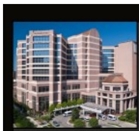
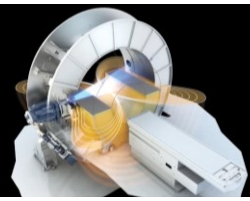


Clinical Implementation of an MR-Guided Treatment Unit

Geoffrey S. Ibbott, Ph.D.

AAPM, August 2, 2017



THE UNIVERSITY OF TEXAS
MD Anderson Cancer Center
Making Cancer History

Disclosures

My institution holds Research Agreements with Varian, Elekta, Philips and Sun Nuclear

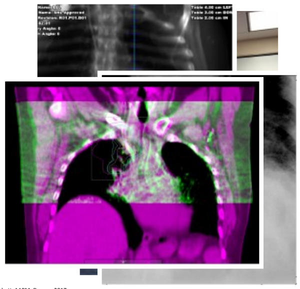
I will be discussing devices that are not currently available for sale, and that do not have FDA clearance.

Objectives

- Review the current status of IGRT
- Review developments leading to MR-based simulation and planning, and MR image-guided radiation therapy
- Briefly describe patient imaging and treatment procedures possible with an MR-guided linac
- Discuss dosimetry issues in the presence of magnetic fields
- Present commissioning data for the Elekta MR-Linac
- Describe experience with use of commercial QA devices

Current Status of IGRT

- kV imaging widely used but relies on bony landmarks or fiducials
- CBCT IGRT has transformed RT practice and perception. Its potential may not have been fully exploited
- However, two issues remain …
- Adequate soft tissue visualization
  - particularly in abdomen and pelvic anatomy
- Intrafraction motion
  - Long acquisition time of CBCT largely limits it to pre-treatment or periodic imaging



G. Ibbott, AAPM, Denver, 2017

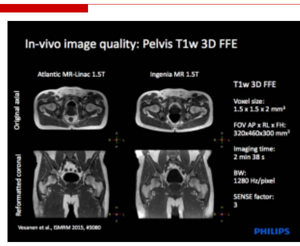
Clinical benefits of MR-IGRT

Soft-tissue visualization
- Difficult-to-image targets and critical structures become 'easy'
- Improved ability to adapt treatment
- Ability to see the tumor not just the organ - GTV boost

Real-time 2D and 3D imaging
- Imaging simultaneous with irradiation
- Gating and tracking without surrogates

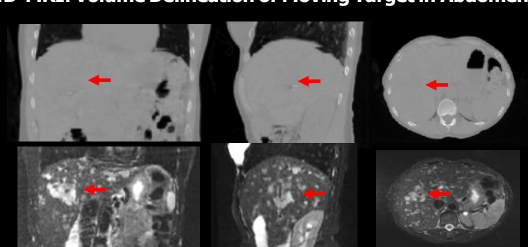
No imaging dose
- Freedom to image at any time

Quantitative imaging
- Tumor treatment response assessment (inter- and intra-fractions)



G. Ibbott, AAPM, Denver, 2017

4D-MRI: Volume Delineation of Moving Target in Abdomen



G. Ibbott, AAPM, Denver, 2017

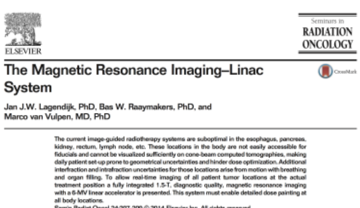
Courtesy of Jing Cai, PhD

6

What are the benefits of MR-Image Guided Radiation Therapy?

A. Imaging can be performed during treatment
B. Better soft tissue contrast than diagnostic CT
C. Able to stop motion better than CBCT imaging
D. Images can be manipulated to provide density data for heterogeneity corrections
E. All of the above

Answer: E. All of the above


ELSEVIER

Seminars in RADIATION ONCOLOGY

The Magnetic Resonance Imaging–Linac System

Jan J.W. Lagendijk, PhD, Bas W. Raaymakers, PhD, and Marco van Vulpen, MD, PhD

The current image-guided radiotherapy systems are suboptimal in the esophagus, pancreas, kidney, rectum, lymph node, etc. These locations in the body are not easily accessible for fiducials and cannot be visualized sufficiently on cone-beam computed tomographies, making daily patient set-up prone to geometrical uncertainties and hinder dose optimization. Additional interfraction and intrafraction uncertainties for those locations arise from motion with breathing and organ filling. To allow real-time imaging of all patient tumor locations at the actual treatment position a fully integrated 1.5-T, diagnostic quality, magnetic resonance imaging with a 6-MV linear accelerator is presented. This system must enable detailed dose painting at all body locations.
Semin Radiat Oncol 24:207-209 © 2014 Elsevier Inc. All rights reserved.

