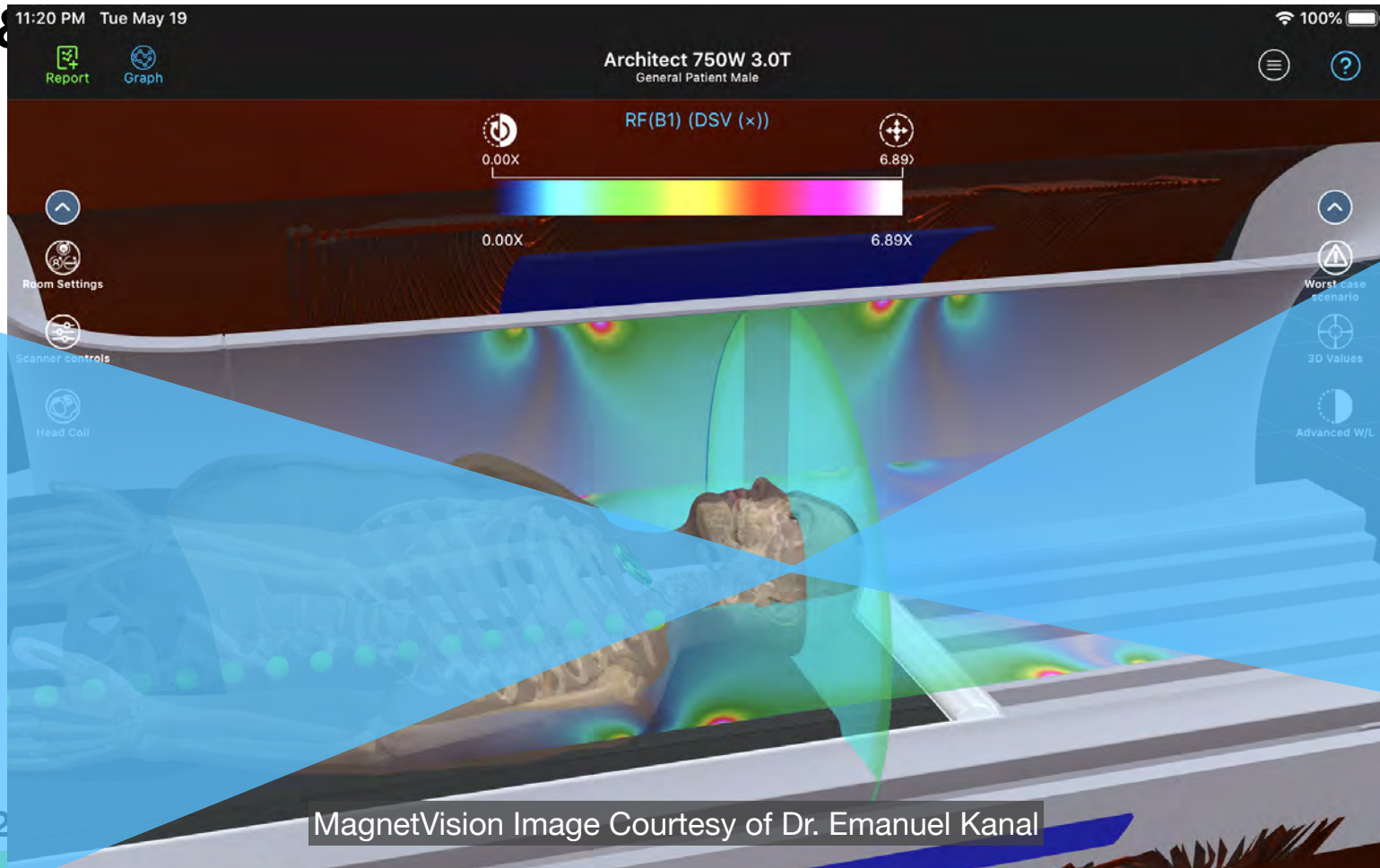
# Radio Frequency (RF) Magnetic Fields

## Plots & Graphs



# Radio Frequency (RF) Magnetic Fields

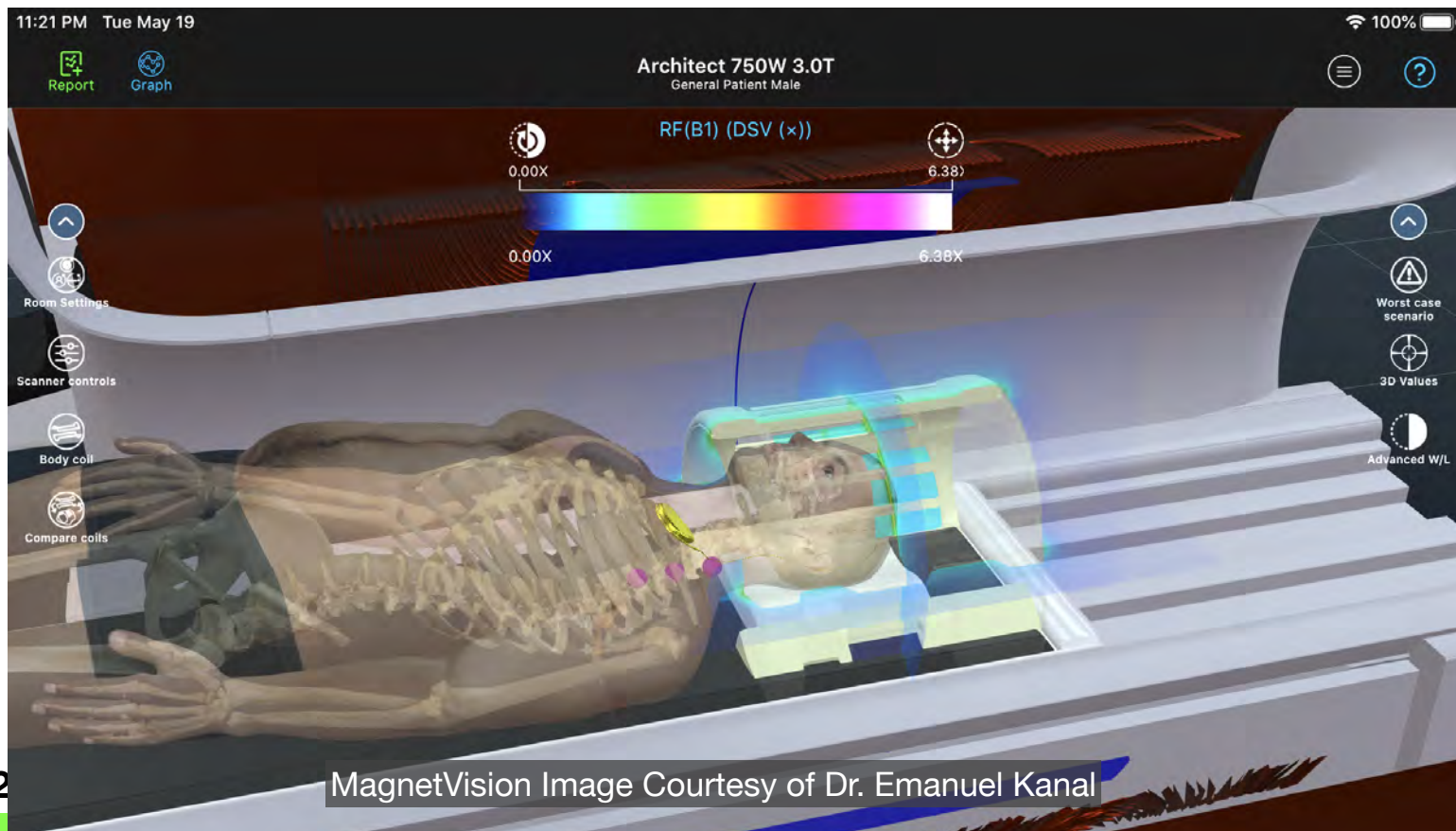
Plots &





# Radio Frequency (RF) Magnetic Fields

## Plots & Graphs



# Radio Frequency (RF) Magnetic Fields

## Plots & Graphs



*Receive Only*



*Transmit / Receive*



*Transmit Only*

# Radio Frequency (RF) Magnetic Fields

## Limitations of SAR

# Radio Frequency (RF) Magnetic Fields

## Limitations of SAR



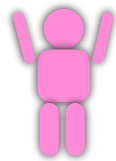
