PROFESSIONAL REQUIREMENTS FOR QUALIFIED MRI PHYSICISTS IN RADIATION THERAPY PHYSICS

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Overview

- Review Radiation Therapy Tasks that can use MRI
- Professional Qualifications in MRI Physics
- Educational Opportunities in MRI Physics
- MRI Physics Accreditation Programs
- MRI Physics Competencies Required for Radiation Therapy Tasks

MRI Simulation

- Flat table-top overlay
- Coil bridges for flex coils
- Pulse sequence modifications include:
  - *Full field-of-view (FOV)*
  - *High receiver BW (minimize CSA and susceptibility effects)*
  - *Increased coverage required for target and Organs at Risk delineation landmarks for registration and IGRT*
  - *Increased image intensity uniformity for registration*

Paulson et al. Medical Physics, 42(1), 2015

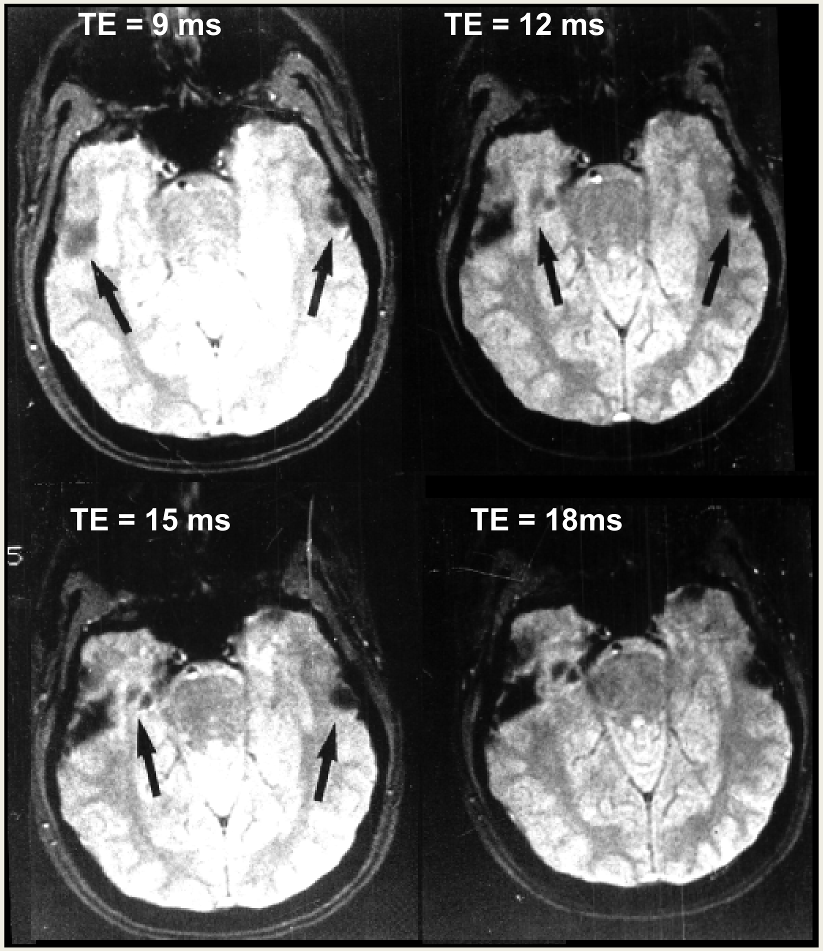
  - *Geometric distortion correction to < 2mm*
  - *Imaging breath-holds tailored to match gating windows used in gated radiotherapy delivery*

MRI-Based Simulation Pulse Sequences

Sequence/Contrast	Site(s)	Artifacts / Confounds
Axial/Saggital T1	Breast, Head and Neck, Prostate, Spine	Swallowing motion, flow artifacts
Axial T2 FLAIR	Brain, Pancreas	CSF pulsation artifacts
Post-contrast T1	Brain, Liver, Spine	Breath-holding
Axial fat-suppressed T1	Cervix, Head and Neck, Liver, Pancreas, Spine	Swallowing motion, flow artifacts
Fat-suppressed T2	Breast, Liver, Rectum	Breath-holding
Axial T2 STIR	Breast, Head and Neck	
Axial ΔT1 (Post T1−Pre T1)	Brain	
Axial Diffusion (ADC)	Brain, Cervix, Head and Neck, Rectum, Rectum	Geometric distortion

Paulson et al. Medical Physics, 42(1), 2015

Susceptibility Artifact

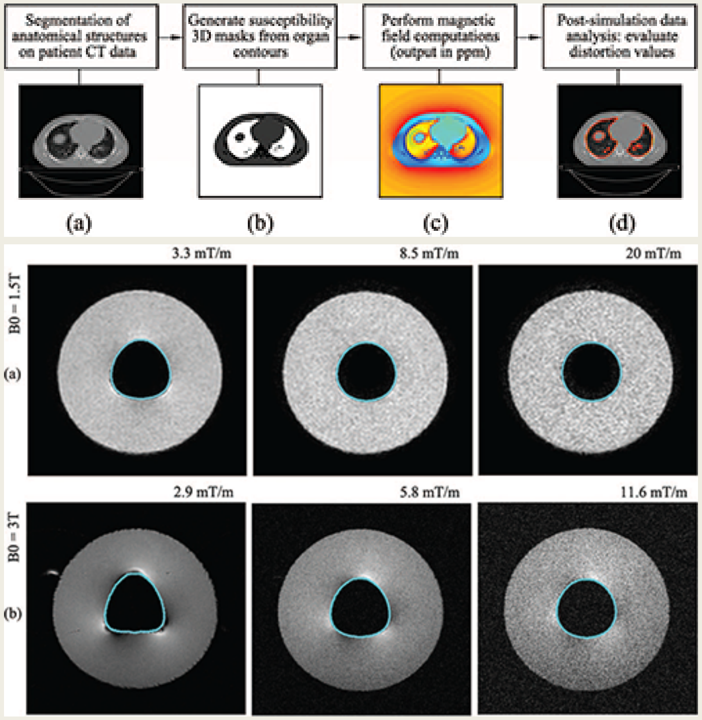


- Creates signal voids.
- Distorts MR images used for treatment planning.
- Becomes worse at longer TE values.
- Becomes worse with increasing B_o field strength.