Lagendijk JJW, Raaymakers BW, van Vulpen M. The Magnetic Resonance Imaging–Linac System. Semin Radiat Oncol. 2014 Jul;24(3):207–9.

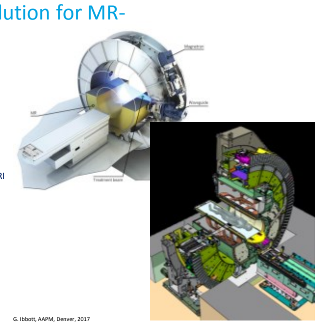
Philips/Elekta Solution for MR-IGRT

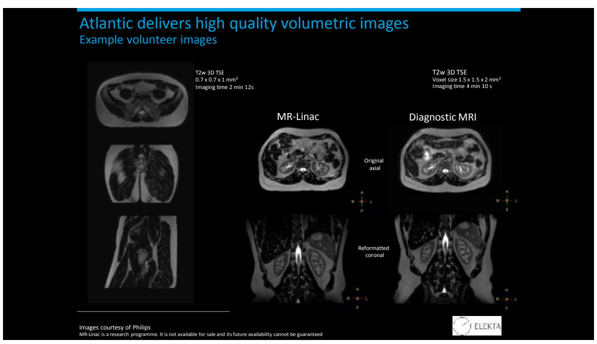
Purpose

Treat the patient while simultaneously imaging with a 'conventional' 1.5T diagnostic MRI

How

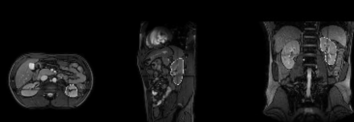
1. Mount the Linac on a rotatable gantry around the MRI magnet
   The radiation isocenter is at the centre of the MRI imaging volume
2. Modify the Linac to make it compatible with the MR environment
3. Modify the MRI system
   Minimize material in the beam path
   Minimize magnetic field at the Linac





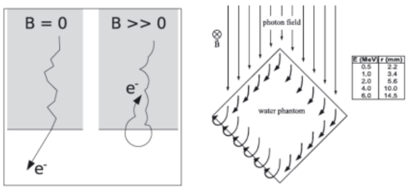
Atlantic can image and detect the target in real time simultaneous with irradiation

- Localization results for Kidney
- Alternating axial, coronal and sagittal slices
- Acquired and processed in 200 ms



MR-Linac is a research programme. It is not available for sale and its future availability cannot be guaranteed

Influence of Magnetic Fields: Electron Return Effect



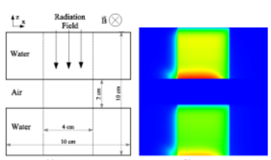
Meijsing et al. PMB 54 (2009) p2993

13

G. Ibbott, AAPM, Denver, 2017

Electron Return Effect

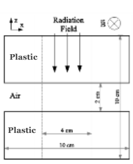
- Simulation (GEANT4)



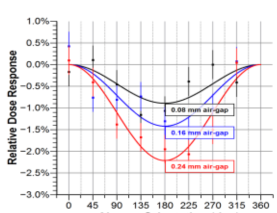
G. Ibbott, AAPM, Denver, 2017

Raaijmakers et al. (2005)

Small Air Gaps



Cannot avoid small air gaps in plastic phantoms

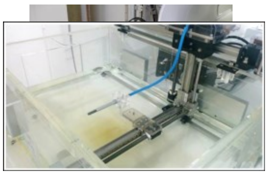


O'Brien et al. PMB (2015)

G. Ibbott, AAPM, Denver, 2017

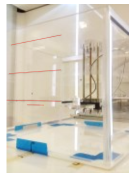
Setup of water tank on couch

Elekta commissioning tank



MDA calibration tank

- Marks on tank
  - d_{20}
  - d_{10}
  - d_{max}
  - Isocenter height
- Ion chamber at isocenter



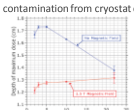
Work contributed by Elekta and Daniel O'Brien 16

See AAPM presentation: **TU-FG-205-7**
O'Brien et al. Tuesday 2:45 pm
"Dose Measurements" Session

Output measurements

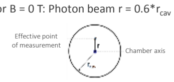
d_{max} vs field size

- For B = 0 T:
  - Differences with increasing field size
  - e^- contamination from cryostat noticeable**
- For B = 1.5 T:
  - d_{max} more constant with increasing field size
  - e^- contamination from cryostat diminished**

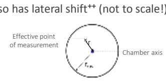


Effective point of measurement for cylindrical ion chamber

- For B = 0 T: Photon beam r = 0.6*r_{cav}



- For B = 1.5 T: offset is cut in about half but also has lateral shift** (not to scale!)