@ 2 W/kg



@ 2 W/kg

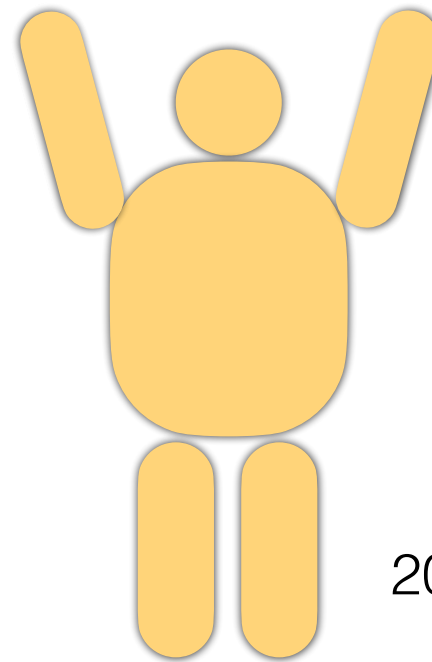
# Radio Frequency (RF) Magnetic Fields

## Limitations of SAR



5 kg

$$@ 2 \text{ W/kg} \times 5 \text{ kg} = 10 \text{ W}$$



200 kg

$$@ 2 \text{ W/kg} \times 200 \text{ kg} = 400 \text{ W}$$

# Radio Frequency (RF) Magnetic Fields

## Faraday's Law of Induction

# Radio Frequency (RF) Magnetic Fields

## Faraday's Law of Induction

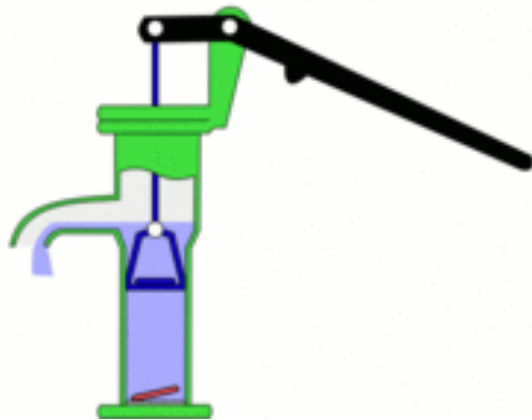
An electrical conductor exposed to a changing magnetic field will experience an induced electrical voltage.

