

# Electromagnetic Fields:

Effects / Volumes / Forces / Harms

Tobias Gilk - September 26, 2022

**GRC** 2022 Dubai Advanced MRI Safety Seminar

EM Fields: Effects / Volumes / Forces Harms

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- Founding Board Member / Past Chair ABMRS
- International Trainer on MRI Safety



# ABMRS Content Disclosure

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As a member of the the Board of the ABMRS, I am prohibited from speaking on specific examination question content, but permitted to provide education on MRI safety concepts and principles.

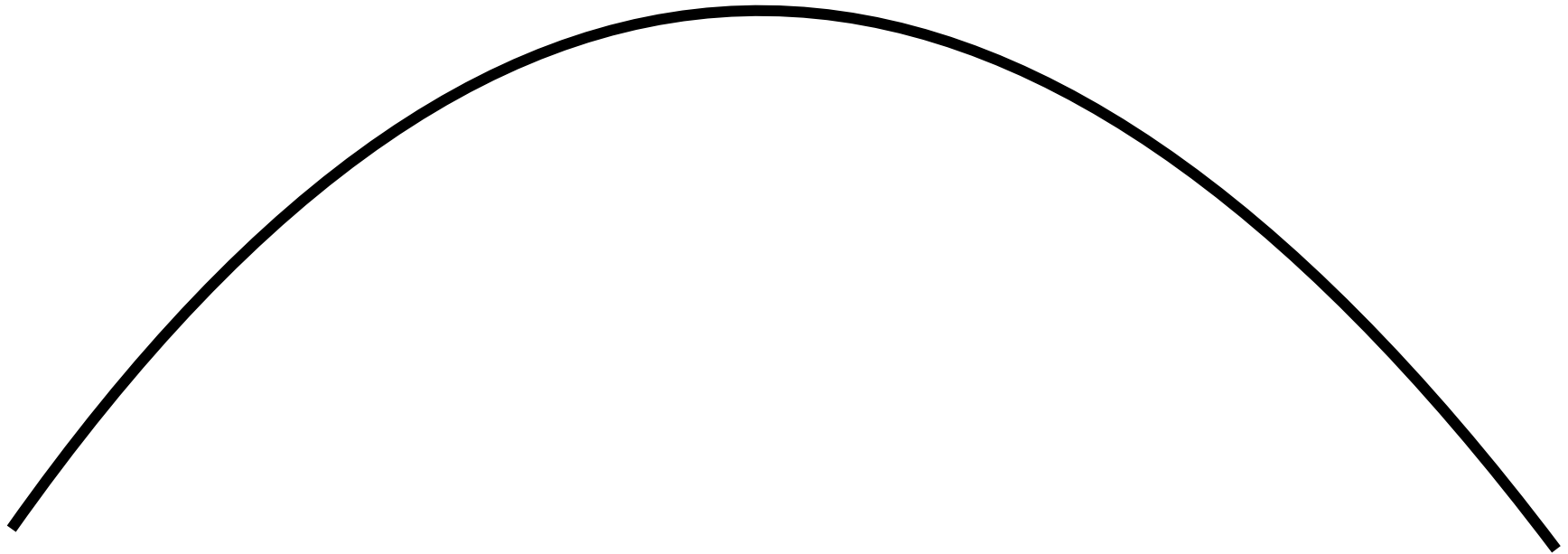
This presentation is not an exam preparation for any examination.

# 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.

# The Arc

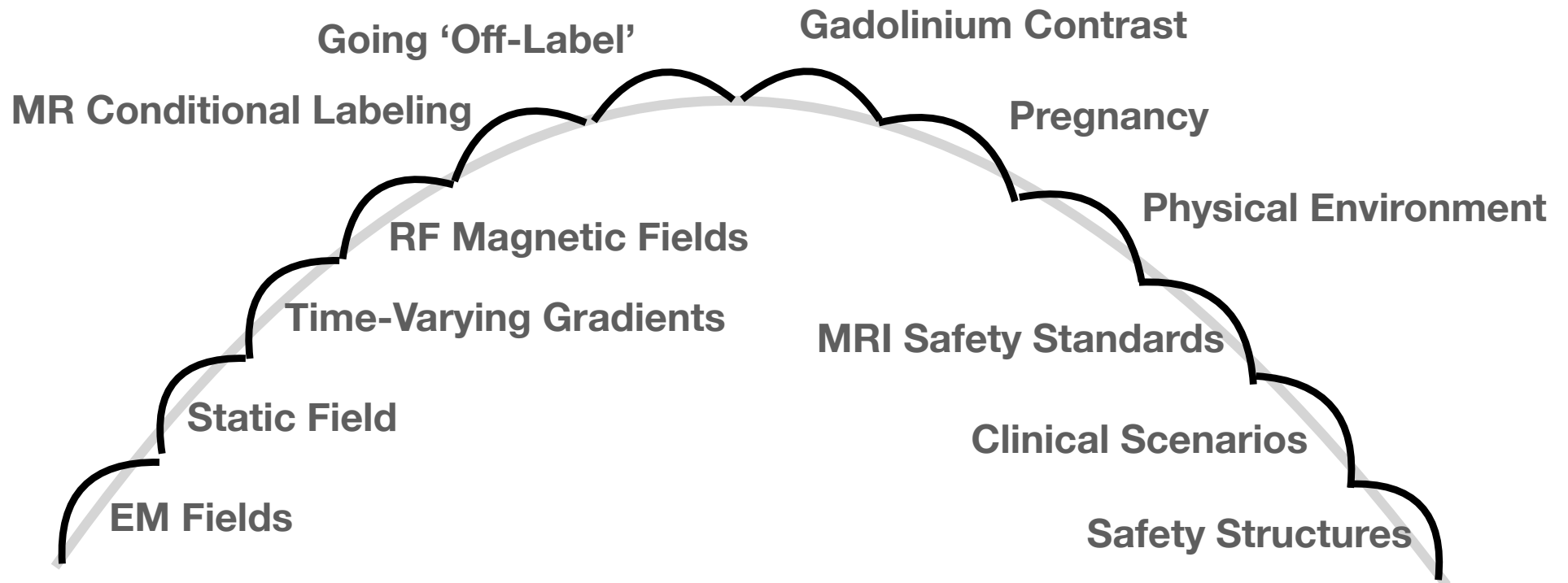
The “Big Picture”



Right Now

Weds Afternoon

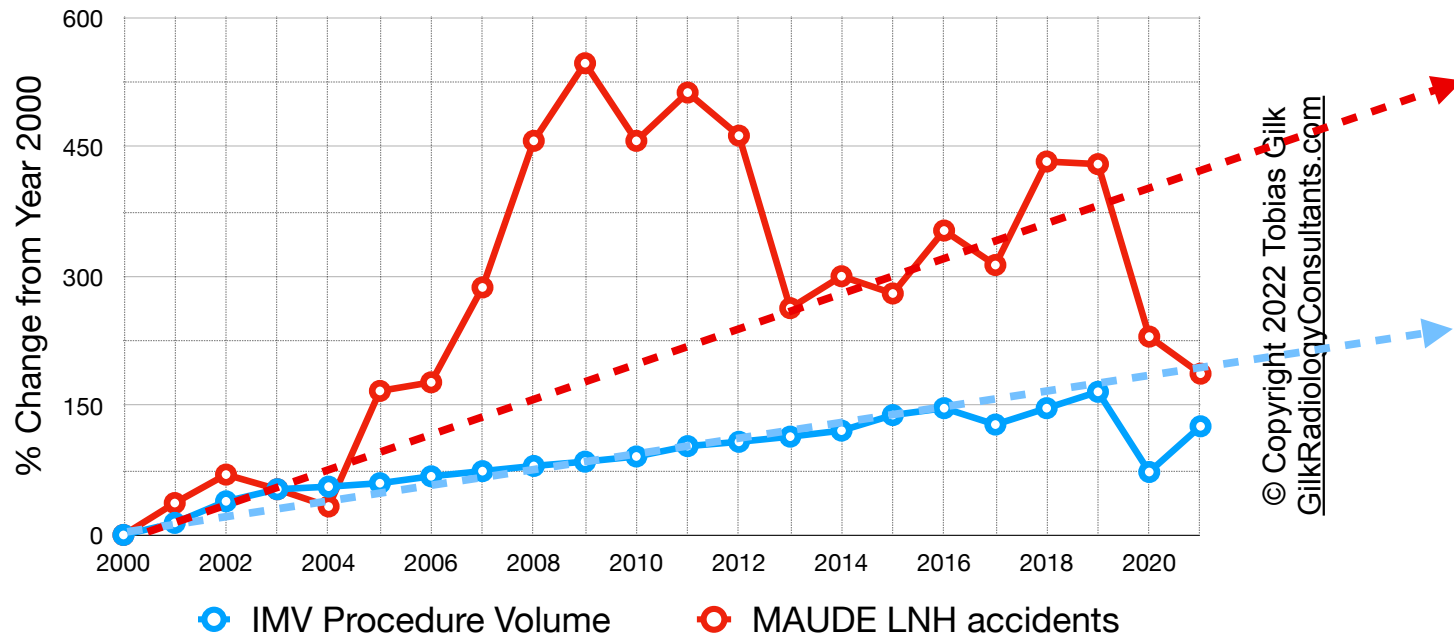
# The Arc



# State of MRI Safety

# State of MRI Safety

## Changes to MRI Adverse Events vs. Volume



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# State of MRI Safety

## ↗ Risk Factors

### MRI Systems

- Higher Field Strengths
- Active Shielding
- Faster / More Powerful Gradients
- Greater RF

### Clinical Usage

- High-Acuity Patients
- Emergent / Trauma
- Image-Guided Procedures
- Anesthesia / Sedation

### Patient Cohort

- Heavier
- Sicker
- More Implants / Devices

# State of MRI Safety

↗ Practice Improvements

***We are* doing better today (compared to 20 years ago),  
but our improvement is slower than risk-factor growth.**

# Outline

## Electromagnetic Fields

- Intro
- Static Magnetic Field (where, when, what, why)
- Time-Varying (Imaging) Gradient Magnetic Field (where, when, what, why)
- Radio Frequency Magnetic Field (where, when, what, why)
- Exposure Model of Risk
- 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

