UMC Utrecht

MRI guided radiotherapy: See while you treat

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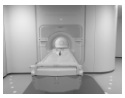
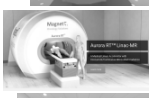
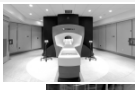
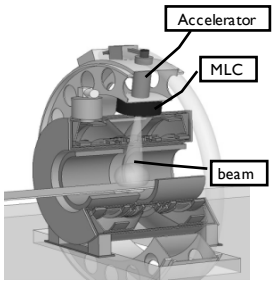
Active developments MRI guided radiotherapy systems

- Utrecht, The Netherlands
  - 1.5 T MRI, 6 MV linac
  - www.elekta.com/mr-linac
- Edmonton, Canada
  - 0.5 T MRI, 6 MV linac
  - www.magnettx.com
- Viewray, Cleveland, USA
  - 0.35 T MRI, 3 Co sources
  - Clinical since 2014
  - www.viewray.com
- Australia MR linac project, Sydney
  - 1.0 T MRI, 6 MV linac
  - www.sydney.edu.au

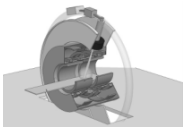




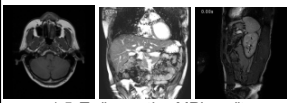

Concept of MRI accelerator



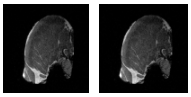
- Simultaneous MRI and irradiation
- Technical issues
  - Magnetic interference
  - Beam absorption
  - RF interference

1.5 T MRI accelerator: Simultaneous beam on and MRI


Artist impression


1.5 T diagnostic MRI quality


First prototype MRI accelerator


No impact of beam on MRI

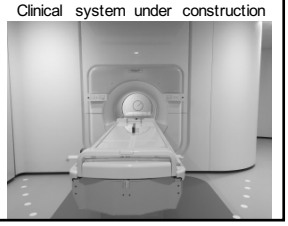
1st, 2nd, 3rd and 4th generation MR linac: from proof of concept to clinical system


Proof of concept simultaneous MRI and irradiation

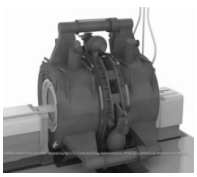

Rotating gantry and MLC


Pre-clinical prototype

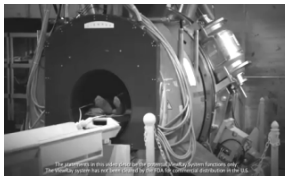
Clinical system under construction



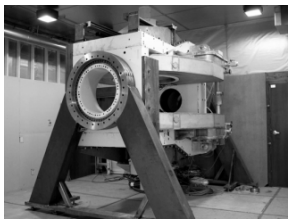
Viewray MRIdian: 3X ^{60}Co + 0.35T magnet



3 ^{60}Co sources
0.35 T superconducting MRI
Siemens MRI back-end
Treated first patient in february 2014
www.viewray.com

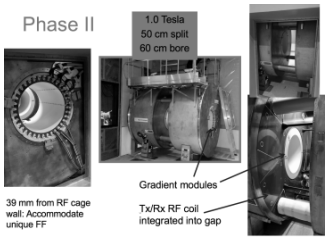


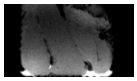
Edmonton project 6 MV linac and 0.5 T MRI



Fallone et al. from Edmonton, CA
6 MV linac + 0.5 T high temperature superconducting magnet
60cm gap
Operational since dec 2008
See www.linac-mr.ca or www.magnettx.com

Australian MRI linac project, 6 MV linac and 1.0 T MRI





1.0T split MRI and Inline linac under construction
60cm bore, 50 cm gap
Prototype with diagnostic 1.5T Siemens
Pictures courtesy Gary Liney, Paul Keall

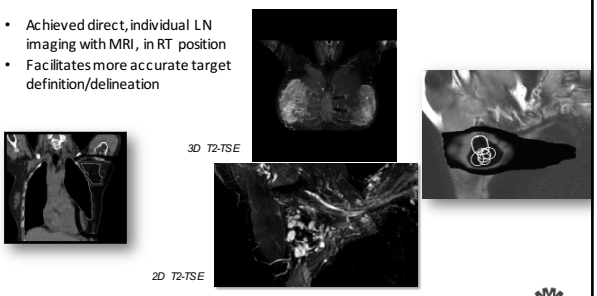
http://sydney.edu.au/medicine/radiation-physics/research-projects/MRI-linac-program.php