# Radio Frequency (RF) Magnetic Fields

## Faraday's Law of Induction

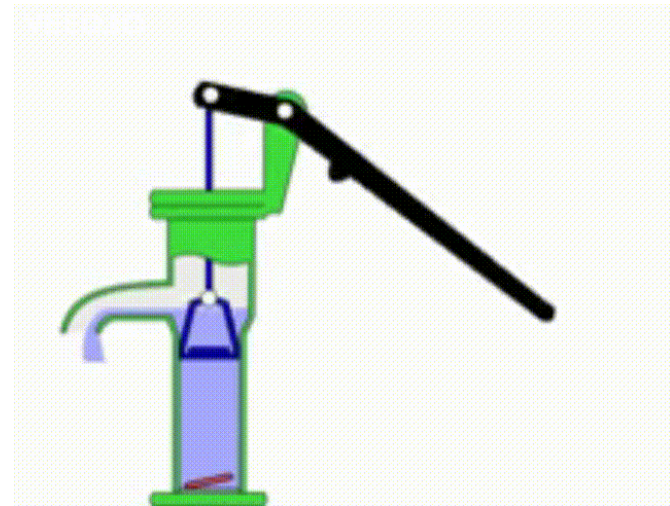
Time-Varying Gradients

1,000's of times per second



RF Magnetic Fields

1,000,000's of times per second





# **Radio Frequency (RF) Magnetic Fields**

## **Physical & Physiological Effects**

# Radio Frequency (RF) Magnetic Fields

## Physical Effects

- Induced Voltages
- Heating

# Radio Frequency (RF) Magnetic Fields

## Induced Voltages

- At RF Amplitudes & Frequencies, Induced Voltages Are Mostly 'Transparent' (Very Little Direct Physiologic Effect)
- But They Also Produce Heat... Lots Of Heat

# Radio Frequency (RF) Magnetic Fields

## Burns

There are three most-common ways for RF power to create a burn...