# MRI Has A Vocabulary Problem...

# MRI Has A Vocabulary Problem...

**Coil**

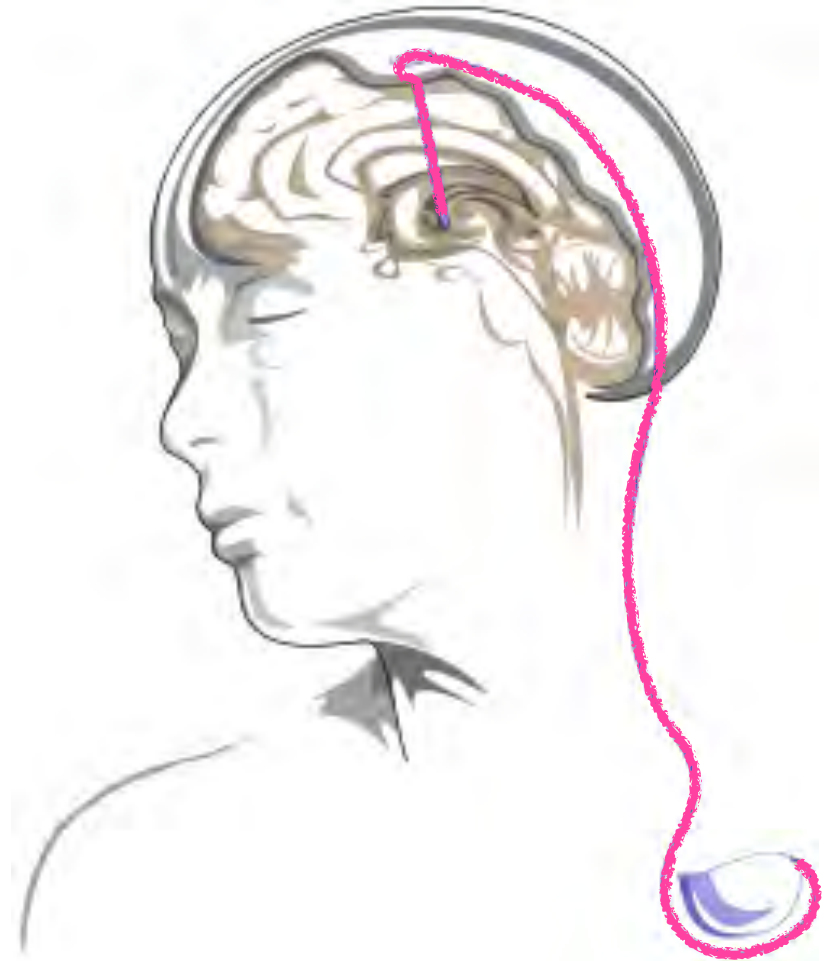
**Gradient**

# Before We Start...

## What Could Go Wrong?

- DBS Patient (6' tall, 200 lbs)
  - MR Conditional at 1.5T
  - “T/R Head Coil Only”
  - 0.1 W/kg
- Indicated Study Is For A Knee

Would You Consider It?



# MRI

## Three Electromagnetic (EM) Fields

- Static Magnetic Field
- Time-Varying (Imaging) Gradient Magnetic Field
- Radio Frequency Magnetic Field



# Static Magnetic Field

## Agenda

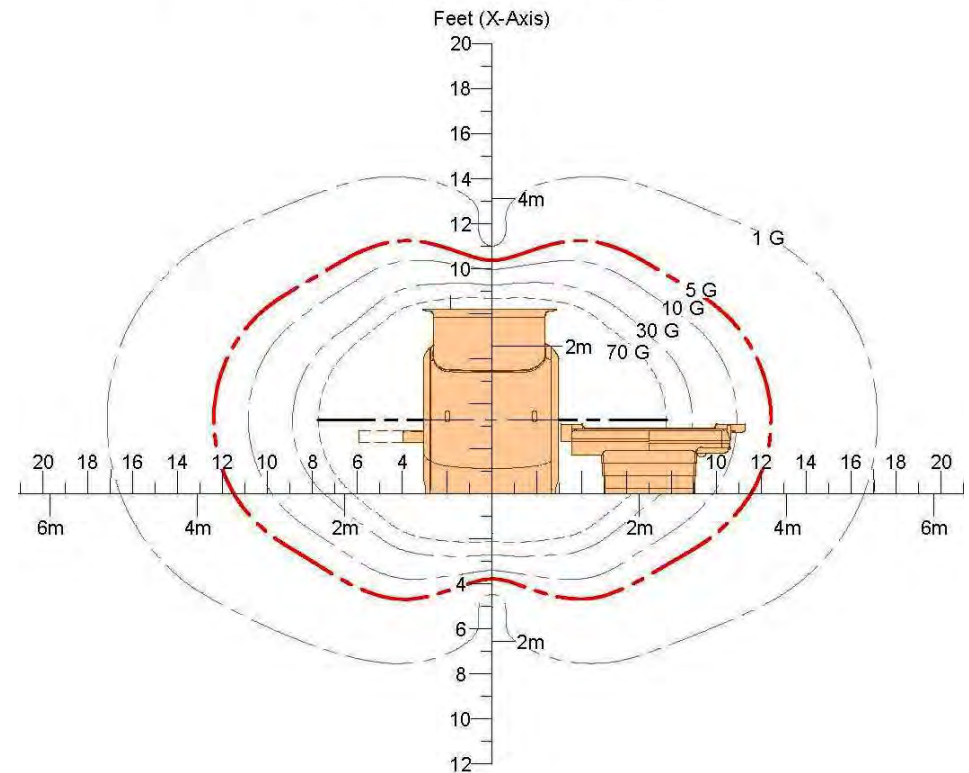
- When & Where
- Field Strength ( $B_0$ ) & Spatial Field Gradient (SFG)
- Units & Measures
- Plots & Graphs
- Physical Effects
- Physiologic Effects

# Static Magnetic Field

## When & Where?

- Always On
- Increases w/ Proximity  
(max usually near mouth of bore)
- Magnetism Not Contained By  
Conventional Construction

**Detail - Magnetic Field Plot, without Magnet Shielding**  
(Static fringe field shown / Not to scale)



# Static Magnetic Field

## Field Strength & SFG

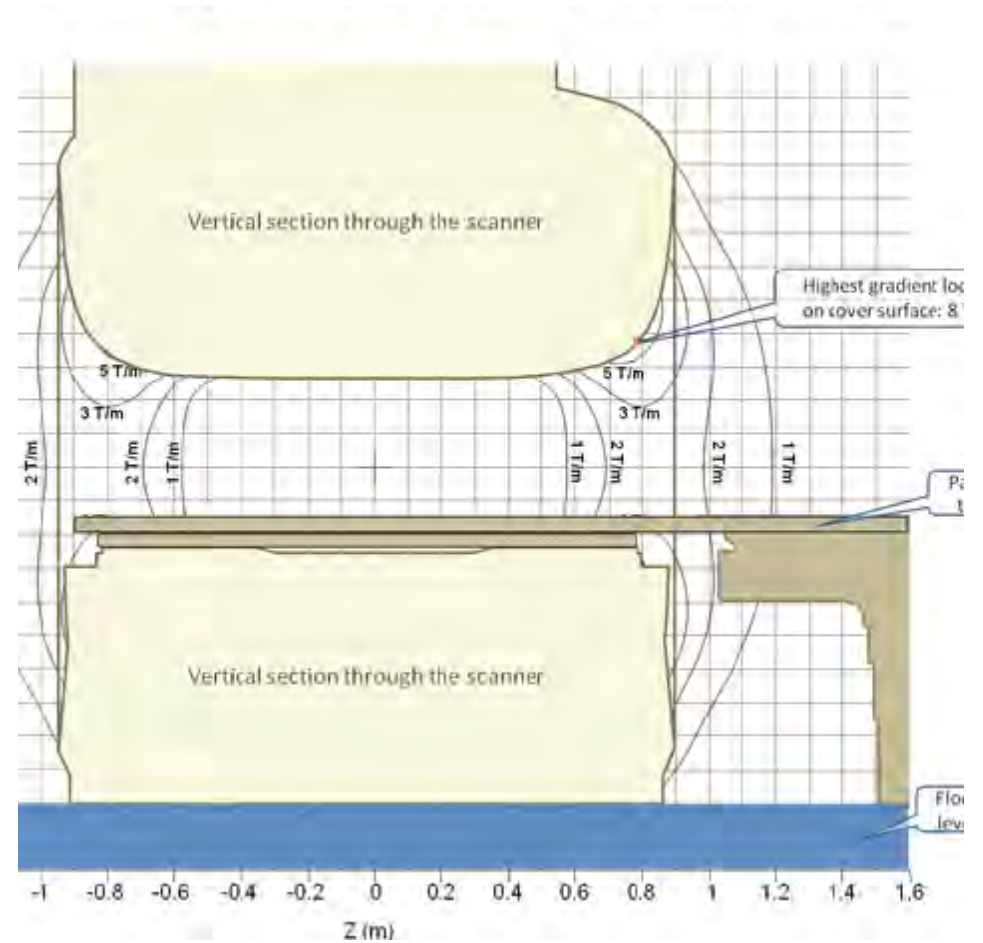
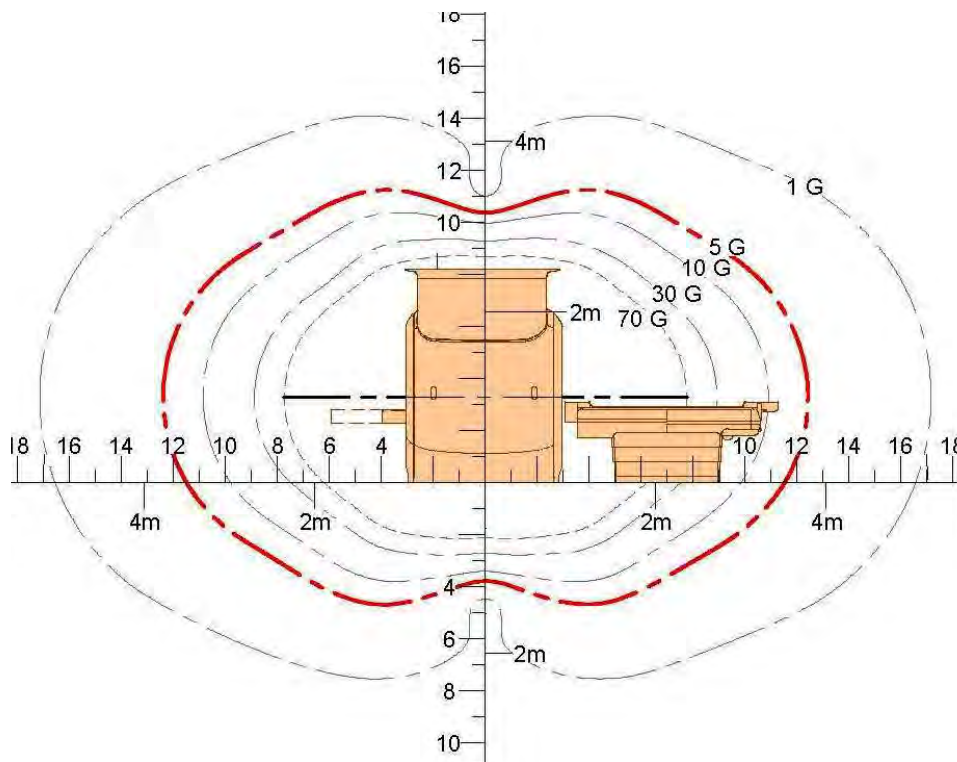
### Field Strength

