MRI-guided Radiation Therapy

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Assistant Professor, Radiation Oncology, University of Toronto
Affiliated Faculty, Guided Therapeutics, Techna Institute, UHN

Radiation Oncology UNIVERSITY OF TORONTO | TECHNA | UHN Princess Margaret Cancer Centre

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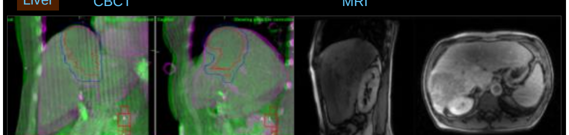
Introduction

MRI-guided radiotherapy

MRI
- best for RTP target delineation, tissue characterization
- excellent soft tissue contrast compared to x-ray imaging (CT/CBCT)
- fast imaging techniques
- multiplanar acquisition

Liver CBCT MRI



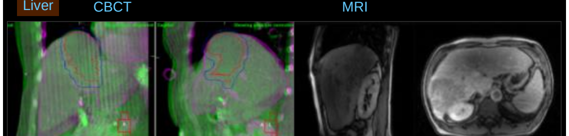
Introduction

MRI-guided radiotherapy

In-room MRI for setup verification | quantify organ motion

Applications:
- liver, pancreas, kidney, prostate, paraspinal, etc.
- SBRT, dose escalation, ↑ target control
- adaptive RT planning (ART)

Liver CBCT MRI



MRIgRT

MR-Linac system integration for MRgRT

MRIgRT

MRI guided RT systems

/ challenge 1 Radiofrequency (RF) interference b/w linac & MR

/ challenge 2 Magnetic field mutual interaction: MR magnet & Linac

/ challenge 3 Dose deposition effects in MR's magnetic field

/ challenge 4 Skin dose effects in MR's magnetic field

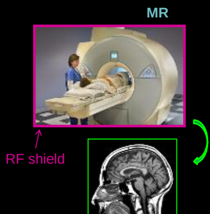
MRIgRT

/ challenge 1

MR-linac systems

1. Radiofrequency (RF) interference

- MR needs to be isolated | Collects weak signal from patient
- Linac is a significant source of RF



MRIgRT

/ challenge 1

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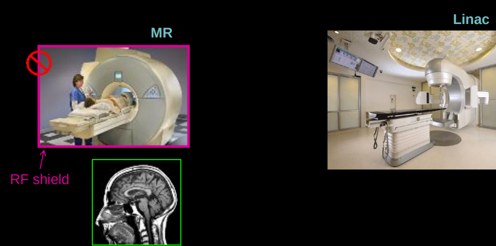

MRIgRT

/ challenge 1

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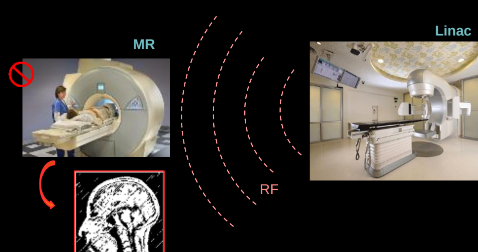


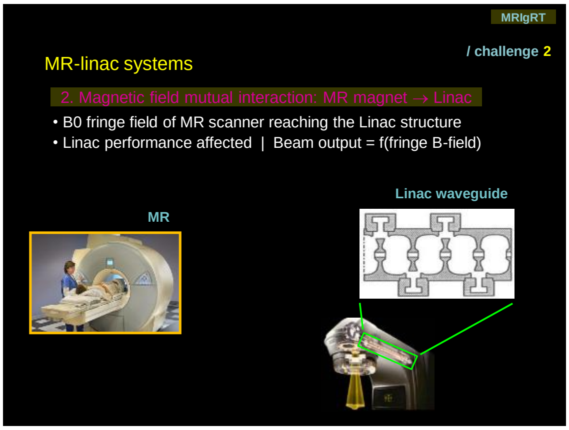
MRIgRT

/ challenge 2

MR-linac systems

2. Magnetic field mutual interaction: MR magnet → Linac

- B0 fringe field of MR scanner reaching the Linac structure
- Linac performance affected | Beam output = f(fringe B-field)