MRI Distortion Management

- System-induced distortions
  - *B_o field inhomogeneities*
  - *Gradient nonlinearities*
- Patient-induced distortions
- Center prescribed imaging volume at magnet isocenter
- Correct distortion with vendor's 3D distortion correction algorithm
- For Superior-Inferior (axial scans) use step-and-shoot:

  - i.e. scanner couch is shifted so that the center of each segment aligned with the scanner isocenter.



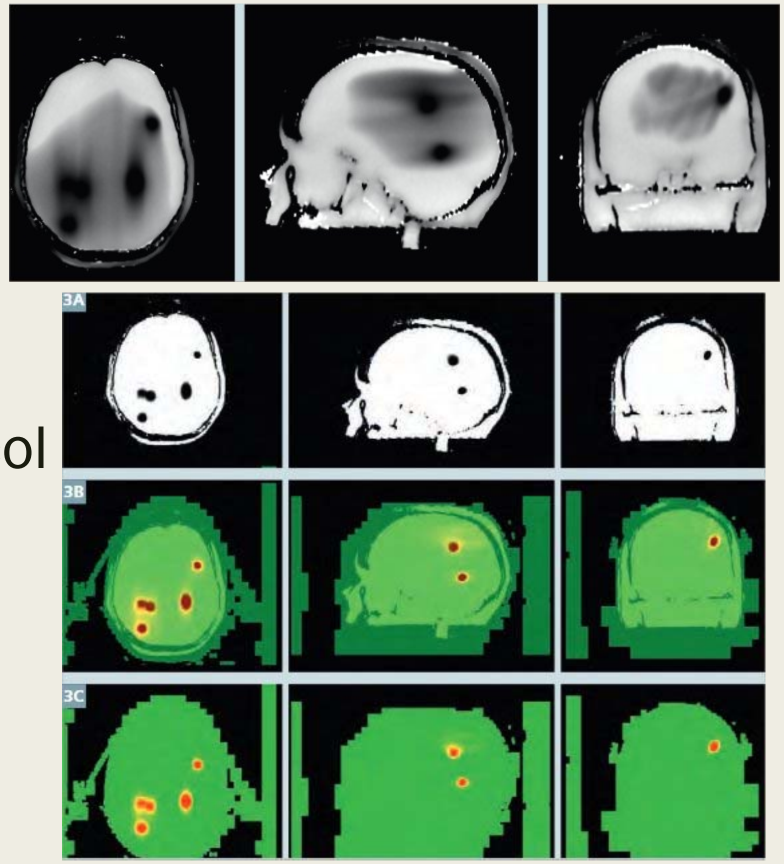
Stanescu et al. Med Phys 39(12), 7185-7193, 2012

The Problem with Quantitative MRI

- MRI signal intensity cannot be directly related to tissue density, electron density or other tissue parameters
- <u>Contrast in MR images is mainly dominated by the relaxation times, T1 and T2</u>.
- Therefore, using MRI for treatment planning is problematic.
- Special MR acquisition methods must be used.
- Then MRI gray scale values to Relative Electron Density with quantitative acquisition methods and careful calibration.

MRI-Based Dosimetry and Patient-Specific Plan Verification

- CT image data of patient’s head
- 3D Print patient-specific phantom
- Fill phantom’s cranial vault with Vinylpyrrolidone based polymer gel
- Perform complex radiation therapy protocol on phantom
- Take phantom to MRI, perform HASTE sequence
- Calculate T2-parametric map
- Rescale T2 values to dose