- Single-Factor Measure
- ‘Nominal’ Field Strength (e.g., “1.5 T” or “3.0 T”)
- Fringe Field Strengths (e.g., 5 Gauss, 100 Gauss)

### Spatial Field Gradient

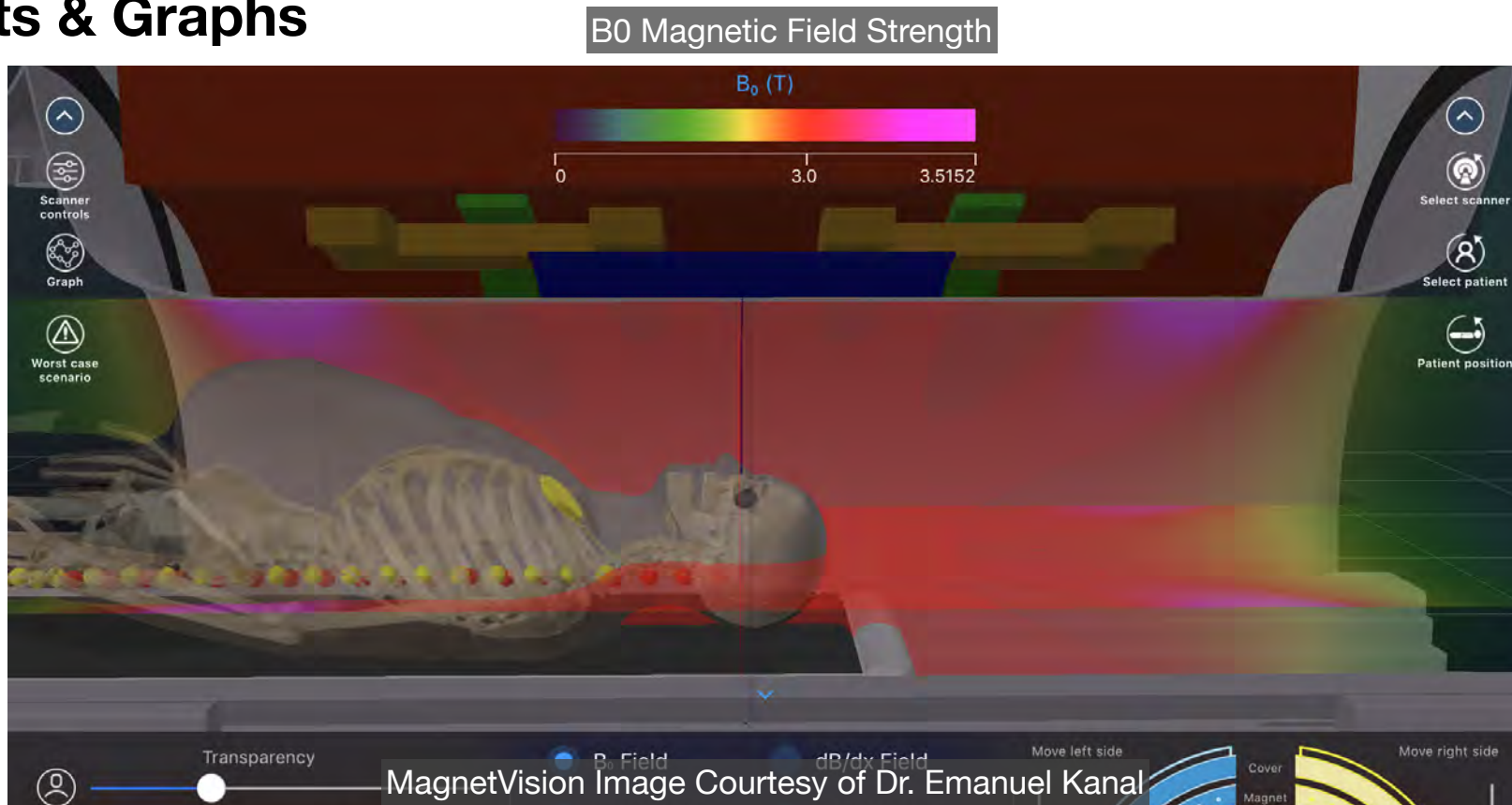
- Two-Factor Measure
- Change In Field Strength Over Distance
- “Steepness” Of Magnetic Field
- Depicted in G/cm or T/m

# Static Magnetic Field Plots & Graphs



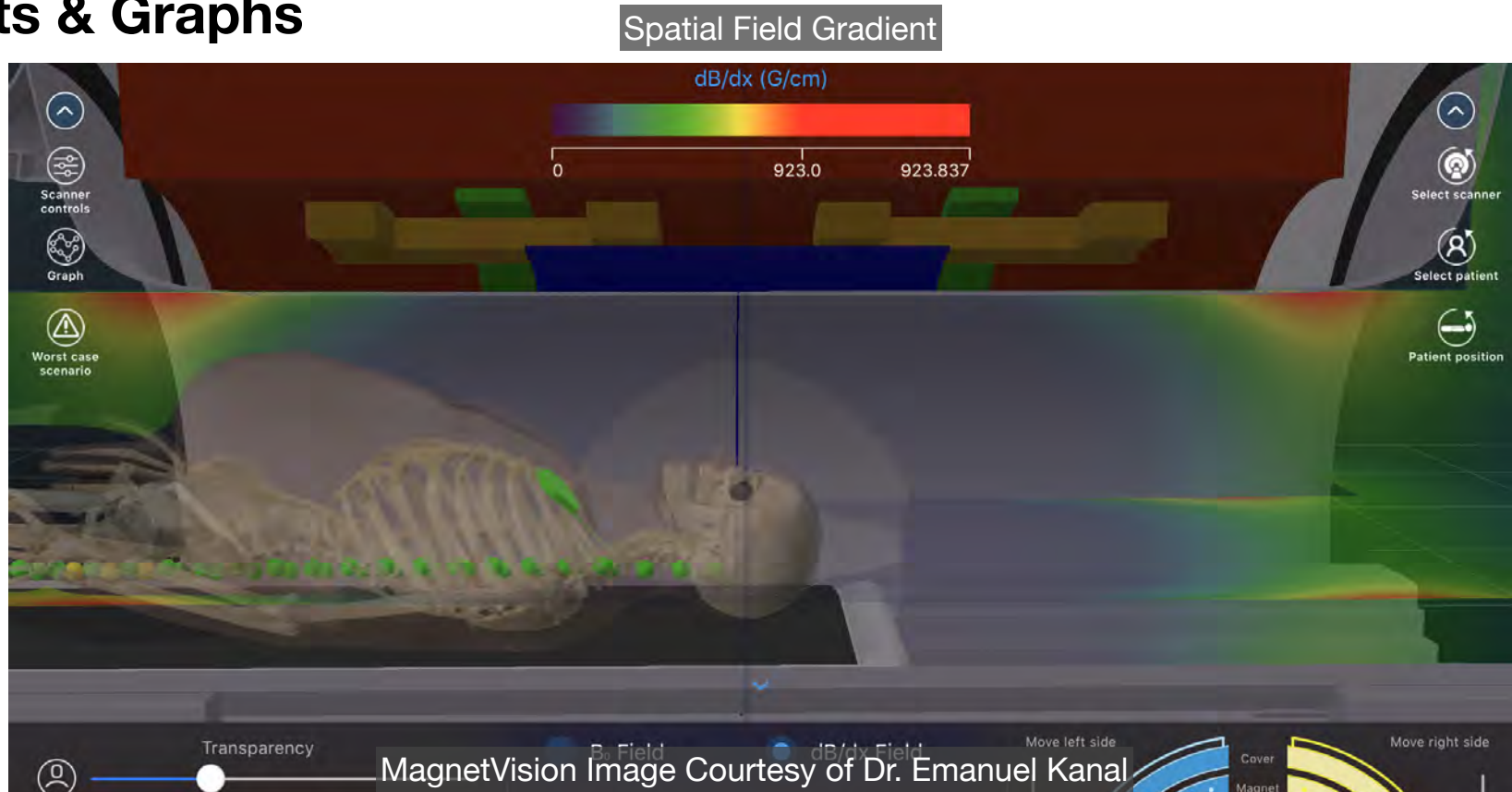
# Static Magnetic Field

## Plots & Graphs



# Static Magnetic Field

## Plots & Graphs



# Static Magnetic Field

## Physical Effects

- Torque / Rotation (Function of  $B_0$ )
- Translation / Attraction (Primarily Function of SFG)
- Lenz Force (Faraday's Law of Induction)

# Static Magnetic Field

## Physiological Effects

- Inner-Ear Effects (vertigo, nystagmus)
- Flow Potential (ECG interference, S-T segment elevation)
- Magneto Hydrodynamic Effect (MHD)



# Time-Varying (Imaging) Gradient Magnetic Fields

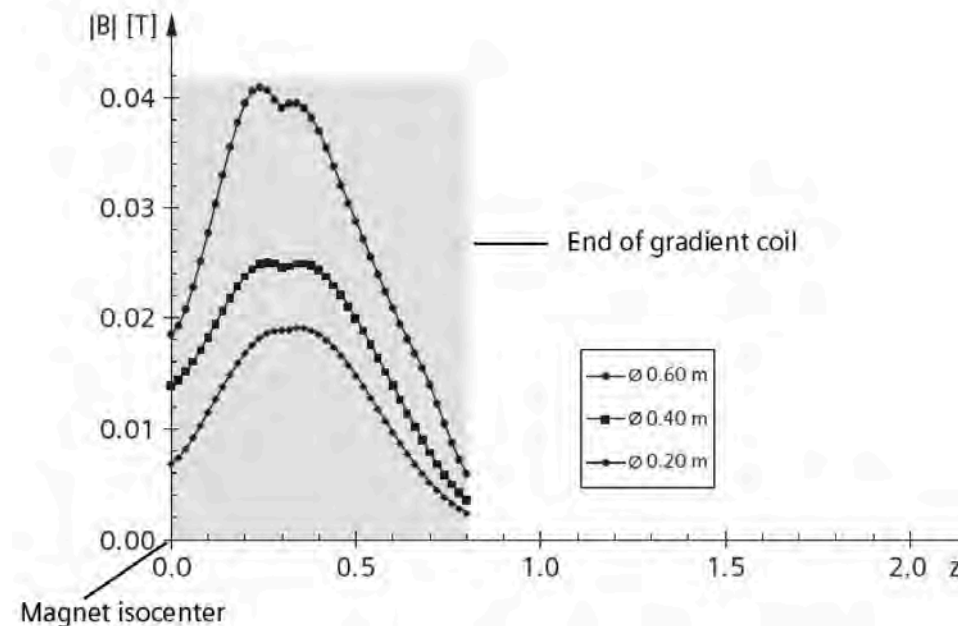
## Agenda

- When & Where
- Amplitude (strength), Slope (steepness), Slew (time & distance change)
- Units & Measures
- Plots & Graphs
- Physical Effects
- Physiologic Effects