MRIgRT
/ challenge 2
MR-linac systems
2. Magnetic field mutual interaction: MR magnet → Linac
• B0 fringe field of MR scanner reaching the Linac structure
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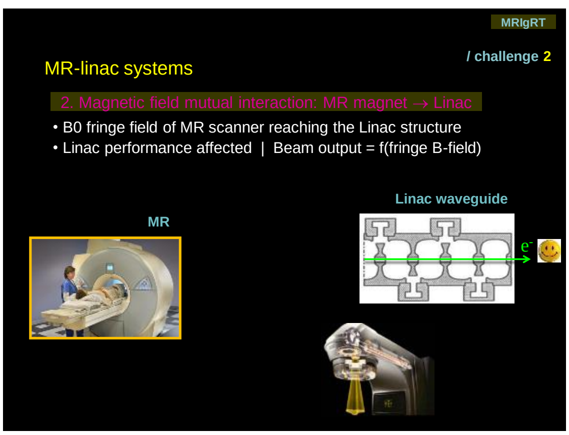
Linac waveguide
MR


MRIgRT
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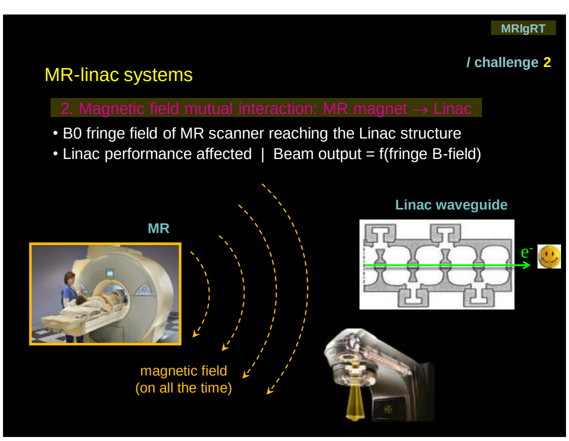
Linac waveguide
MR
e^-


MRIgRT
/ challenge 2
MR-linac systems
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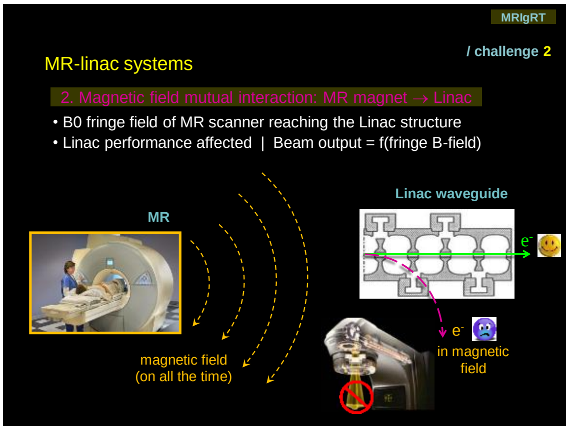
Linac waveguide
MR
e^-
magnetic field
(on all the time)