- Near-Field / Proximity Burn
- Large-Calibre Body Loop
- Resonant Circuit

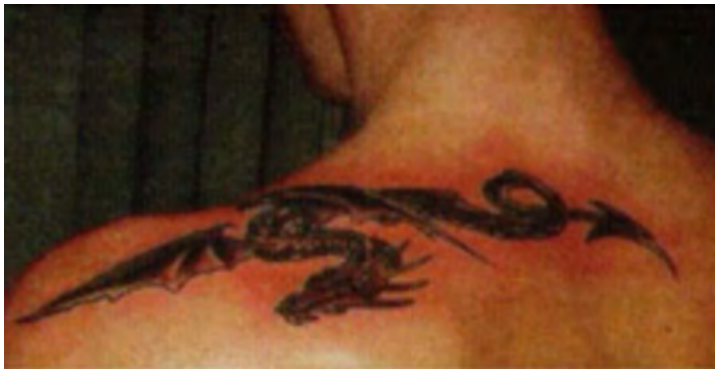
# Radio Frequency (RF) Magnetic Fields

## Burns

- The Following Images May Be Upsetting

# Radio Frequency (RF) Magnetic Fields

## Burns (1st & 2nd Degree)



# Radio Frequency (RF) Magnetic Fields

## Burns (3rd Degree)



# Radio Frequency (RF) Magnetic Fields

## Burns (4th Degree)





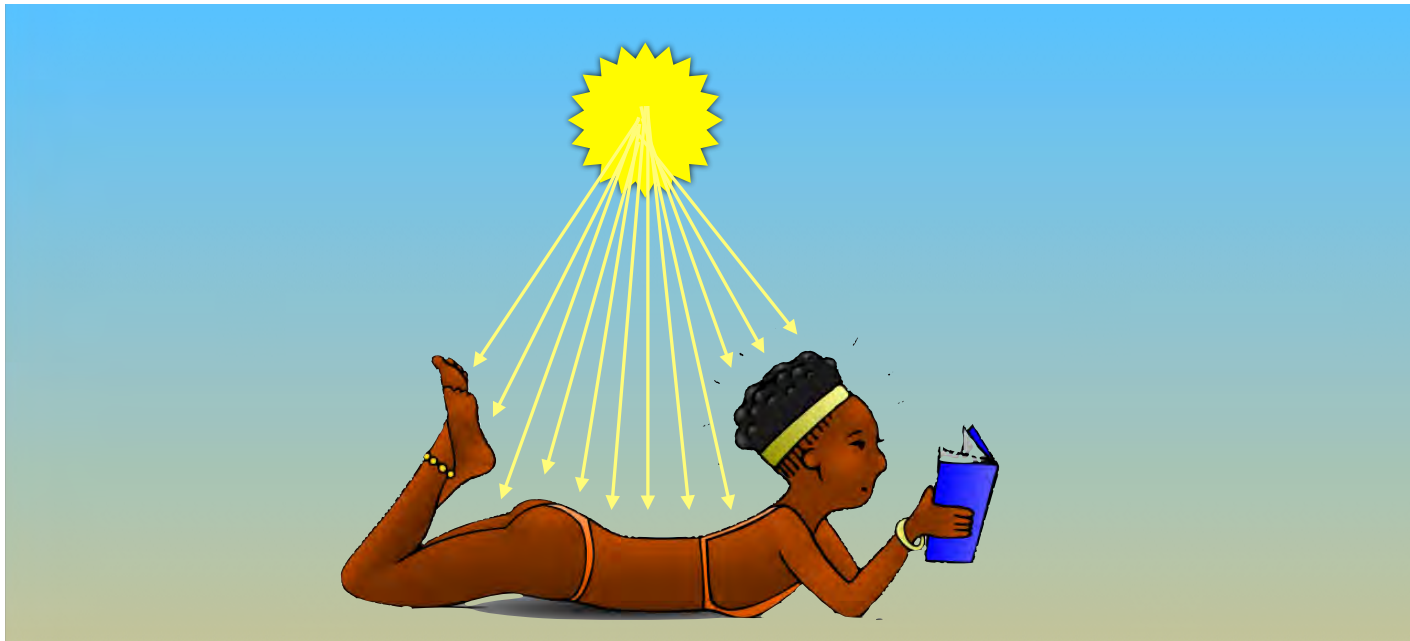
# Radio Frequency (RF) Magnetic Fields

## Physical / Physiologic Effects

- Diffuse Thermal Loading  
(What SAR Is Actually Good At...)
- Focal Heating

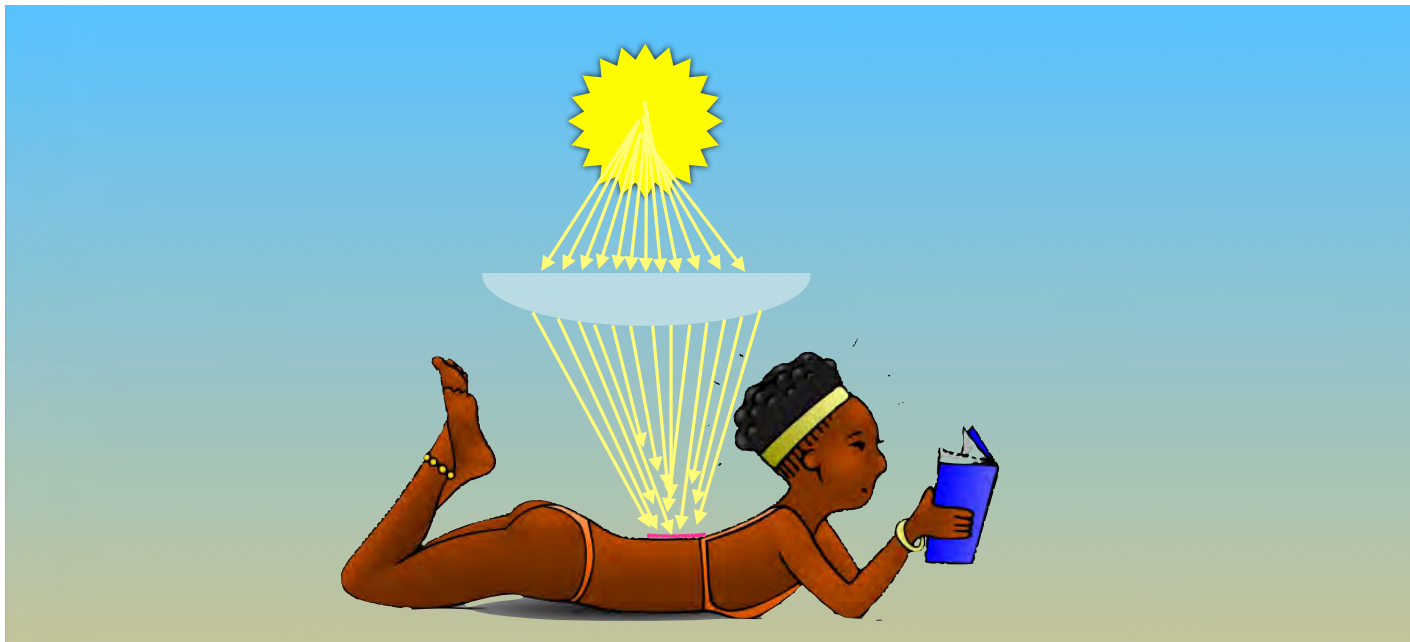
# Radio Frequency (RF) Magnetic Fields

## Physical / Physiologic Effects



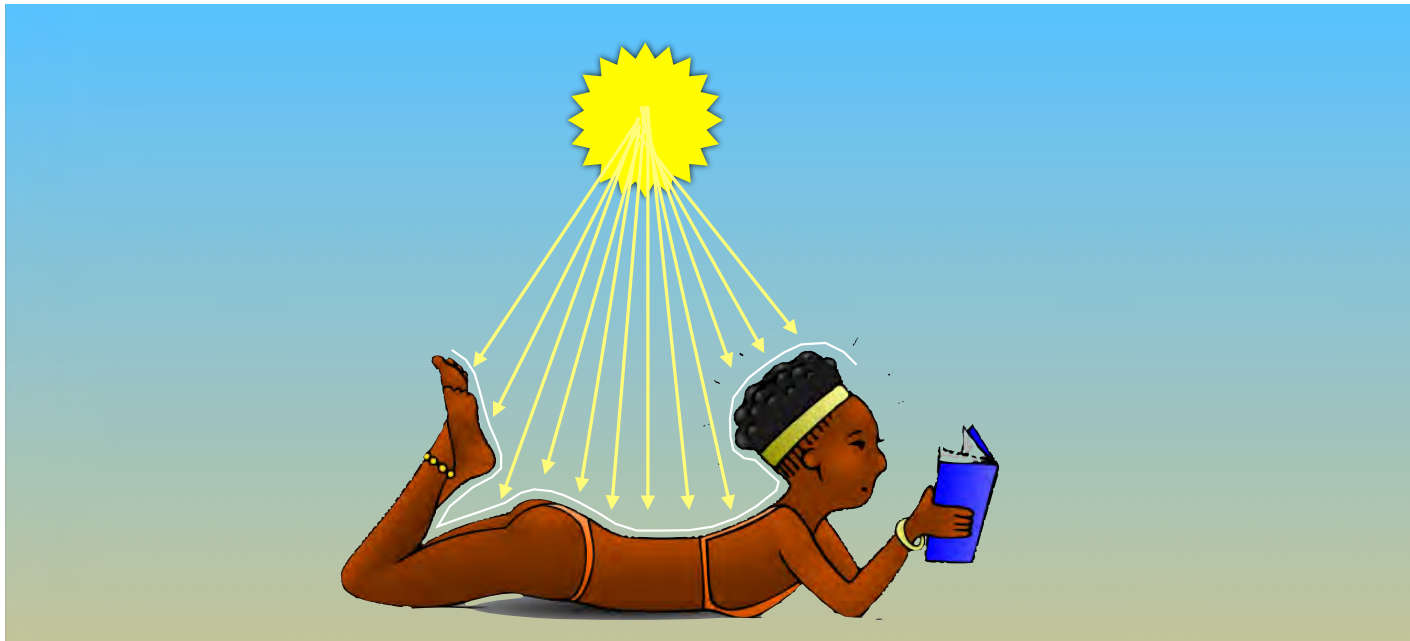