# Time-Varying Gradients

## When & Where?

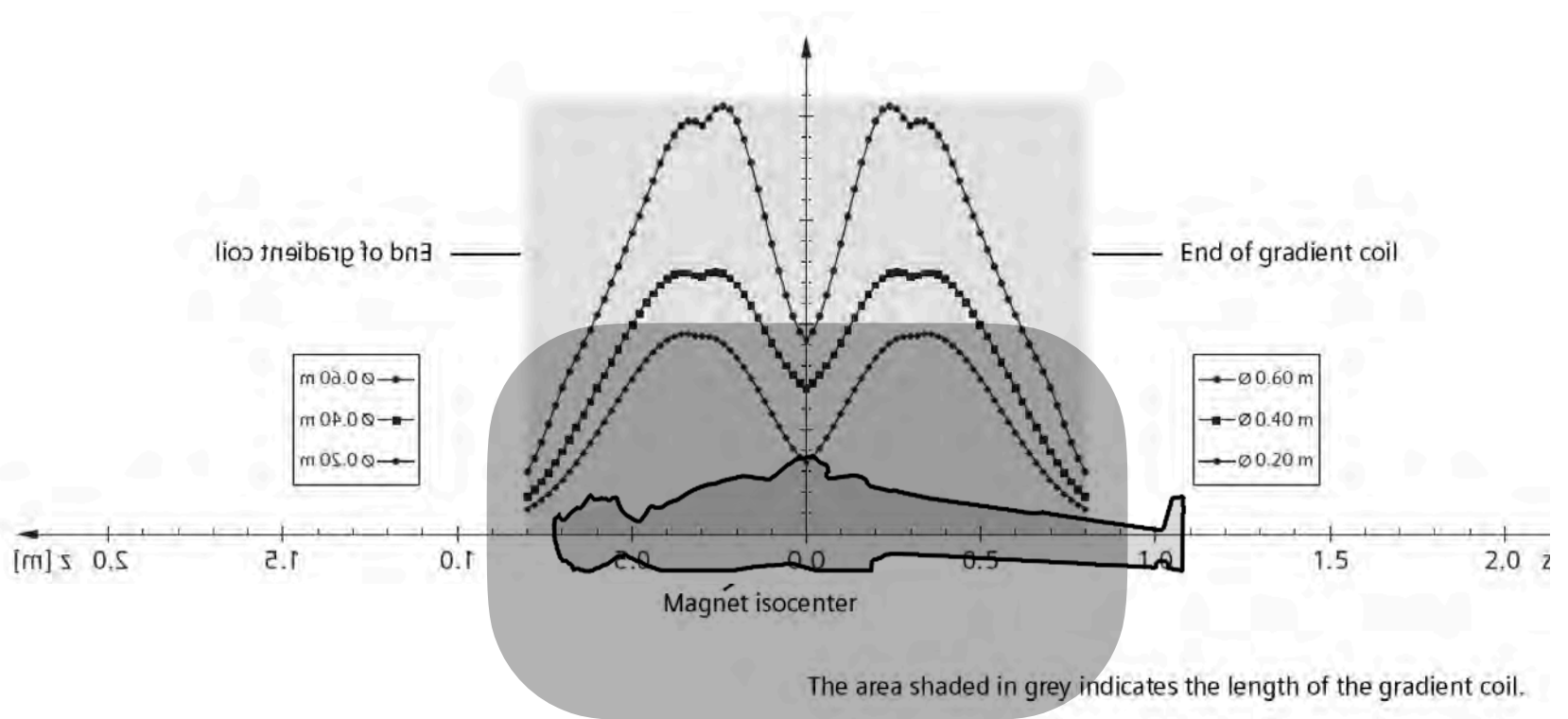
- On Only During Imaging
- Close To Minimum At Isocenter
- Max ~30 cm S-I, Radially
- Drops Rapidly Further Than 30 cm
- Functionally Insignificant Beyond Face Of Bore



The area shaded in grey indicates the length of the gradient coil.

# Time-Varying Gradients

## When & Where?



# Time-Varying Gradients

## Amplitude, Change Rate, Slope

### Amplitude

- Single-Factor Measure
- Maximum Change In Effective Field Strength
- Usually Represented In Milli (m) Tesla (T), or mT

### Change Rate

- Two-Factor Measure
- Change In Strength Over Time ( $\Delta B/\Delta t$ )
- Usually Represented In T/s, or mT/s

### Slope

- Two-Factor Measure
- Like Spatial Gradient, Change In Strength Over Distance ( $\Delta B/\Delta x$ )
- Usually Represented In T/m, or mT/m

# Time-Varying Gradients

## Rise-Time, Slew

### Rise-Time

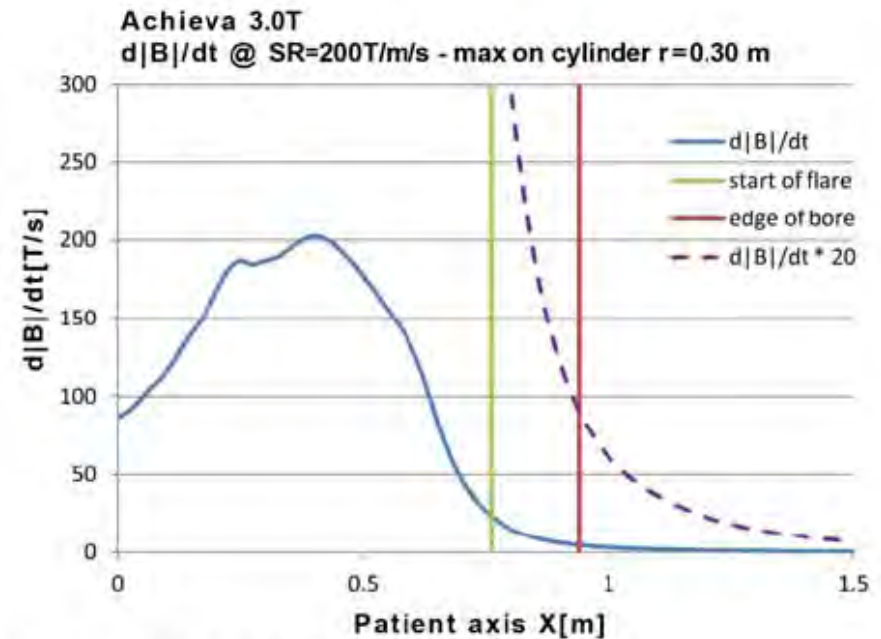
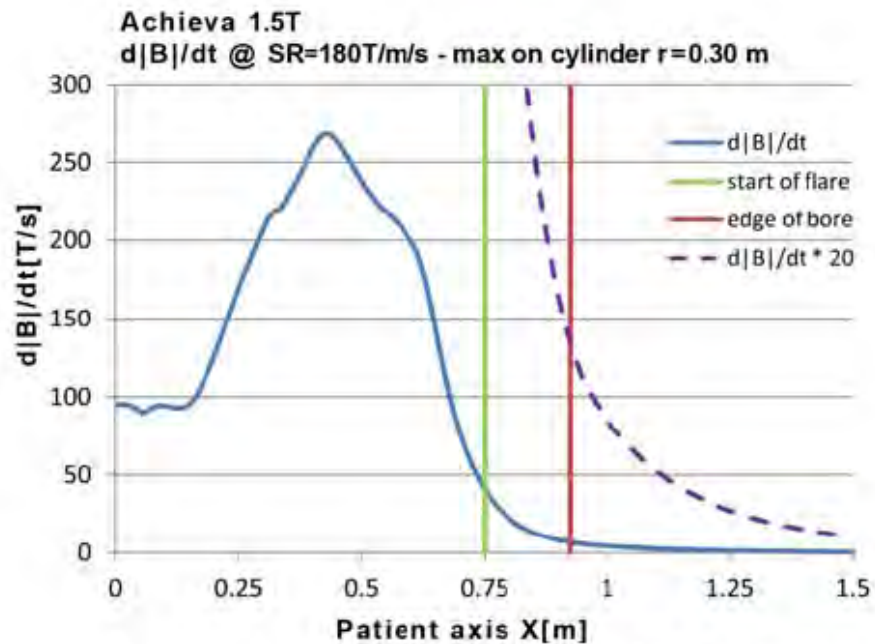
- Single-Factor Measure
- Time Required To Go From Gradients Off To Full Power
- Usually Represented In Milli (m) seconds (s), or ms

### Slew

- Three-Factor Measure
- Most Complete Measure Of Gradients (strength, distance, time)
- Usually Represented In T/m/s or mT/m/ms

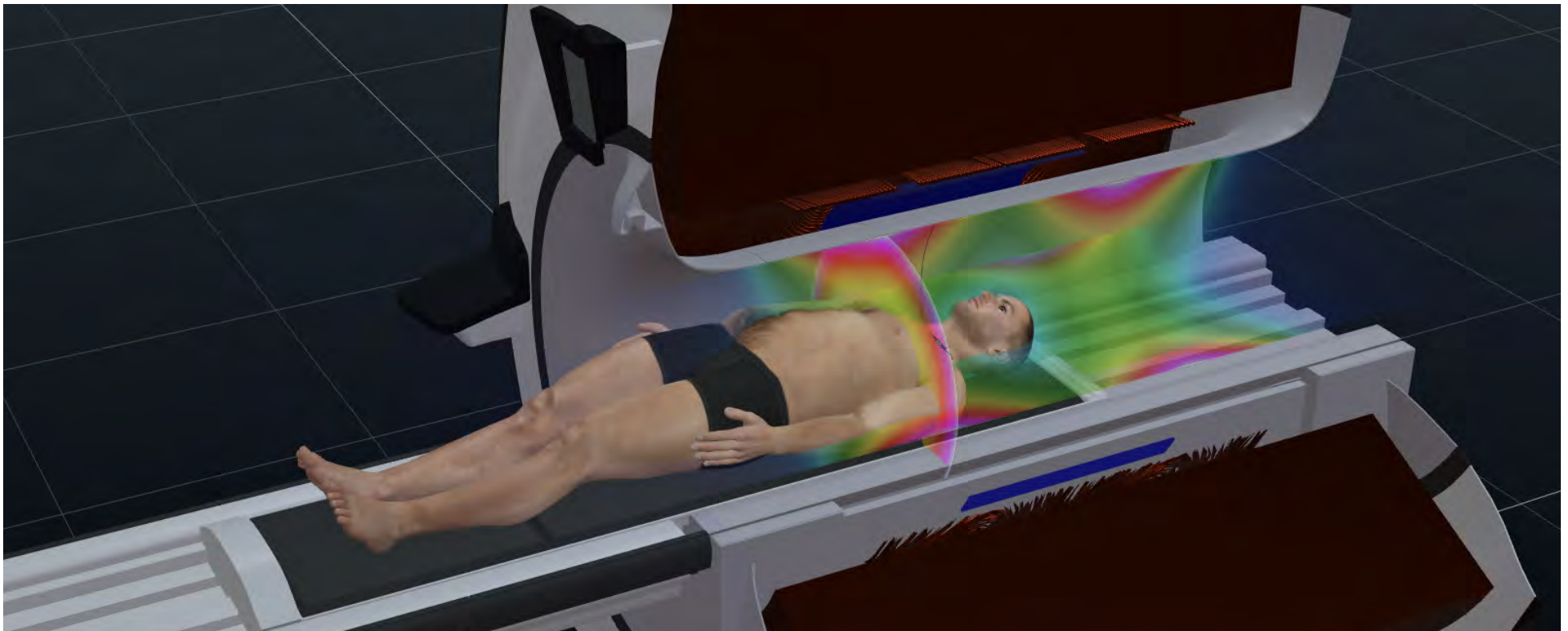
# Time-Varying Gradients

## Plots & Graphs



# Time-Varying Gradients

## Plots & Graphs



# Time-Varying Gradients

## Physical Effects

- High-Frequency Vibration
- Faraday's Law of Induction (TVG-Induced Voltages)