** Data submitted for publication

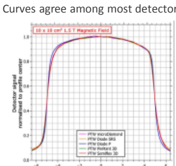
Work contributed by Daniel O'Brien 17

See AAPM presentation: **TU-FG-205-7**
O'Brien et al. Tuesday 2:45 pm
"Dose Measurements" Session

Profiles

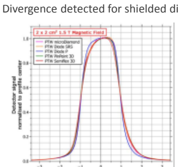
10 x 10 cm^2:

- Lateral shift removed for comparison
- Curves agree among most detectors**



2x2 cm^2:

- Lateral shift removed for comparison
- Divergence detected for shielded diode**

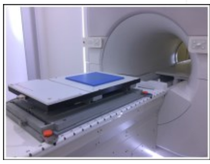


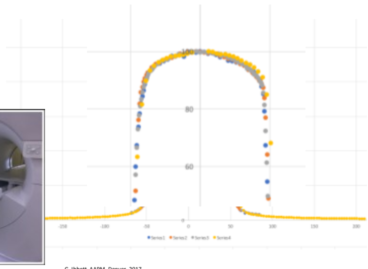
** Data submitted for publication

Work contributed by Daniel O'Brien 18

Measurements of beam profile

- Plastic scintillator
- Diode
- microDiamond
- Ion chamber array

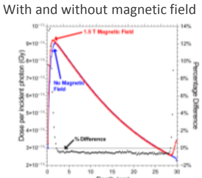




See AAPM presentation: **TU-FG-205-7**
O'Brien et al. Tuesday 2:45 pm
"Dose Measurements" Session

Percent Depth Dose

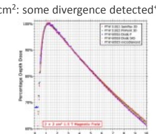
With and without magnetic field



O'Brien et. al (2016) Med. Phys., 43

Percent Depth Dose

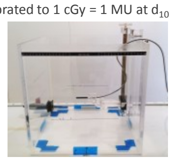
- Need correction for effective point of measurement**
- 10 x 10 cm^2: curves agree among most detectors**
- 2x2 cm^2: some divergence detected**



Calibration – TRS398

Standard Imaging MR-compatible Exradin A1SLMR ion chamber in water tank (B = 1.5 T)

Calibrated to 1 cGy = 1 MU at d_{10}



Which of the following dosimetry systems and conditions is likely to be most affected by the Electron Return Effect in an MR-Linac?

A. Polymer gel dosimeter immersed in a water phantom
B. Diode detector embedded in plastic matrix
C. Optically-stimulated luminescence detector (OSLD) sandwiched in bolus material
D. Ionization chamber in water-equivalent plastic phantom

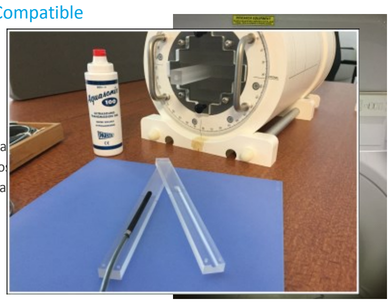
Answer: D. Ionization chamber in water-equivalent plastic phantom

Reference dosimetry in magnetic fields: formalism and ionization chamber correction factors

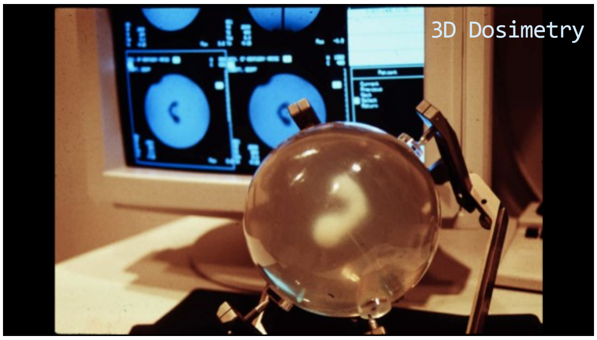
D. J. O'Brien[a]
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030
D. A. Roberts
Elekta Limited, Crawley, West Sussex RH10 9RR, United Kingdom
G. S. Ibbott
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030
G. O. Sawakuchi[b]
Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030 and Graduate School of Biomedical Sciences, The University of Texas, Houston, Texas 77030

O'Brien DJ, Roberts DA, Ibbott GS, Sawakuchi GO. Reference dosimetry in magnetic fields: formalism and ionization chamber correction factors. Med Phys.; 2016 Aug;43(8):4915–27.