# Radio Frequency (RF) Magnetic Fields

## Physical / Physiologic Effects



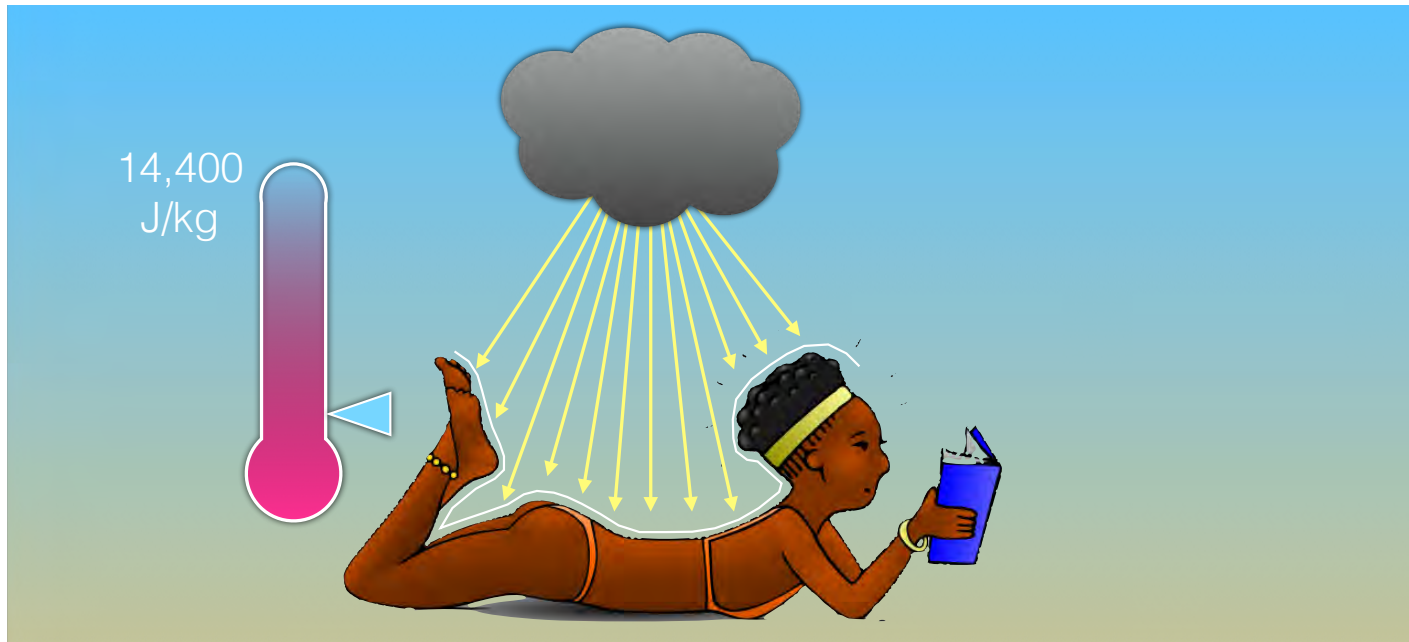
# Radio Frequency (RF) Magnetic Fields

## Physical / Physiologic Effects



# Radio Frequency (RF) Magnetic Fields

Why SED Is Dumb...



# Radio Frequency (RF) Magnetic Fields

## The Problem With Leads

- Voxels Of Deposition
- Magnetism & Electricity: Conjoined Twins
- Insulation & 'Who Is In The Driver's Seat?'

# Radio Frequency (RF) Magnetic Fields

## Voxels Of Deposition

- MR System Controls Are Based On Exposure To Human Beings
- What Happens When There's Something Other Than Human Tissues w/in Volume of Deposition?