# Time-Varying Gradients

## Physiological Effects

- Peripheral Nerve Stimulation (PNS)
- Lead-Potentiated Neuromuscular Stimulation
- False-Feedback Of Active Devices (Inappropriate Therapy)

# Radio Frequency (RF) Magnetic Fields

## Agenda

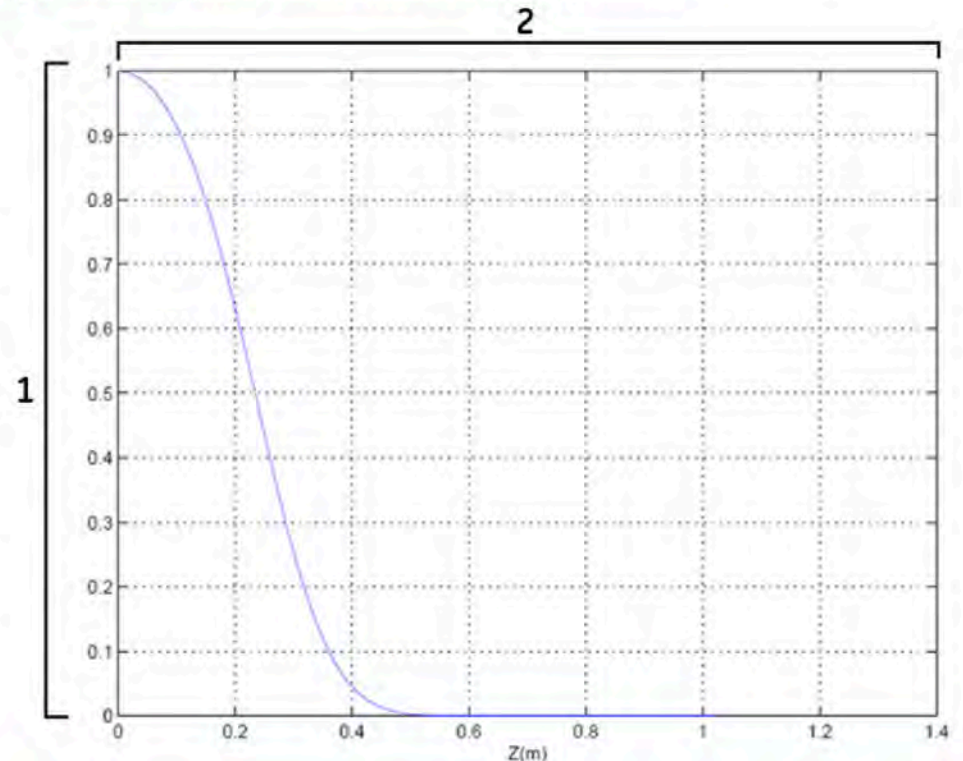
- When & Where
- Collimation??
- Units & Measures (SAR, SED,  $B_{1+RMS}$ )
- Plots & Graphs
- Physical Effects
- Physiologic Effects

# RF Magnetic Fields

## When & Where?

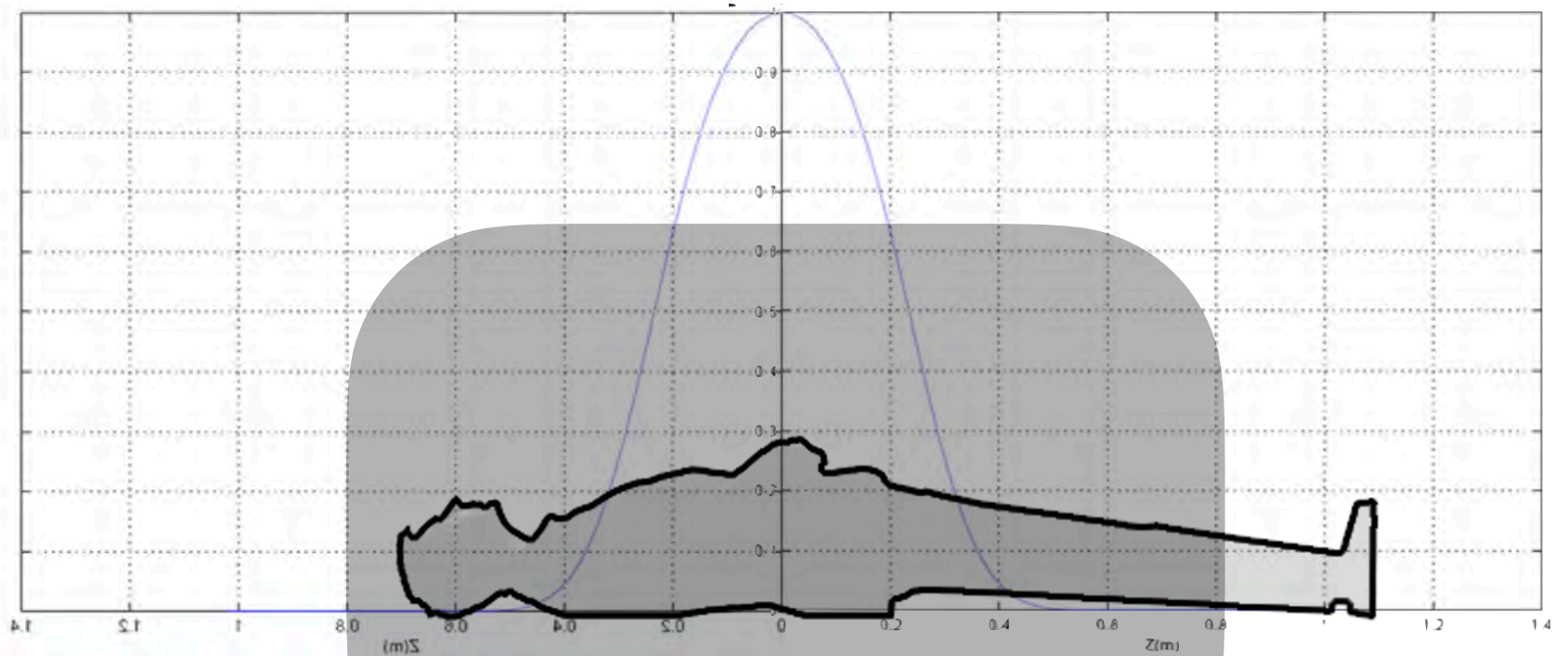
- On Only During Imaging
- What Manufacturers Tell You (vs. what's real)
- Drops Rapidly Further Than 30 cm
- Functionally Insignificant Beyond Face Of Bore
- Collimation?

Figure 2-2: Plot of the Square of B1 Normalized to Isocenter for the Body Birdcage Coil on Axis.



# RF Magnetic Fields

## When & Where?



# RF Magnetic Fields

## SAR, SED, B1+RMS

### SAR

- Measures *Rate* Of Absorbed Energy Averaged Across Mass
- Whole Or Partial Body
- Useful For Diffuse Thermal Loading (but on device labels for focal heating risk?!?)

### SED

- SAR x Time
- Assumes All Heat Energy Remains In Patient (No Shedding Of Thermal Load)
- Pop-Up Warnings
- Lock-Outs

### B1+RMS

- Standardized Across Vendors / Platforms
- Measure Of Absorbed Energy
- Also Poor For Focal Heating Risk, But Generally Safer & More Permissive Than SAR

# RF Magnetic Fields

## SAR, SED, B1+RMS

### SAR

- Watts Per Kilogram (W/kg)
- Whole Body Averaged
- Head
- Extremity (Partial Body)

### SED

- Joules Per Kilogram (J/kg), or Thousand (kilo) Joules Per Kilogram (kJ/kg)
- Joule = Watts x Seconds

### B1+RMS

- Micro (One-Millionth) Tesla,  $\mu\text{T}$

# RF Magnetic Fields Plots & Graphs

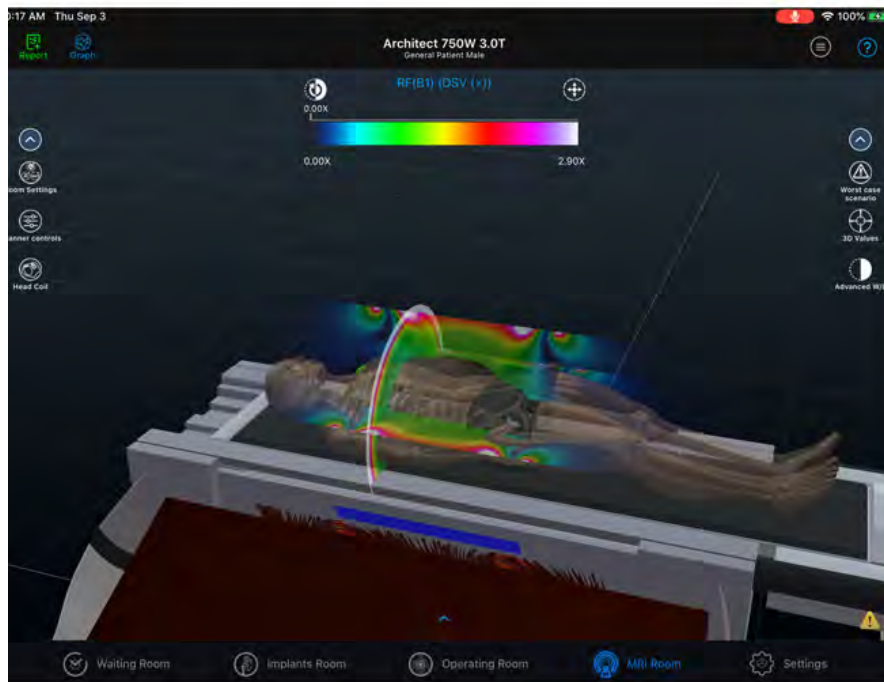


Figure 2-6: Plot of the Square of B1 Normalized to Isocenter for the Body Birdcage Coil on Axis.