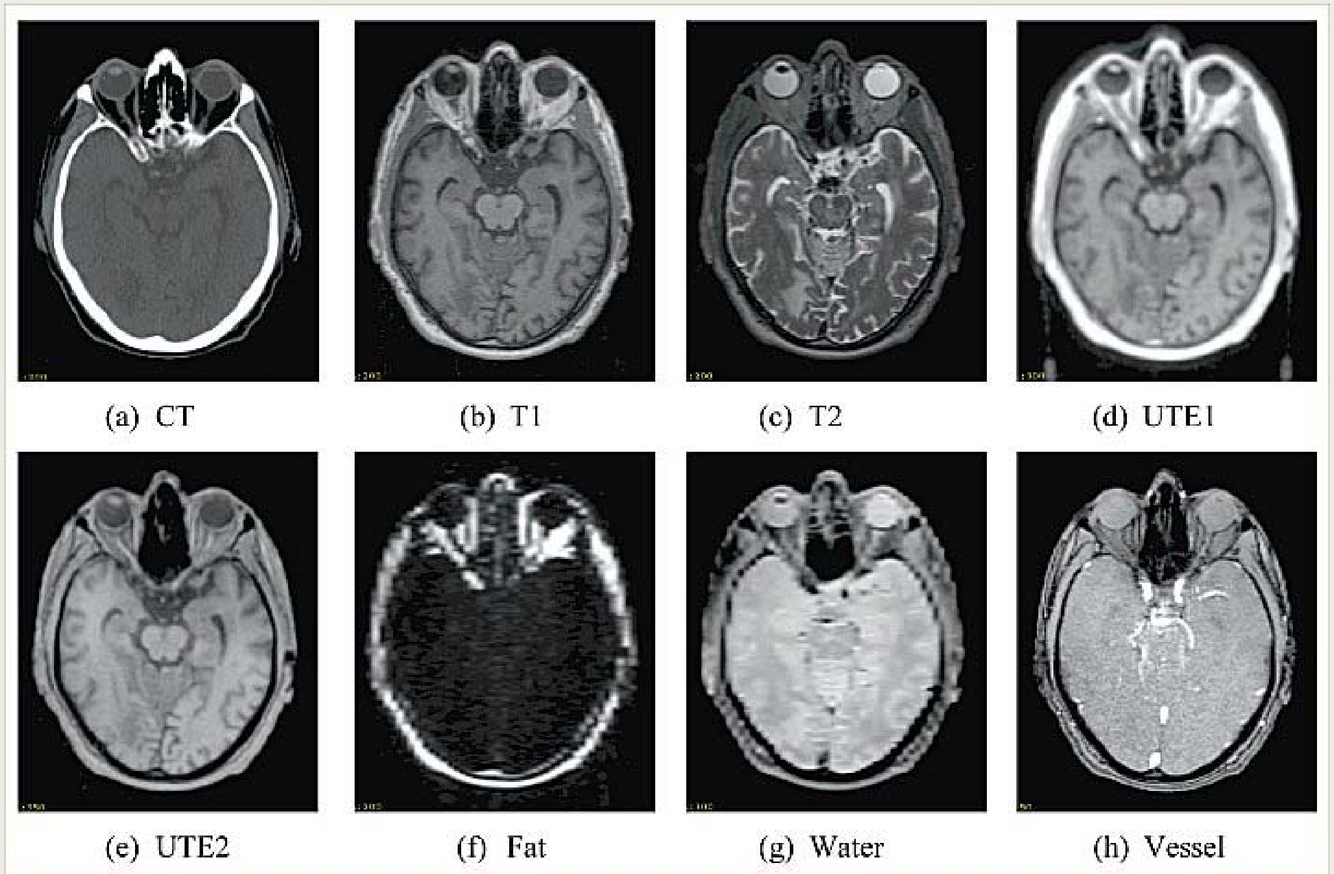


Synthetic CT by MRI

A. CT scan
B. T1-weighted MP-RAGE
C. T2-weighted 3D-FSE
D. UTE1: TE= 60 μs
E. UTE2: TE = 4460 μs

Double TE GRE

F. Dixon Fat image
G. Dixon H_2O image
H. 2D TOF MR angiography

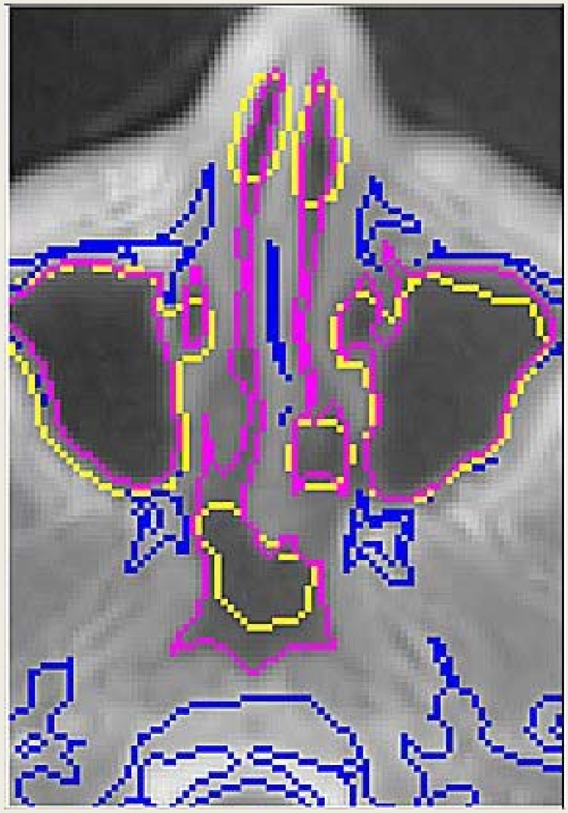


Hsu et al. Phys Med Biol. 2013 December 7; 58(23)

Synthetic CT by MRI

Typically, MR images are registered to CT images to transfer soft-tissue contrast information seen on MRI into the CT-based patient representation of Relative Electron Density for dose calculations used in treatment planning.

- Accurate geometry
- Accurate electron density
  - *Water/Fat quantitation with MRI*
  - *Ultra-Short TE (UTE) methods for imaging bone*



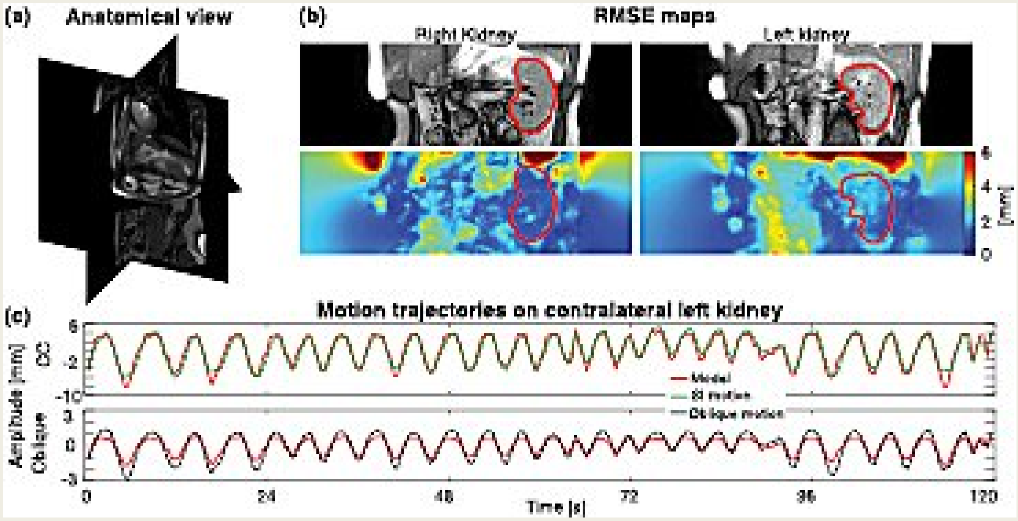
Hsu et al. Phys Med Biol. 2015

4D-MRI Technology

- MR can acquire an image in an arbitrary plane by changing the direction of magnetic field gradient
- Two non-coplanar image views provided critical motion characterization, because the most significant displacements are in the cranial-caudal direction
- Volumetric 4D MRI is practical with parallel acquisition using large RF coil arrays
- Up to 16-fold acceleration possible for a 32-channel system
- View-sharing, or TRICKS, further speeds acquisition