# Radio Frequency (RF) Magnetic Fields

## The Conjoined Twin Conundrum

- Enters As Magnetism
- Encounters Good Electrical Conductor
- Switches To Electricity



# Radio Frequency (RF) Magnetic Fields

## Insulation & 'Who Is In The Driver's Seat?'

- Magnetism Passes Through Electrical Insulation
- Enters Lead (Designed To Be Electrically Conductive)
- Electricity In Driver's Seat
- Can't Exit Through Insulation

# Radio Frequency (RF) Magnetic Fields

## Insulation & 'Who Is In The Driver's Seat?'

- Capped Leads May Exacerbate Problem
  - Only Half As Many Ways Out

# Radio Frequency (RF) Magnetic Fields

## Current Back To Pulse Generator

- Devices With Leads



# Radio Frequency (RF) Magnetic Fields



## Current To Organ / Structure

- Devices With Leads



# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

- Because Of Faraday’s Law, RF Energy In Patient Tissues Wants To Behave Like Electricity...
  -  Electrical Conductors =  Paths (Path of Least Resistance)
  - Path To Form A Circle... I Mean Circuit

# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

- Large Caliber Body Loops

# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

- Electrically Conductive Materials

# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

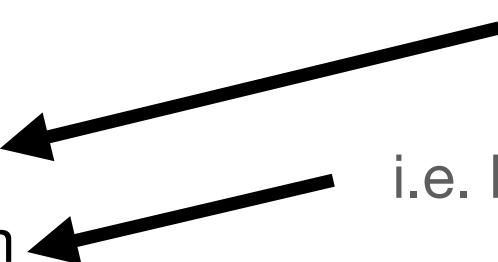
- Resonant Circuit





# Radio Frequency (RF) Magnetic Fields

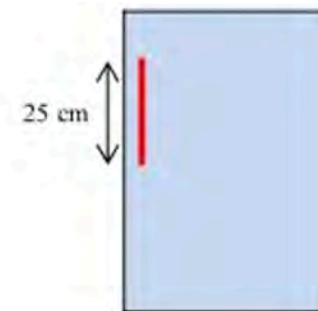
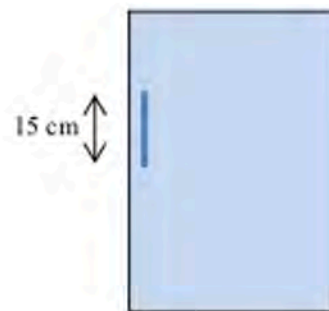
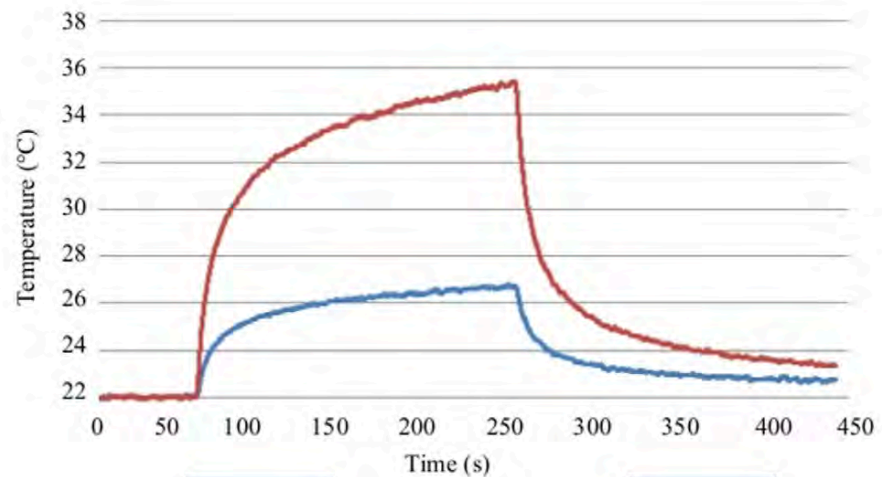
“Think Like An Electron”

- Resonant Circuit
    - ‘Worst Case’ Lengths For Linear Conductors = 1/2 Wavelength
      - 3.0 T - 12 - 15 cm
      - 1.5 T - 25 - 30 cm
      - 1.0 T - 37 - 45 cm
      - 0.55 T - 67 - 82 cm
      - 0.064 T - 5.75 - 7.0 m
- i.e. Siemens Max
- i.e. Hyperfine Swoop
- 

# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

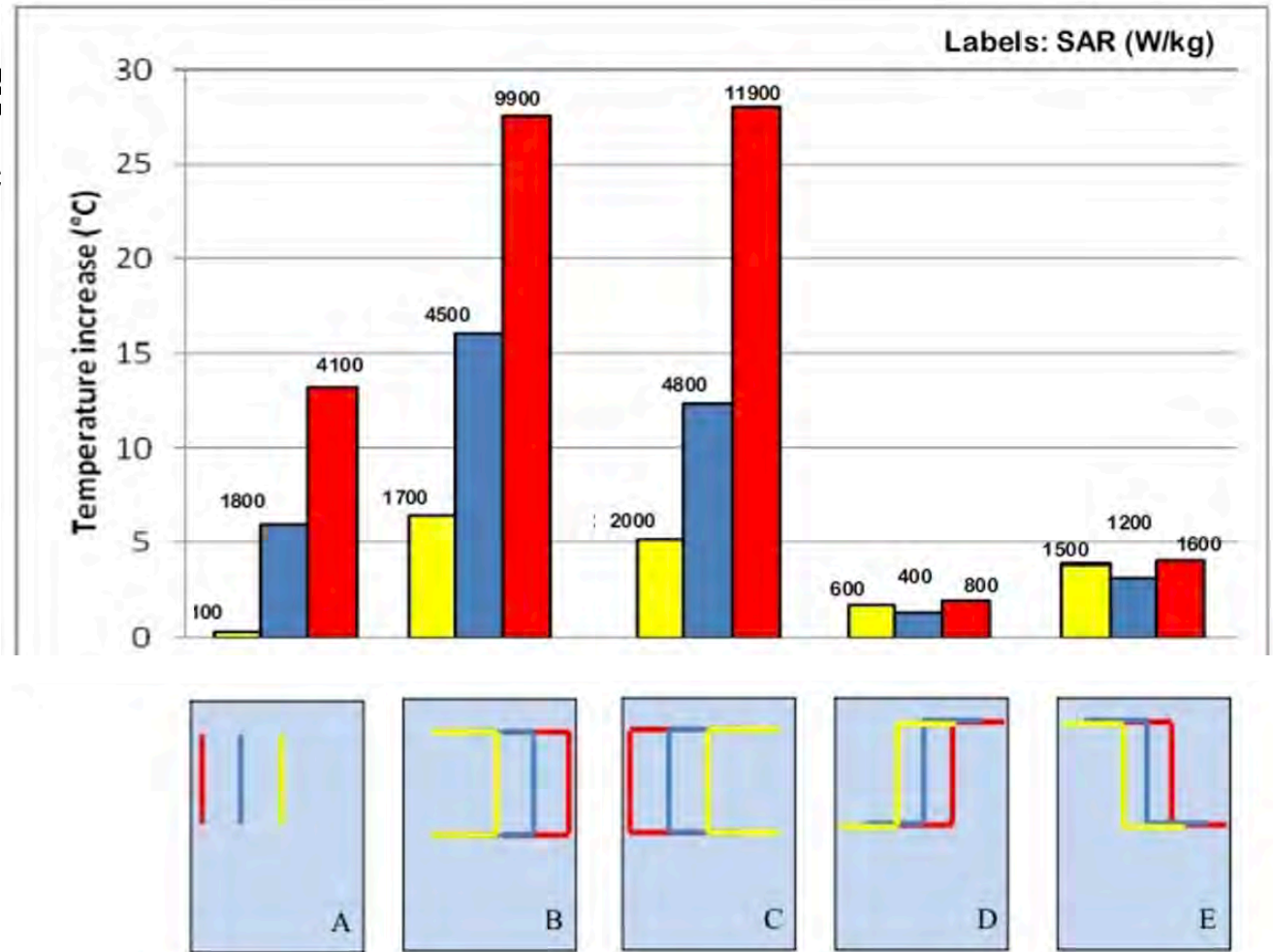
- Resonant Circuit
- 1.5 T



# Radio Frequency

“Think Like An Elec

- Resonant Circuit



<https://link.springer.com/content/pdf/10.1186/1475-925X-7-11.pdf>

# Radio Freque

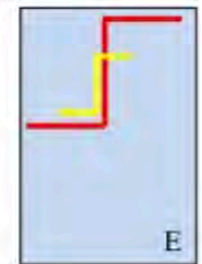
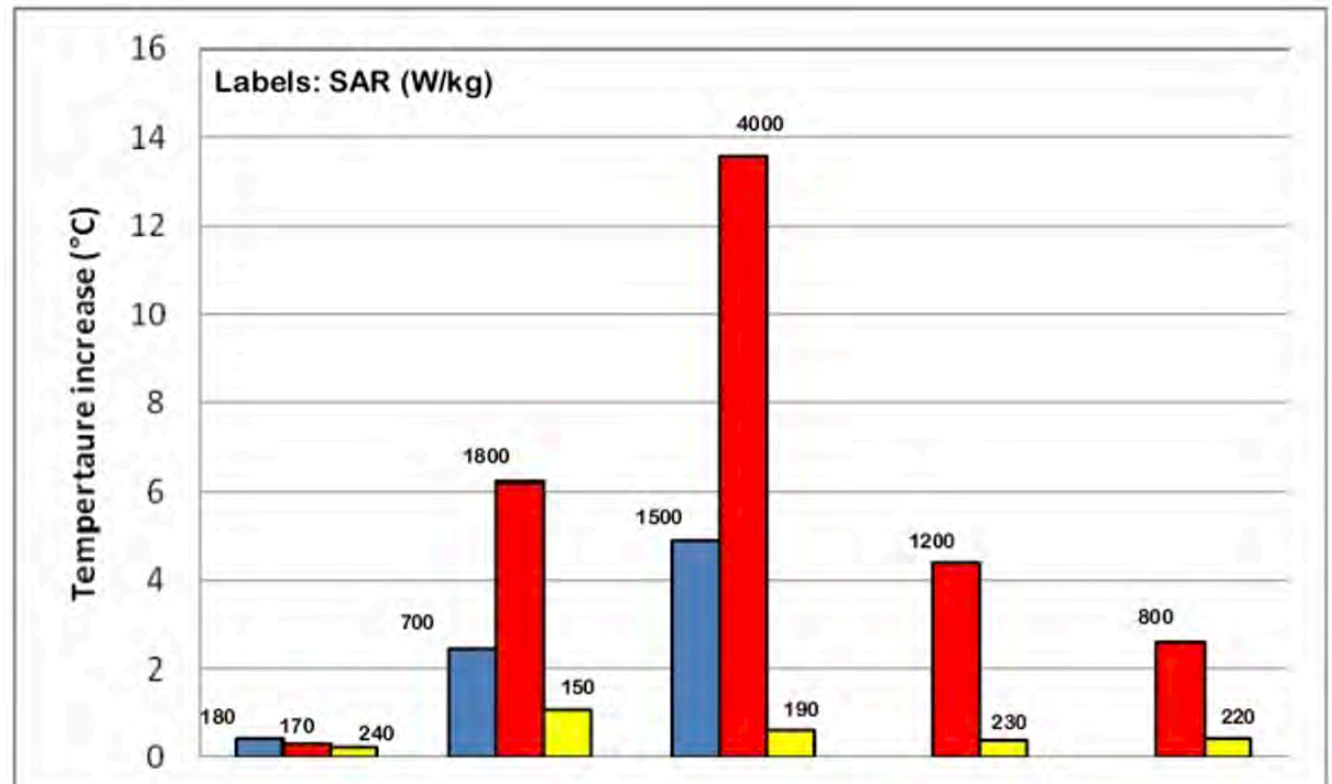
“Think Like An Elect