MRIgRT
/ challenge 2
MR-linac systems
2. Magnetic field mutual interaction: MR magnet → Linac
• B0 fringe field of MR scanner reaching the Linac structure
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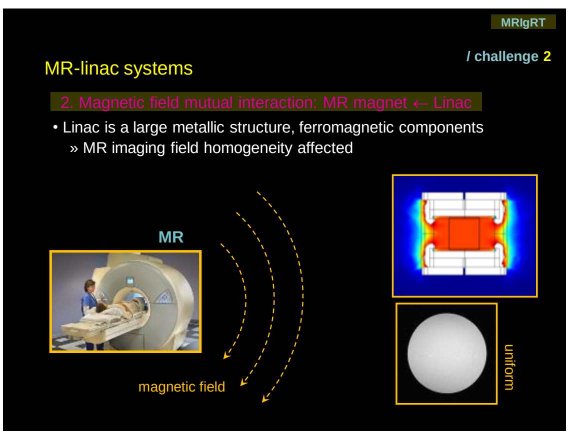
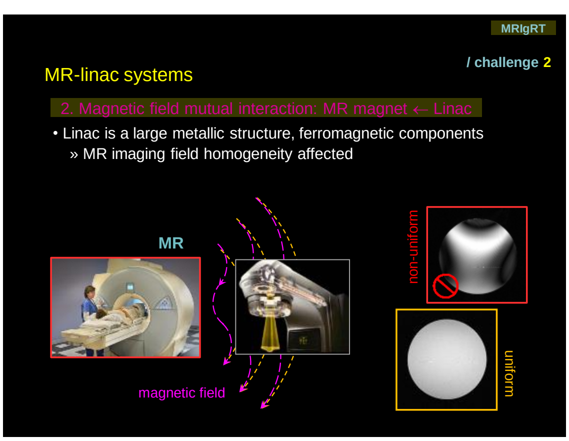
Linac waveguide
MR
e-
e-
in magnetic field
magnetic field
(on all the time)


MRIgRT
/ challenge 2
MR-linac systems
2. Magnetic field mutual interaction: MR magnet ← Linac
• Linac is a large metallic structure, ferromagnetic components
» MR imaging field homogeneity affected
MR
magnetic field
uniform


MRIgRT
/ challenge 2
MR-linac systems
2. Magnetic field mutual interaction: MR magnet ← Linac
• Linac is a large metallic structure, ferromagnetic components
» MR imaging field homogeneity affected
MR
magnetic field
non-uniform
uniform

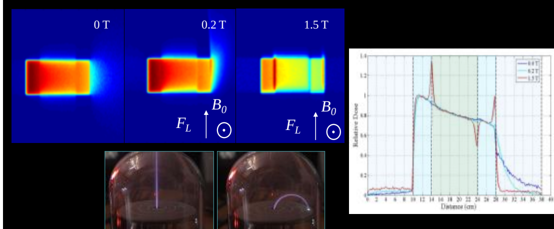
MRIgRT

/ challenge 3

MR-linac systems

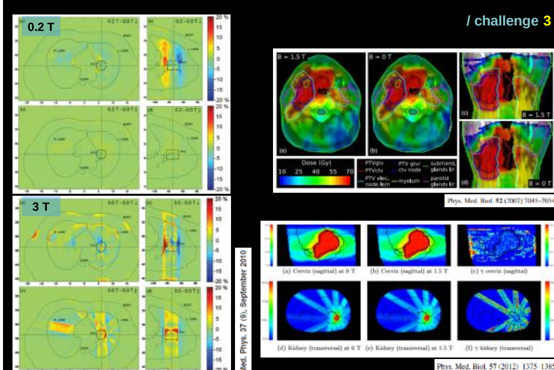
3. Dosimetry in MR's magnetic field

- e trajectories perturbed by the presence of B0 → Lorentz force
  - » effect = f(KE, B0, interface)



MRIgRT

/ challenge 3



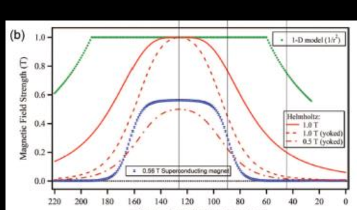
MRIgRT

MR-linac systems

/ challenge 4

Skin dose effects in MR's magnetic field

- x-ray beam - scattered/contaminant electrons - linac head, air
- trajectories affected by MR's magnetic field → increased patient dose



Skin dose in longitudinal and transverse linac-MRIs using Monte Carlo and realistic 3D MRI field models
Med. Phys. 39 (10), October 2012
A. Keyvanloo
Department of Oncology, Medical Physics Division, University of Alberta, 11560 University Avenue, Edmonton, Alberta T6G 1Z2, Canada

Electron contamination modeling and skin dose in 6 MV longitudinal field MRIgRT: Impact of the MRI and MRI fringe field
Med. Phys. 39 (2), February 2012
B. M. Oborn
Illawarra Cancer Care Centre (ICCC), Wollongong, NSW 2500, Australia and Centre for Medical Radiation Physics (CMRP), University of Wollongong, Wollongong, NSW 2500, Australia