4D MRI and 4D Radiation Therapy

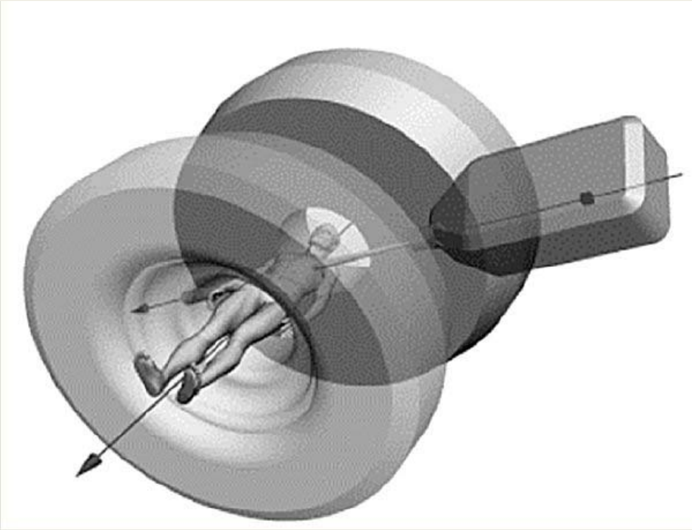
- Time information required for motion characterization in 4D volumetric imaging can be obtained using respiratory gating or motion tracking technique



Stemkens et al. Phys Med Biol, 61(14), 2016

- 4DRT aims to track and compensate for target motion during radiation treatment, minimizing normal tissue injury, especially critical structures adjacent to the target.
- 4DRT requires 4D imaging, 4D radiation treatment planning (4D RTP), and 4D radiation treatment delivery (4D RTD.

Online Targeting



Constantin *et al Med. Phys.* **38** *4174–85, 2011*

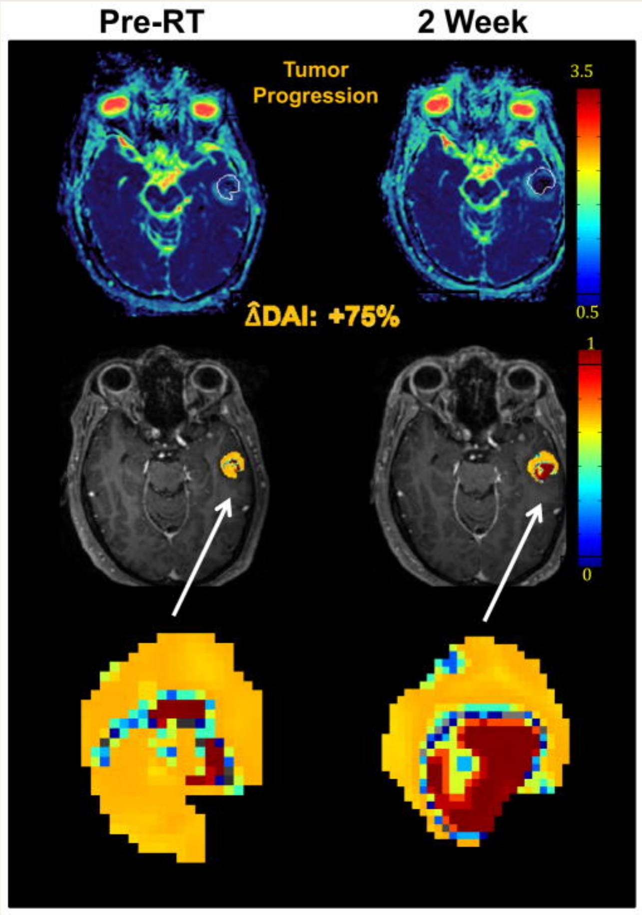
- Hybrid MRI-linac radiotherapy technology
- Allows direct target visualization for treatment guidance
- Allows patient set-up based on the actual position, shape and motion characteristics.
- Actual motion tracking during irradiation can be used for real-time treatment guidance and adaptation
- Can also record anatomical changes for dose reconstruction and dose accumulation

Treatment Response and Adaptations

- Diffusion Weighted MRI
  - *In a tumor with high cellularity, the motion of water molecules is more restricted.*
  - *Treatments result in increased ADC values due to cell swelling, tumor lysis and necrosis.*
- Dynamic Contrast-Enhanced (DCE) Perfusion Imaging
  - *Maps the distribution of tumor perfusion, blood volume, & mean transit time.*
  - *Have shown prognostic and predictive value for response of certain cancers to therapy.*

Diffusion Weighted Imaging (DWI)