- 1.5 T

— 15 cm

— 25 cm

— 45 cm



# Radio Frequency (RF) Magnetic Fields

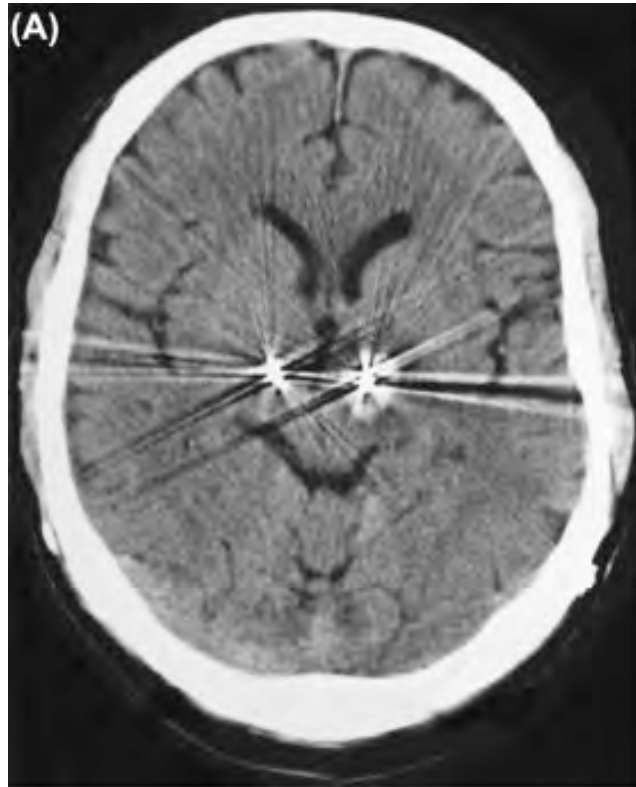
“Think Like An Electron”

- Resonant Circuit
  - ‘Worst Case’ Lengths For Linear Conductors = 1/2 Wavelength
    - 3.0 T - 12 - 15 cm
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    - 1.0 T - 37 - 45 cm
    - 0.55 T - 67 - 82 cm
    - 0.064 T - 5.75 - 7.0 m

# Radio Frequency (RF) Magnetic Fields

“Think Like An Electron”

- DBS (bilateral)
- One extended lead
- L-Spine Study



# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

- Positionally
- “Collimation” (Local T/R Coil Use)
- RF Settings

# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

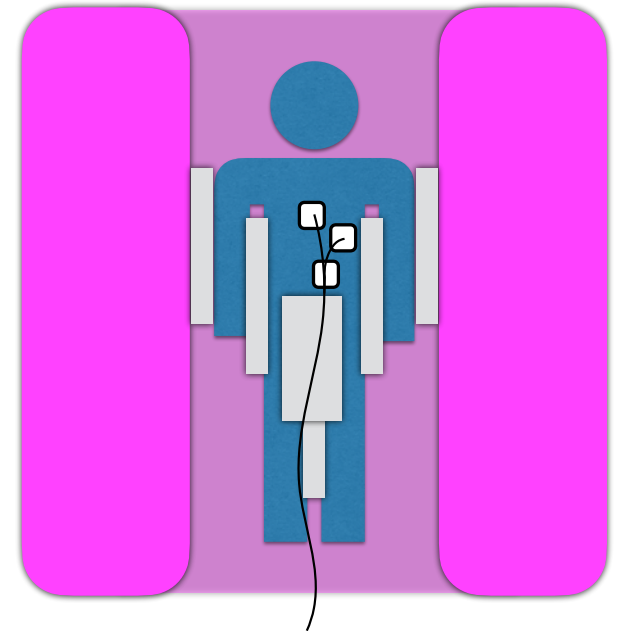
- Positionally
  - If The Object Of Concern Is Wholly Outside The RF Body Coil Transmitter & Receiving No Incident RF Energy (Consider Electrical Pathways), What Risk Is There?



# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

- Padding
  - Patient From Bore Wall (Body Coil)
  - Patient From Own Tissues
  - Patient From Electrical Conductors



# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

- “Collimation”
  - If You Can Limit The Volume Of RF Irradiation By Using A Local T/R Coil...

# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

- RF Settings
  - If You Can 'Dial-Back' SAR / B1+RMS To Acceptable Values (For Both Heating Risk & Image Quality...)

# Radio Frequency (RF) Magnetic Fields

## How We Manage RF Risks

- ScanWise (Philips)
  - Allows For Control Of Level Of RF Output
  - Not Positionally Aware
- MR Output Conditioning (MROC)

# Q&A

# Thank You

**Tobias Gilk, MRSO, MRSE**



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