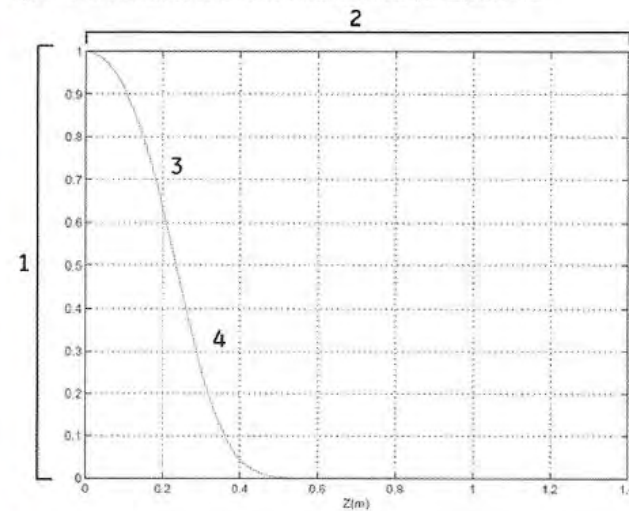
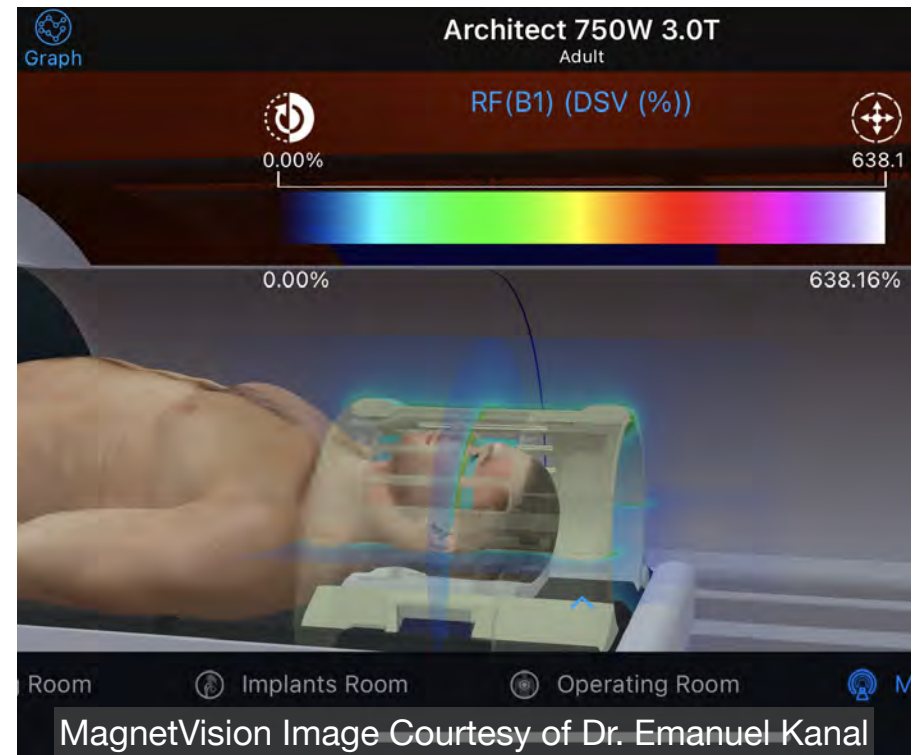
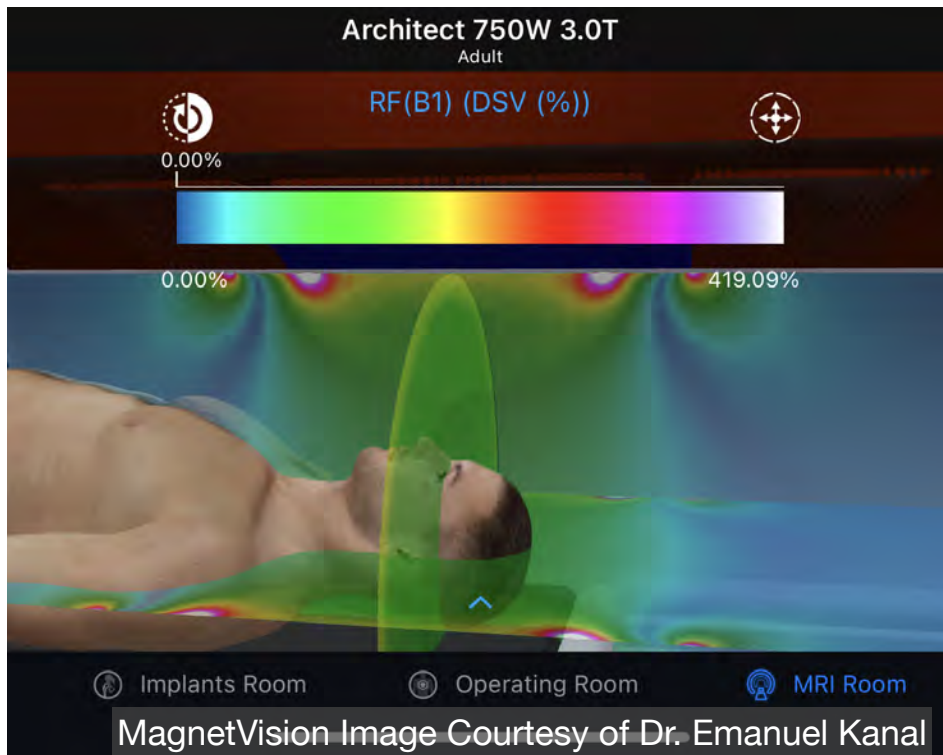


Table 2-12: Image legend

#	Description
1	Square of B1 normalized to isocenter.
2	Square of B1 normalized to isocenter for body birdcage coil on axis.
3	The point (0.707) at which RF transmission is reduced by 3 dB from maximum at isocenter.
4	The point (0.316) at which RF transmission is reduced by 10 dB from maximum at isocenter.

# RF Magnetic Fields

## Plots & Graphs





# RF Magnetic Fields

## Physical Effects

- Diffuse Heating
- Faraday's Law of Induction (RF-Induced Voltages)
  - Focal Resistance (Focal Heating)

# RF Magnetic Fields

## Physiological Effects

- See Physical Effects

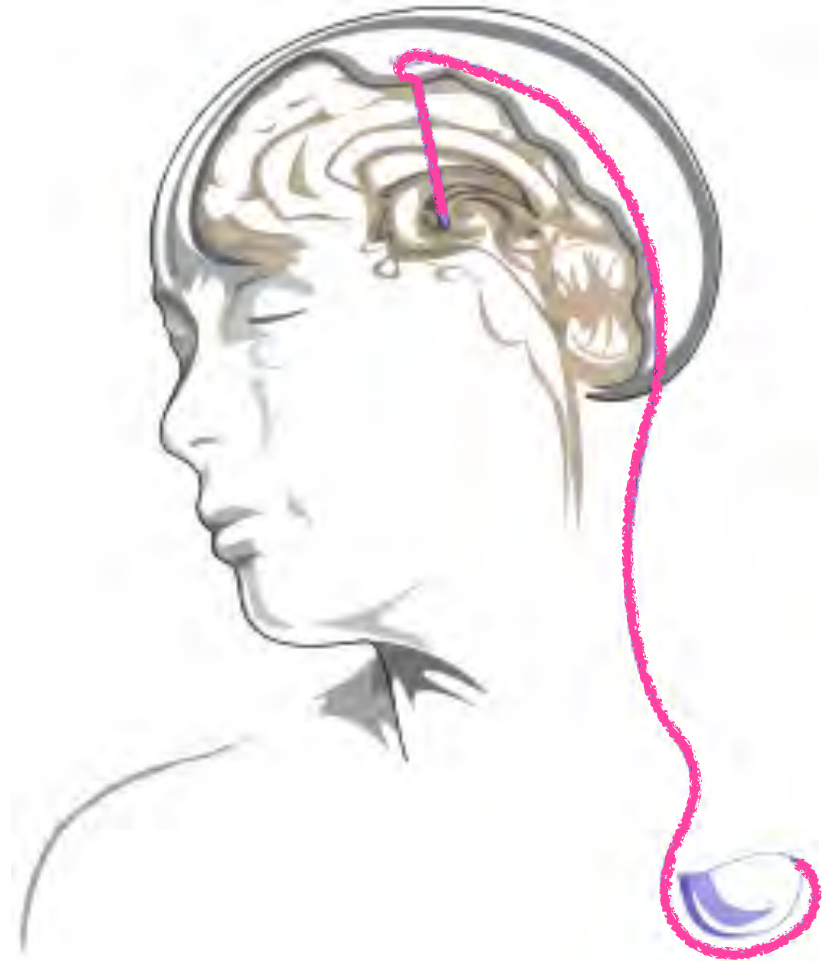
# Risks Are A Function Of Exposure

- If Exposure Is Zero, What Is Risk?