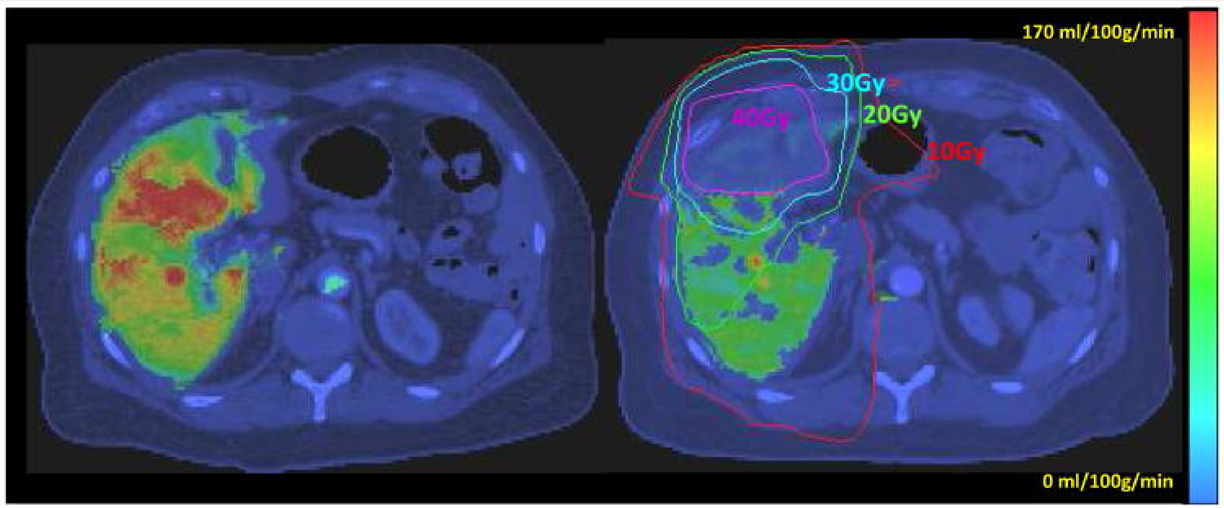
- DWI measures the mobility of cellular water in tissue without exogenous contrast agent.
- DWI improves RT treatment planning by characterizing tumor tissue properties required for tumor grading and target volume delineation.
- DWI is also a sensitive marker for alterations in tumor cellularity and could be used in the early assessment of RT treatment response.



Tsien et al. Semin Radiat Oncol. 2014 Jul; 24(3): 218–226

Dynamic Contrast-Enhanced Perfusion Imaging

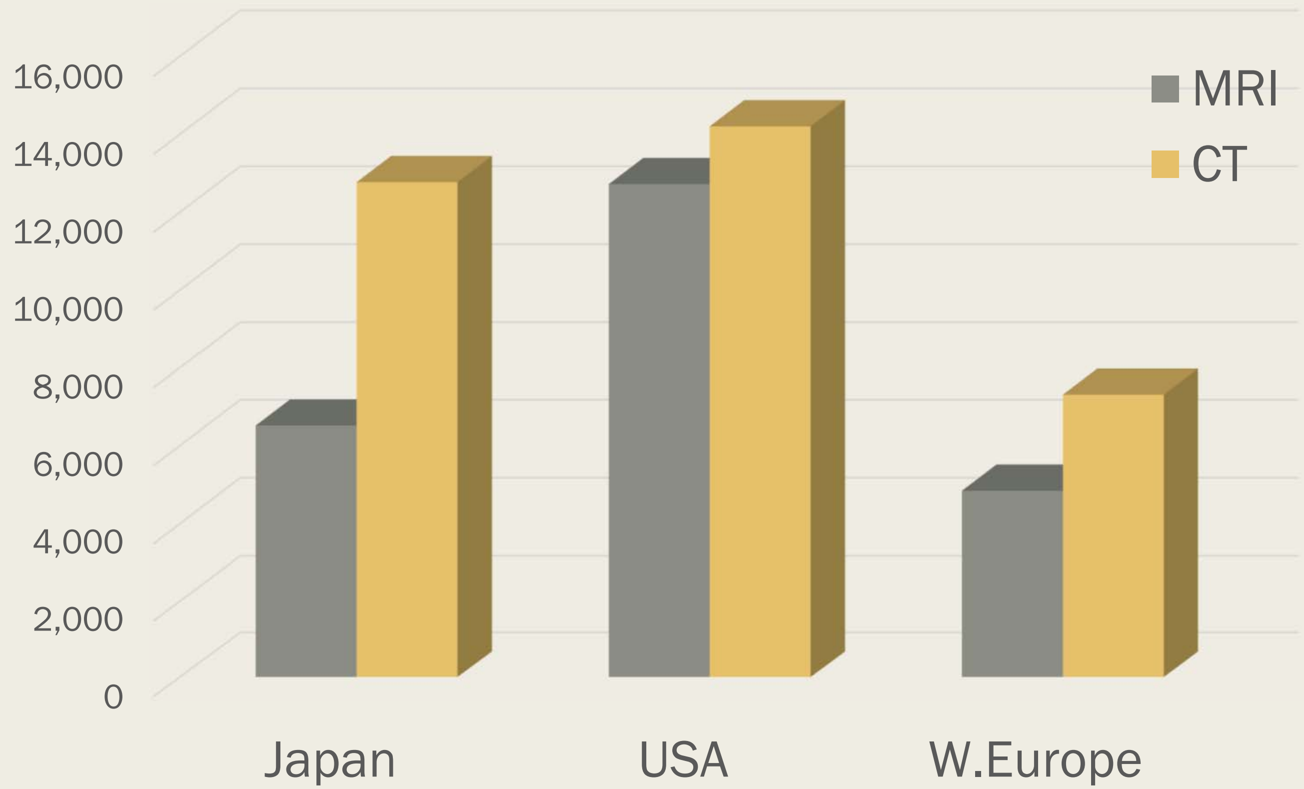
- T1 mapping can be employed to help convert dynamic changes in MRI signal into concentration-vs-time curves
- Validation will require standardization, reproducibility, accuracy and robustness assessments, as well as clinical validation of the sensitivity and specificity.



K_{trans} map shows changes in tumor permeability following RT.