MRI radiotherapy system: design choices

- Accelerator or Cobalt
  - RT performance versus RF interference
  - Viewray announced Linac based system
    - (Viewray press release March 14th, 2016)
- Open or closed magnet
  - Scatter versus MRI performance
- B_0 field strength/orientation
  - MRI performance (SNR)
  - Radiotherapy performance (Impact on dose)

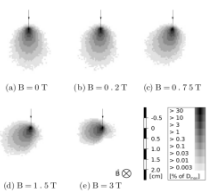
MRI can open new opportunities: E.g. lymph node imaging for breast radiotherapy

- Achieved direct, individual LN imaging with MRI, in RT position
- Facilitates more accurate target definition/delineation



Van Heijst et al.

Beam perpendicular or parallel with magnetic field



Dose deposition perpendicular to B field
6MV photons in water
0, 0.2, 0.75, 1.5 and 3T magnetic field
(from Raaijmakers et al., 2008)

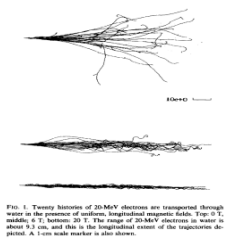
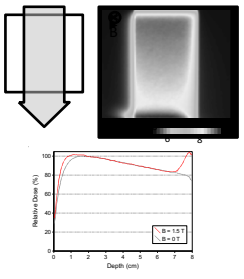
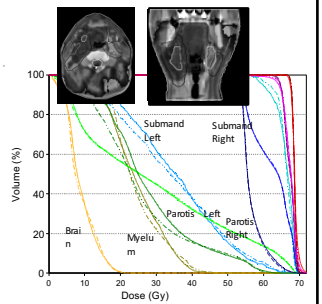


FIG. 1. Twenty histories of 20-MeV electrons are transported through water in the presence of uniform, longitudinal magnetic fields. Top: 0 T, middle: 0.7 T, bottom: 20 T. The range of 20-MeV electrons in water is about 9.3 cm, and this is the longitudinal extent of the trajectories depicted. A 1-cm scale marker is also shown.

Dose deposition parallel to B field
20 MeV electrons in water
0, 6 and 20T magnetic field
(from Bielajew, 1993)

Dose deposition perpendicular to a magnetic field

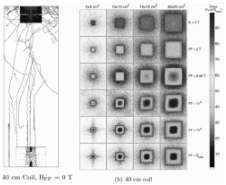




Electron Return Effect (ERE) at tissue-air interfaces due to Lorentz force. From Raaijmakers et al., 2005

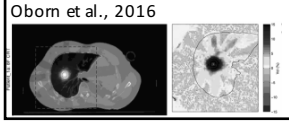
IMRT with inclusion of B field yield **similar plans as 0T**. From Raaijmakers et al., 2007

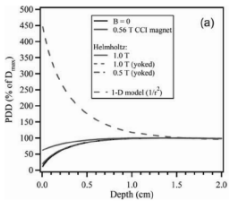
Dose deposition parallel to a magnetic field



Increased surface dose from ionisations in air column. From Oborn et., 2012

Can be exploited for lung tumours, Oborn et al., 2016

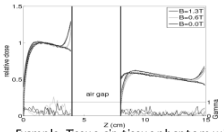




Depends on magnetic fringe field from Keyvanloo et al., 2012

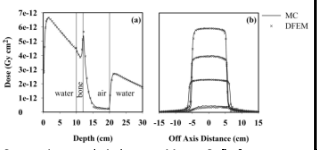
IMRT in B fields is well feasible, dose calculations need to include impact from magnetic fields

- Monte Carlo based dose engines
  - Viewray
  - Elekta



Example Tissue-air-Tissue phantom with GPUMCD from Hissoiny et al., 2011

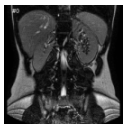
- Analytical method
  - St Aubin et al., 2016
  - Boltzman transport equation with magnetic field



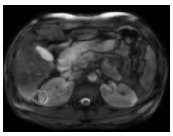
Comparison analytical versus Monte Carlo for water-bone-air-water phantom, from St Aubin et al., 2016

Summary

- Hybrid MRI radiotherapy systems are (getting) in the clinic



- Different systems, all have same goal: "**See-while-you-treat**"
- Also opens new tumor sites for radiotherapy
  - e.g. Non-invasive GTV ablation in kidney
- MRI can provide the real 4D anatomy
  - Daily, few seconds, real-time
  - During beam delivery



- On-line and ultimately real-time plan adaptation
- Start simple, learn and prepare real-time procedures (e.g. QA)