# Do You Remember...

## Would You Consider?

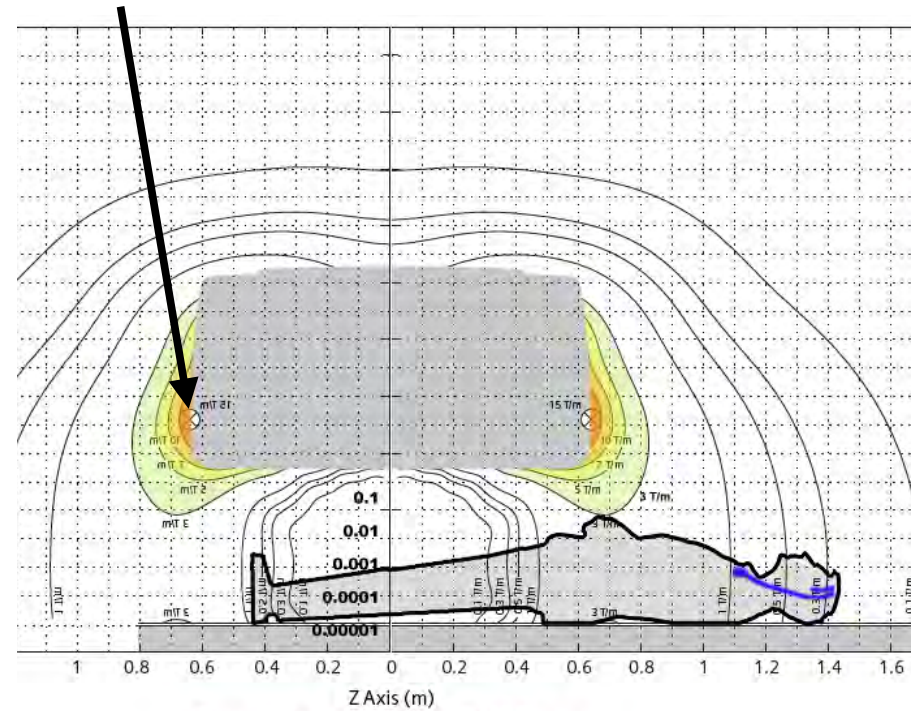
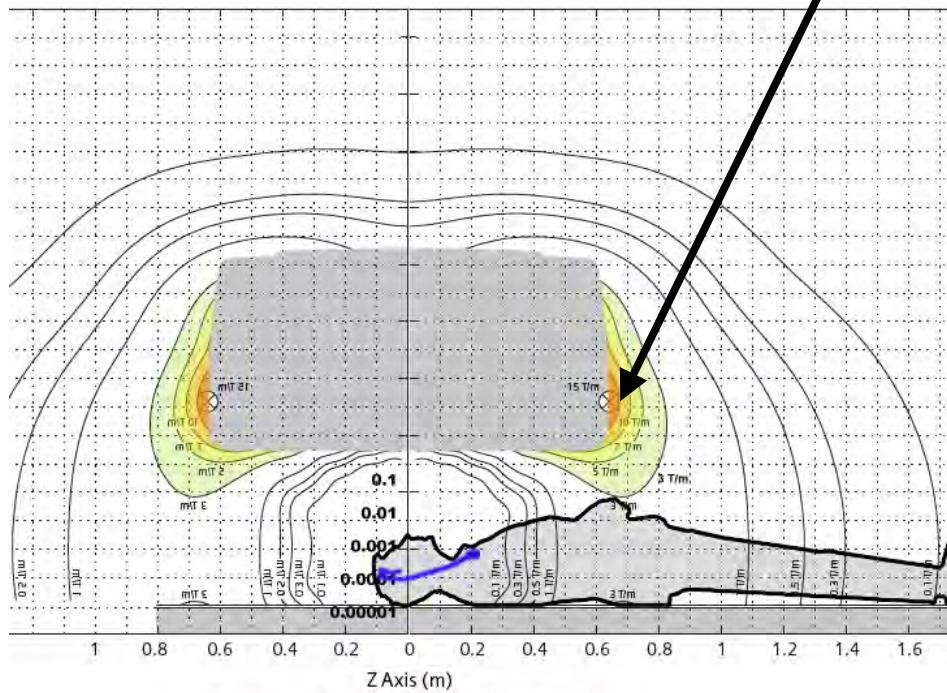
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  - MR Conditional
  - “T/R Head Coil Only”
  - 0.1 W/kg
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# Do You Remember...

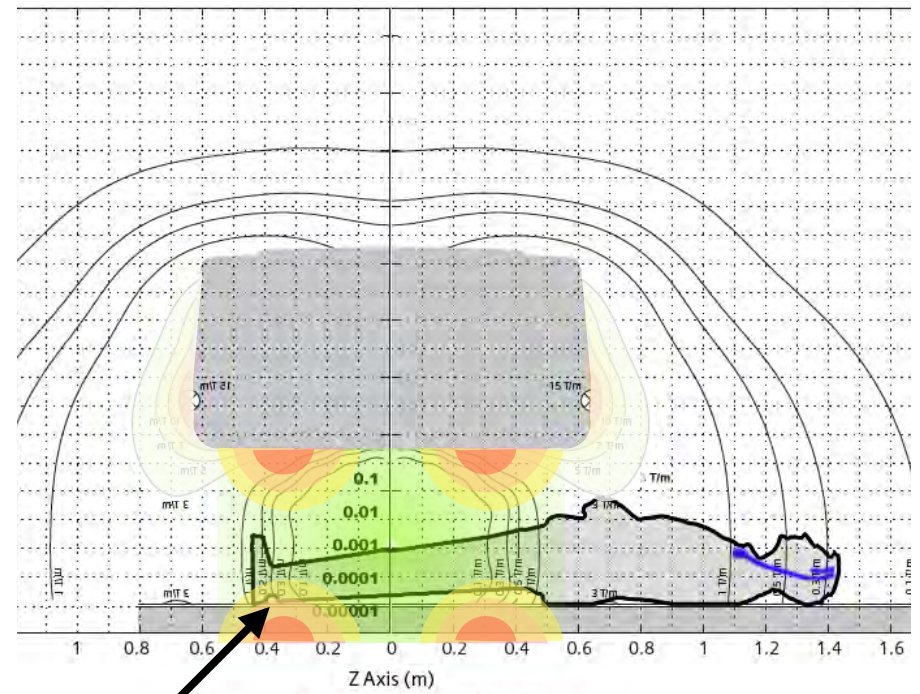
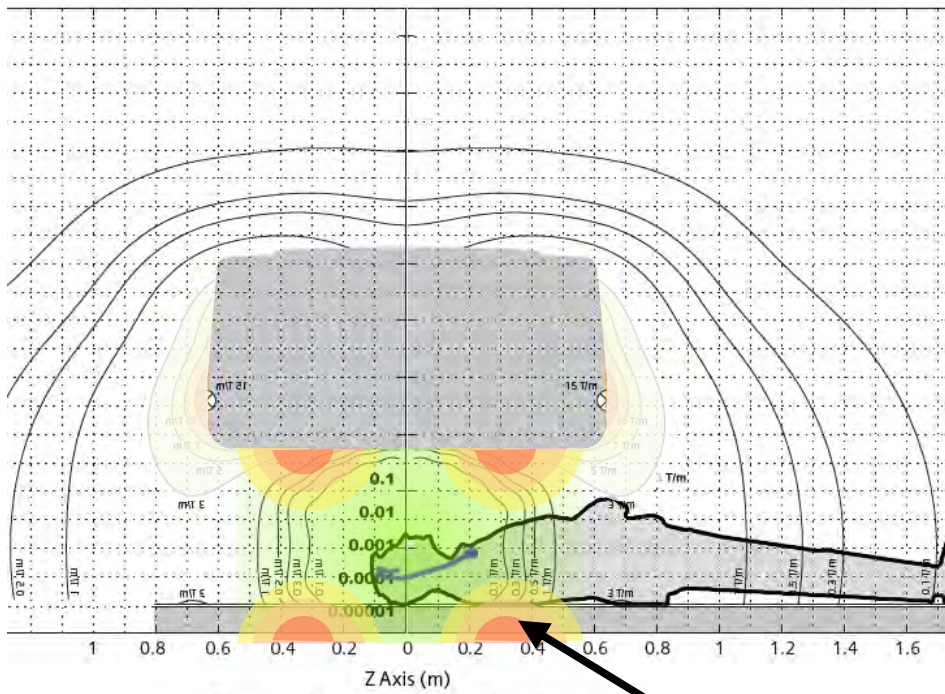
## Would You Consider?

Spatial Gradient



# Do You Remember...

## Would You Consider?

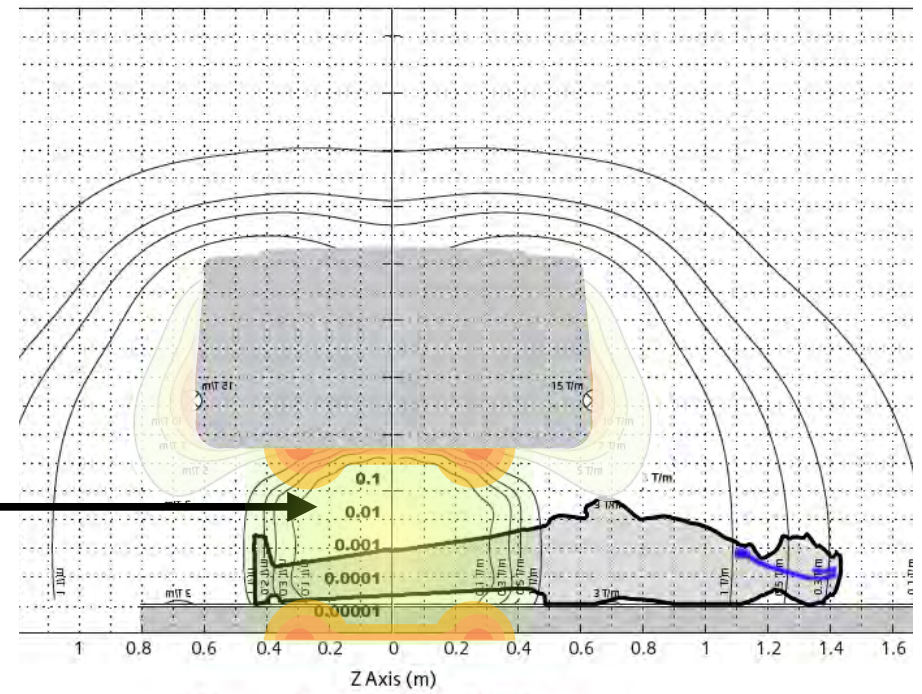
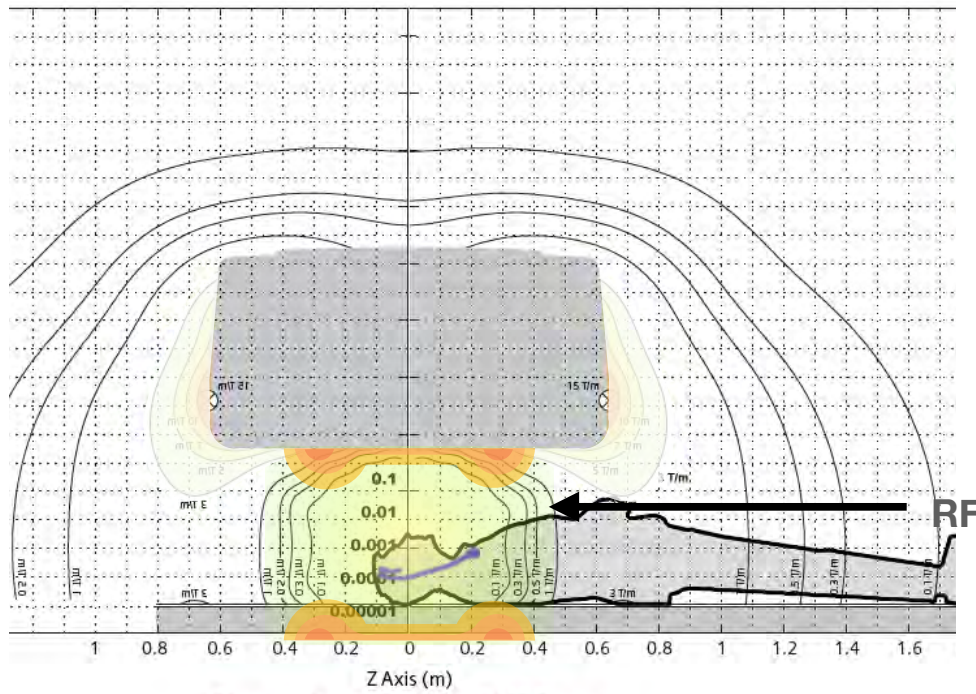