Cao et al, Med. Phys. 34(2):604-612, 2007

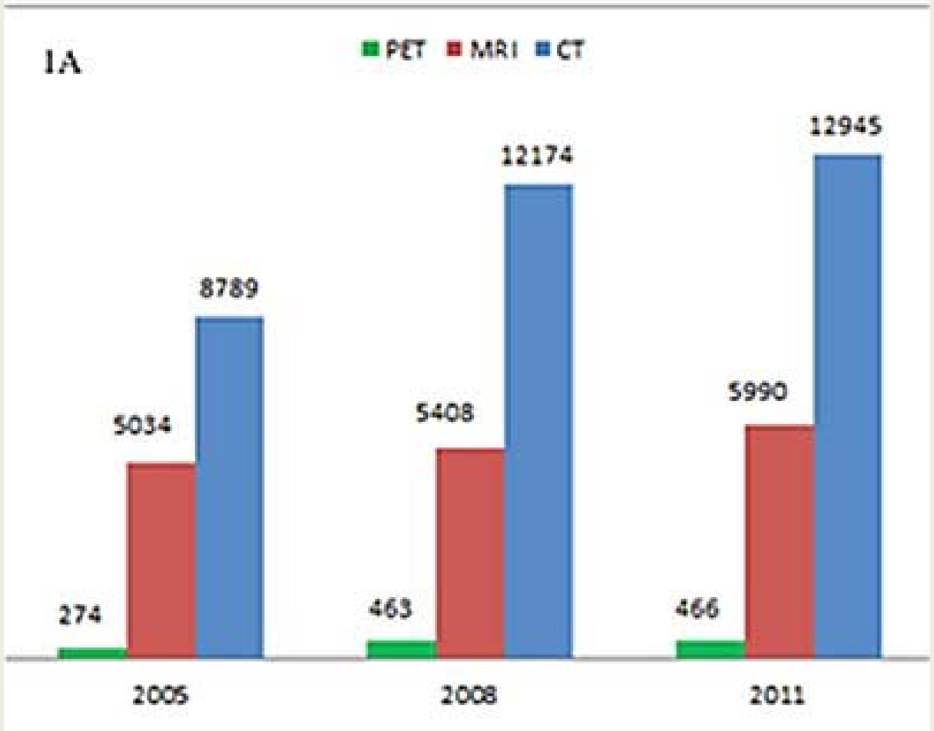
MRI and CT Systems by Region
(2015 or most recent)

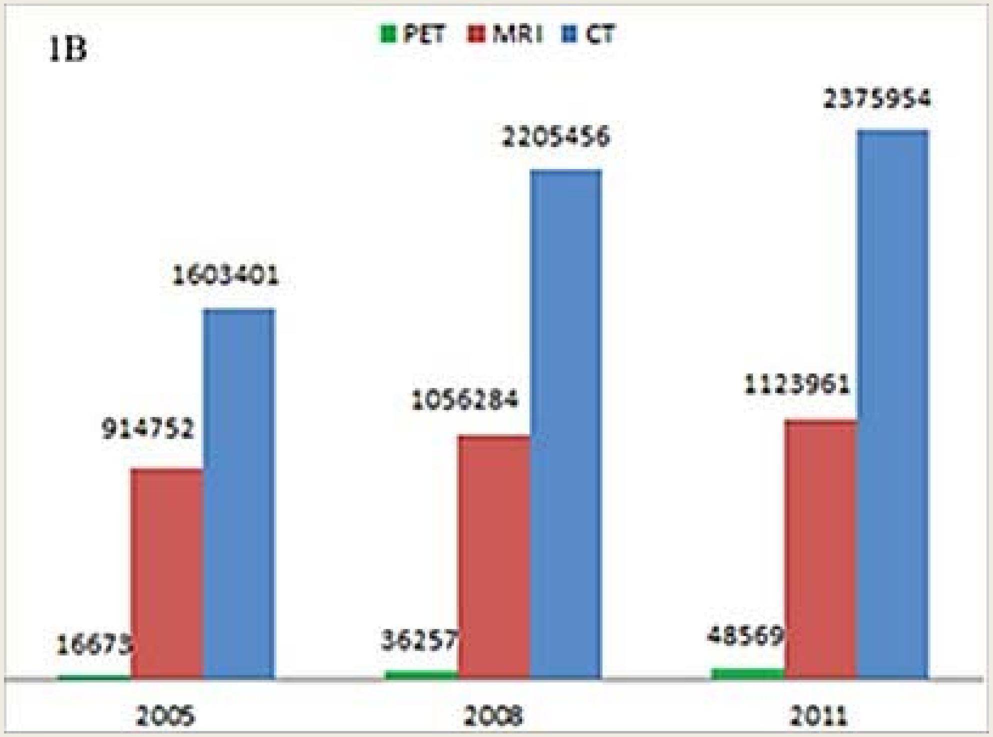


Source: OECD Health Statistics 2017 http://www.oecd.org/health/healthdata

JAPAN

Number of devices (1A) and utilizations (1B) of CT, MRI and PET.





Matsumoto M, Koike S, Kashima S, Awai K (2015) Geographic Distribution of CT, MRI and PET Devices in Japan: A Longitudinal Analysis Based on National Census Data. PLOS ONE 10(5): e0126036. https://doi.org/10.1371/journal.pone.0126036
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0126036