Initial Testing of MR-Compatible ArcCheck QA Device

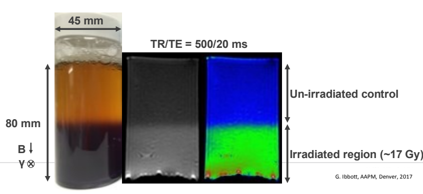


- Power supply moved awa
- Must use MV beam to po
- Must calibrate in MR Lina

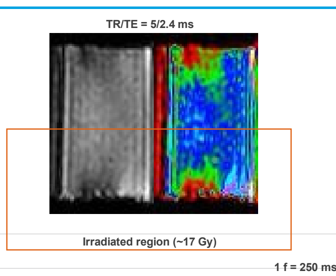


MR Imaging of Irradiated Gel

- Irradiated dosimeter with un-irradiated region shown below with T_1-weighted MR images in gray and RGB scale

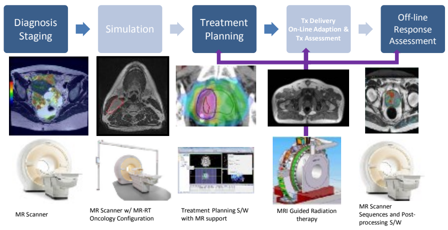


Change in irradiated region during beam-on can be seen with T_1-T2-weighted balanced-Fast Field Echo (b-FFE) MR images



MRI's role is growing in Radiation Oncology

Expansion to Treatment Time imaging



MR Images courtesy of Philips

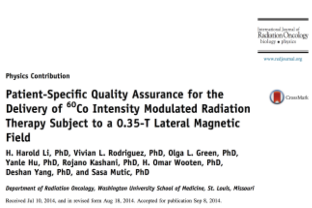
G. Ibbott, AAPM, Denver, 2017

What precaution is required to use a diode array QA device with an MR-Linac?

A. The device must be wrapped in aluminum foil
B. The device must be immersed in a water phantom to eliminate air gaps
C. The power supply must be moved out of the high-strength magnetic field
D. The signal cable must be grounded externally

G. Ibbott, AAPM, Denver, 2017

Answer: C. The power supply must be moved out of the high-strength magnetic field


International Journal of Radiation Oncology biology • physics

www.redjournal.org

Physics Contribution

Patient-Specific Quality Assurance for the Delivery of ^{60}Co Intensity Modulated Radiation Therapy Subject to a 0.35-T Lateral Magnetic Field

H. Harold Li, PhD, Vivian L. Rodriguez, PhD, Olga L. Green, PhD, Yanle Hu, PhD, Rojano Kashani, PhD, H. Omar Wooten, PhD, Deshan Yang, PhD, and Sasa Mutic, PhD

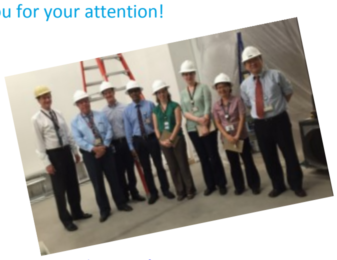
Department of Radiation Oncology, Washington University School of Medicine, St. Louis, Missouri

Received Jul 10, 2014, and in revised form Aug 18, 2014. Accepted for publication Sep 8, 2014.

Li HH, Rodriguez VL, Green OL, Hu Y, Kashani R, Wooten HO, et al. Patient-specific quality assurance for the delivery of (60)Co intensity modulated radiation therapy subject to a 0.35-T lateral magnetic field. International journal of radiation oncology, biology, physics. 2015 Jan 1;91(1):65–72.

G. Ibbott, AAPM, Denver, 2017

Thank you for your attention!



Thanks to:
Hannah Lee, Yvonne Roed, Diane Choi, Ryan Lafratta, Mitchell Carroll, Mamdooh Alqathami, Jihong Wang