Time-Varying Gradient

EM Fields: Effects / Volumes / Forces Harms

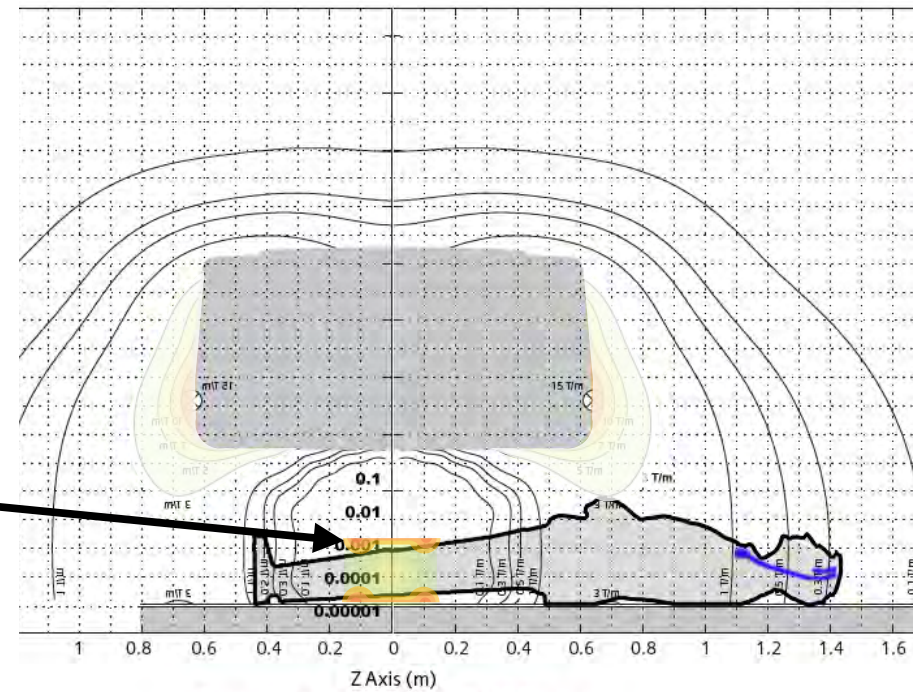
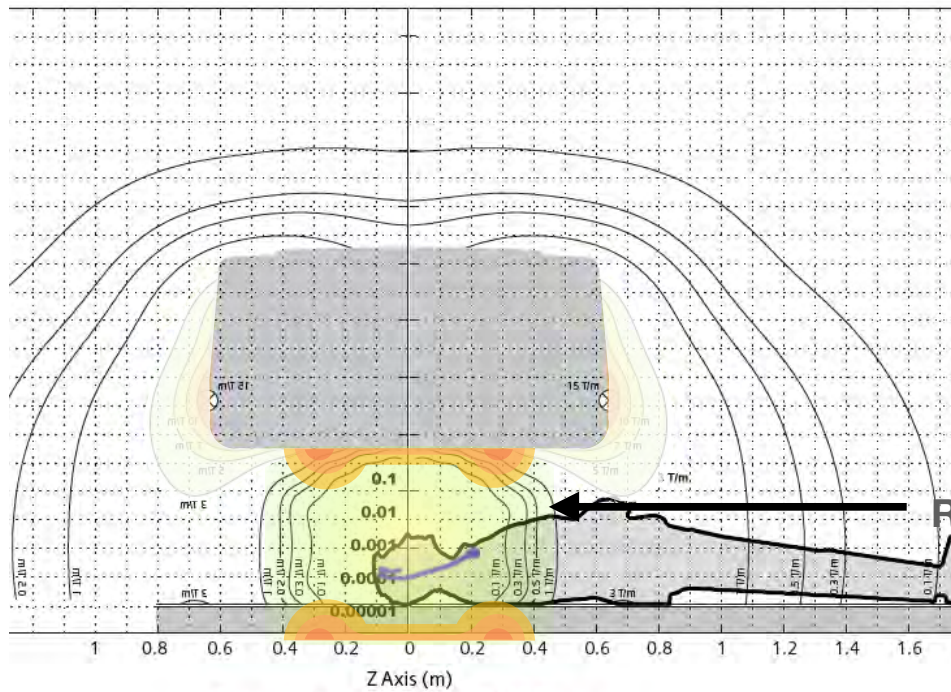
# Do You Remember...

## Would You Consider?



# Do You Remember...

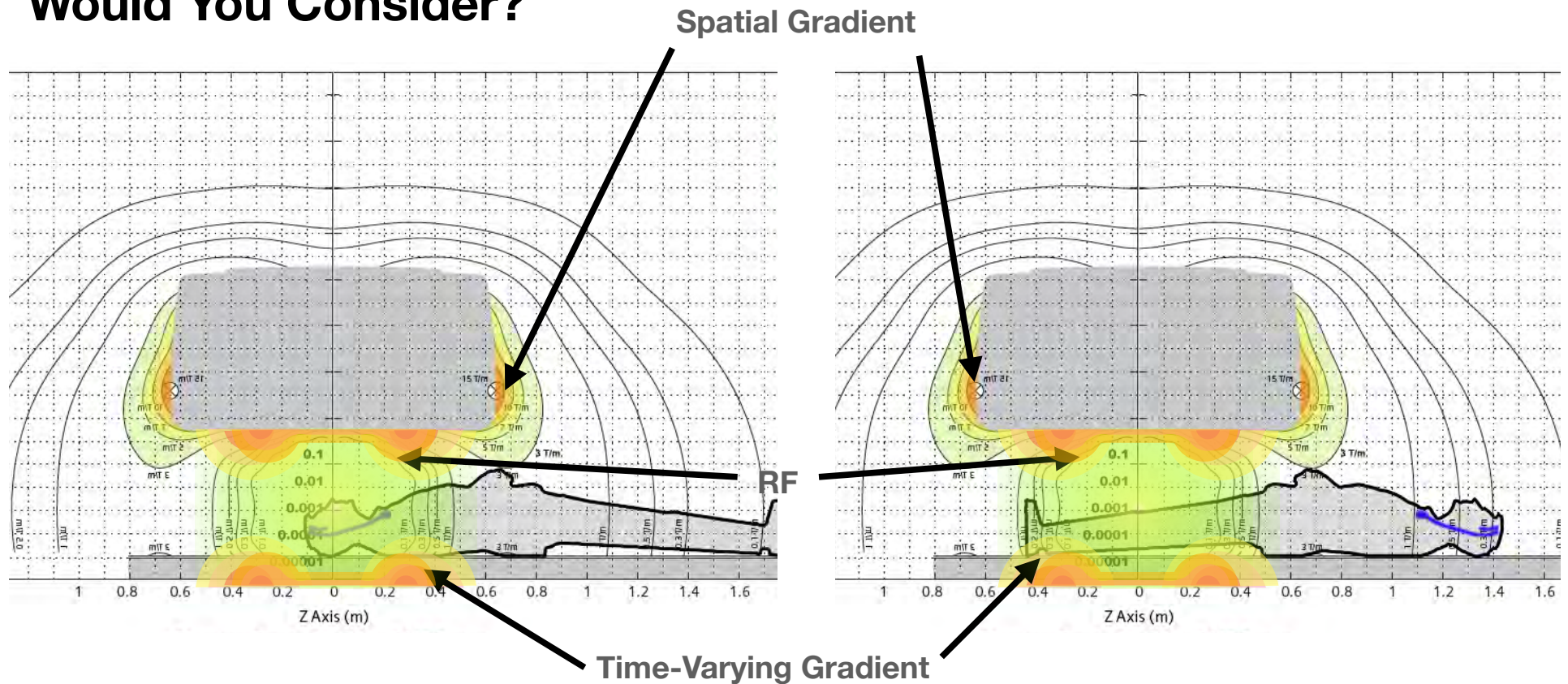
## Would You Consider?





# Do You Remember...

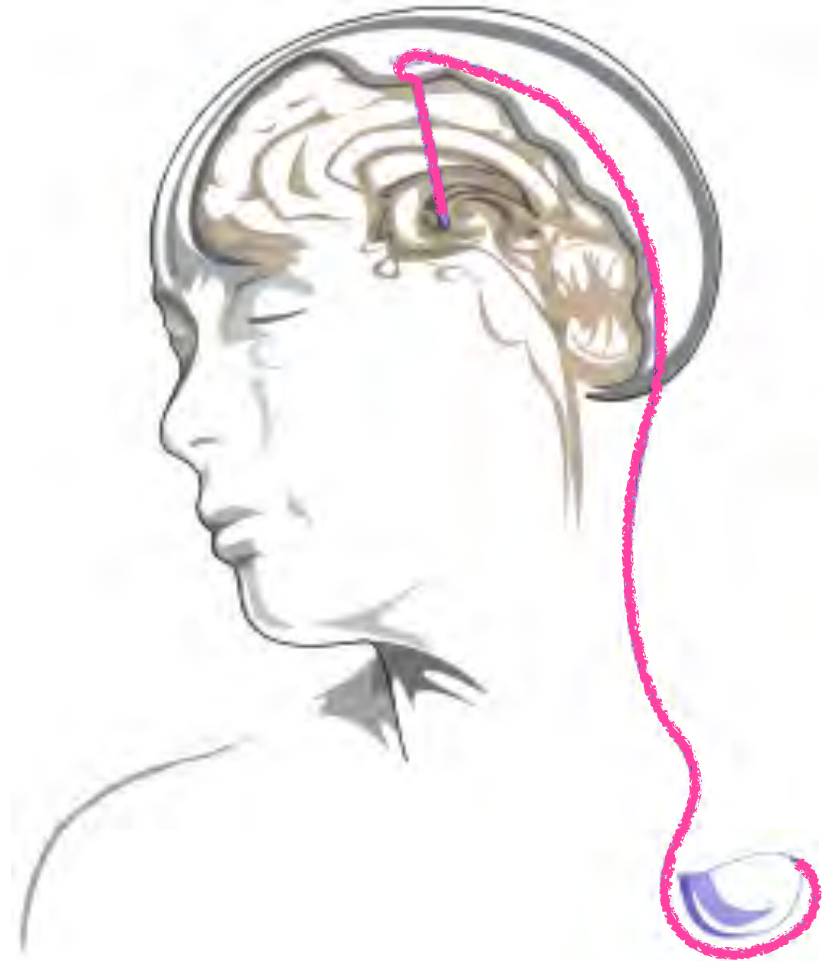
## Would You Consider?



# Do You Remember...

## Would You Consider?

- DBS Patient (6' tall, 200 lbs)
  - MR Conditional at 1.5T
  - “T/R Head Coil Only”
  - 0.1 W/kg
- 
- Indicated Study Is Knee



# Q&A

# Thank You

**Tobias Gilk, MRSO, MRSE**



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