PLOS ONE TENTH ANNIVERSARY

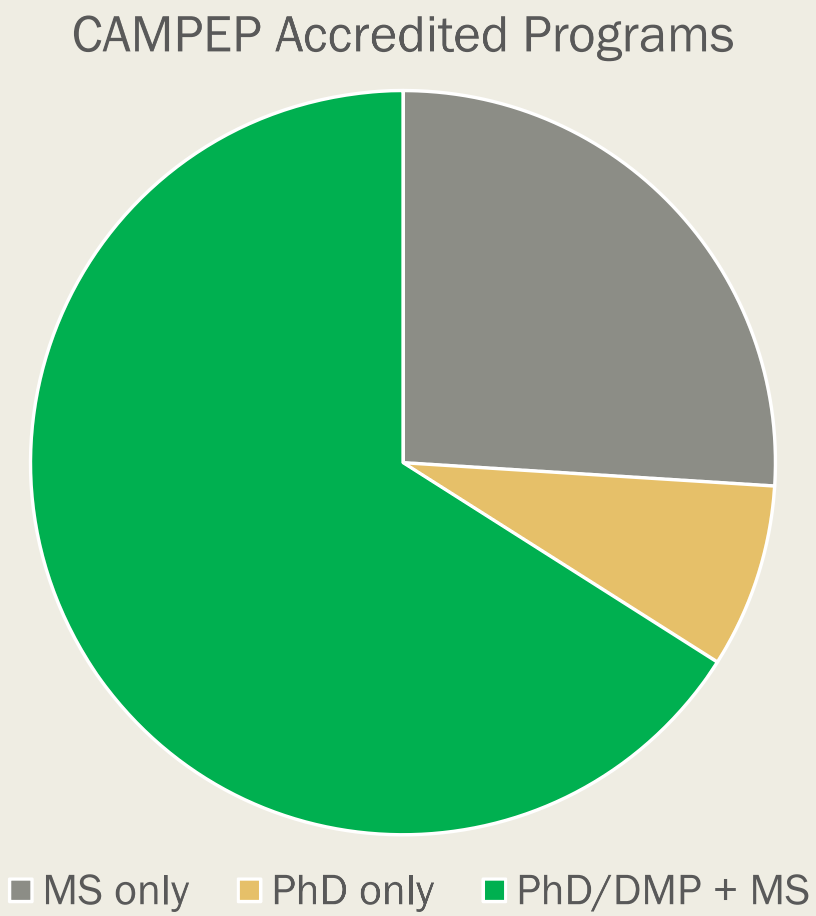
AAPM Qualified MRI Physicist

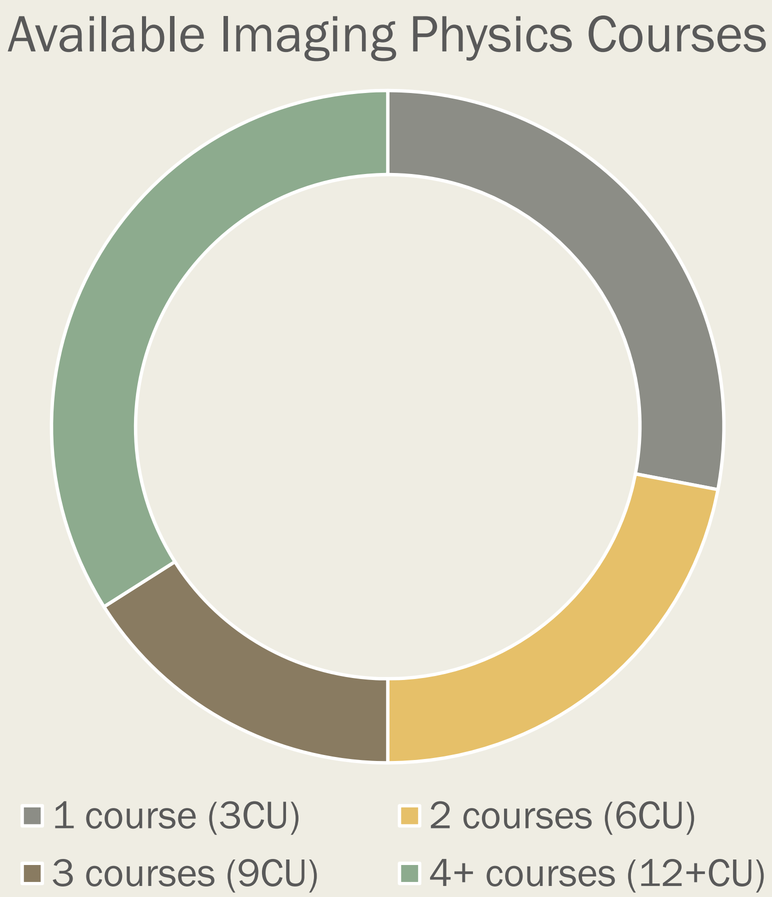
- AAPM only recognizes MRI Physics Qualifications in the context of being a Qualified Diagnostic Medical Physicist.
- Requires certification by:
  - *The American Board of Radiology; or*
  - *The American Board of Medical Physics (currently ABMP doesn't offer Diagnostic Medical Physics certification but already ABMP certified Diagnostic Medical Physicists can maintain certification); or*
  - *The Canadian College of Physicists in Medicine.*

ACR Qualified MRI Physicist/Scientist

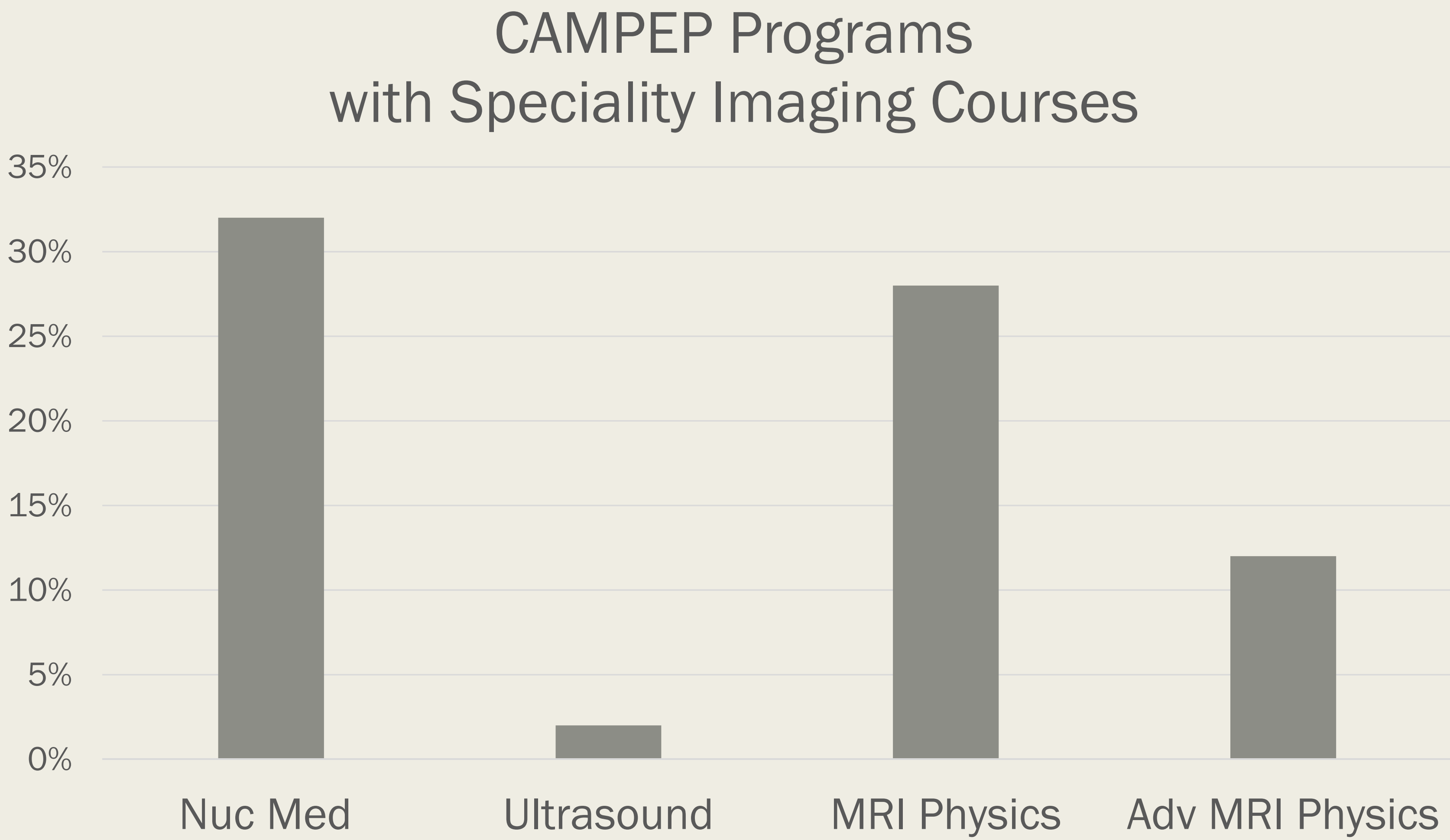
Qualifications	Medical Physicist	MR Scientist
Initial	• Diagnostic Physics by ABR • Imaging Physics or MRI Physics by ABMP • Imaging Physics or MRI Physics by CCPM	• Graduate degree in a physical science involving NMR or MRI • 3 years of experience in clinical MRI
Continuing Experience	Upon renewal, 2 MRI unit surveys in prior 24 months	
Continuing Education	15 CEU/CME (1/2 Cat 1) in prior 36 months (includes credits pertinent to the accredited modality)	

Training in MRI Physics





Available Specialty Imaging Training



Where to Gain MRI Experience

- OJT in Clinical MRI Simulation & Treatment Planning in RT Dept.
- OJT in QC & Protocol Development in Radiology Dept.
- Project Participation at MRI Research Centers
- Medical Physics Residency Programs

ABMP MRI Physics Qualifications

- The applicant must possess a graduate degree in Physics, Medical Physics, or other appropriate and related field, from an accredited university.
- A minimum of two years full time equivalent comprehensive patient related experience in MRI physics under supervision of board-certified medical physicist (can be in residency program)
- Two letters, attesting that the candidate meets the experience requirements (1 physicist, 1 physician)
- Note: Degree from CAMPEP-accredited program not required
- Note: No CAMPEP-accredited residency program required

CCPM MRI Physics Certification

- Possess a Masters or Doctoral degree from an accredited university or college in Medical Physics, Physics, Science with Physics as a major option, Engineering or Applied Mathematics.
- A minimum of two years full time equivalent comprehensive patient related experience in MRI physics following the qualifying degree
- Three letters, attesting that the candidate meets the experience requirements (2 physicist, 1 physician)
- Note: Degree from CAMPEP-accredited program not required
- Note: No CAMPEP-accredited residency program required

ABMP and CCPM Exam Processes

	ABMP	CCPM
Written	Part 1: general medical physics *OR* MRI science (MC)	Part 1: general medical physics, anatomy/biology (MC, matching)
		Part 2: MRI safety (MC/short answer)
Written	Part 2: MRI Physics (MC)	Part 3: MRI physics (essay)
		Part 4: Imaging physics (essay)
Oral	Seven questions on areas of competency (next slide)	instrumentation, clinical applications, specialty knowledge & techniques.

MC = multiple choice

ABMP MRI Physics Exam

Anyone who has passed ABR Part 1 (General Medical Physics Exam) can skip Part1 of ABMP Exam and proceed directly to Part II – written MRI Physics Exam

ABMP MRI Physics Accreditation

General Education/Experience Requirements:

1. Basic Physics of Nuclear Magnetic Resonance
2. Magnetic Resonance Imaging Theory and Reconstruction
3. MR Image Characteristics and Artifacts
4. Advanced MR Imaging Techniques & System Features
5. Contrast, MR Angiography & Cardiac MRI
6. MR Technology and Equipment Quality Control
7. Site Planning and Safety of MR Studies

MRI Expertise for RT Tasks

COMPETENCY/ TASK	DISTORTION CORRECTION	SYNTHETIC CT	ONLINE TARGETING	4D MRI	TREATMENT RESPONSE
Basic NMR Physics	X	X	X	X	X
MR Image Formation	X	X	X	X	X
MR Artifacts	X	X	X	X	X
Advanced MRI Methods		X	X	X	X
Contrast Agents, MRA & Cardiac MRI		X	X	X	X
MRI Technology & Quality Control	X	X	X	X	X
MRI Safety and Site Management	X	X	X	X	X

Summary

- MRI can provide exceptional image data for use in multiple phases of radiation cancer therapy
- However, the use of MRI in RT requires a high degree of competence and understanding of sophisticated MRI methods and procedures.
- Programs are in place for professional credentialing (certification) in MRI Physics however,
  - *"MRI Physicist" is not a specialty recognized by the AAPM and prescribes no special competencies for undertaking MRI physics*
  - *MRI physics specific courses are not required in CAMPEP-accredited graduate programs*

Summary

- Despite plenty of MRI systems across the developed world, there are limited opportunities for medical physicists to gain hands-on, practical experience in MRI
- If these issues are not addressed, there will be a shortage of qualified medical MRI physicists to accommodate future needs for technical expertise in MRI for radiation therapy

Fin