MRIgRT

MRIgRT systems

/ challenge 1 RF interference
- Relocate linac main RF sources in adjacent rooms
- Enclose linac head or MR in a Faraday cage

/ challenge 2 Magnetic field mutual interaction: MR magnet & Linac
- Passive & active magnetic shielding
- Physical separation

/ challenge 3 Dosimetry in MR's magnetic field
- Effects ↑ when magnetic field ↑
- Monte Carlo dose computations

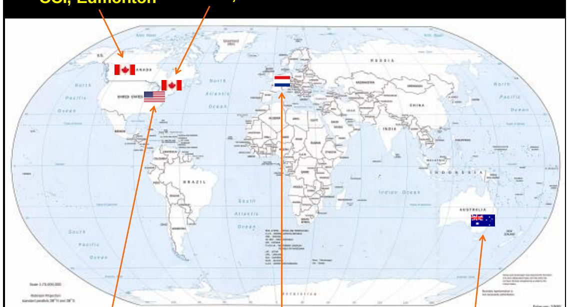
/ challenge 4 Skin dose effects in MR's magnetic field
- System configuration
- Treatment planning strategies

MRIgRT

MRIgRT

CCI, Edmonton

PMCC, Toronto



ViewRay, WashU

UMC, Utrecht

Univ. of Sydney

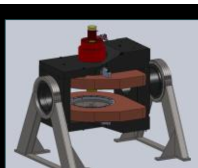
CCI, Edmonton, Canada

Functioning Whole-body Linac-MR Installed in 2013

SEEING TREATING ADAPTING

www.linac-mr.ca

Courtesy of G. Fallone



Room size:
5.9 x 6.0 x 3.6 (m)

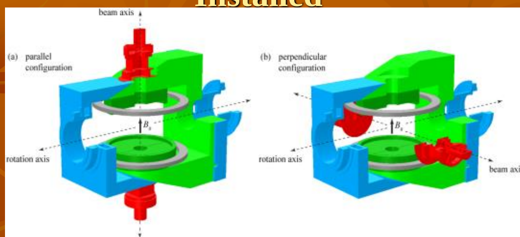
System specs:
MR scanner: 0.6T | Paramed - MgB2 (He free technology)
Linac: 600C

- System installed in pre-existing RT vault through the maze
- 60 cm patient gap → intention to investigate MR with 80 cm gap
- Gantry rotation: 1 rpm
- Magnet ramp up/down: 20 min (for servicing)
- Linac head on rails for servicing

Adapted from G. Fallone

SEEING TREATING ADAPTING

Current Whole Body Installed



biplanar magnet assembly
superconducting coil
treatment assembly
gantry support link

Courtesy of G. Fallone

SEEING TREATING ADAPTING

SUMMARY SURFACE DOSE

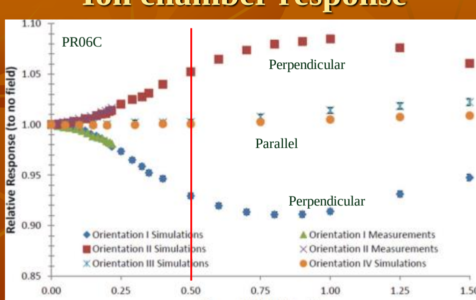
	PERPENDICULAR	PARALLEL
ENTRY	DECREASE BY < 1/2	INSIGNICANT INCREASE
EXIT	INCREASE BY > 1/2	SAME as Bo=0

A. Keyvanloo, B. Burke, B. Warkentin, T. Tadic, S. Rathee, C. Kirkby, D.M. Santos, B.G. Fallone, *Skin Dose in Longitudinal and Transverse Linac-MRIs using Monte-Carlo and realistic 3D MRI field models*, Medical Physics, 39(10), pp.6509-6521(2012).

Courtesy of G. Fallone

SEEING TREATING ADAPTING

Ion chamber response



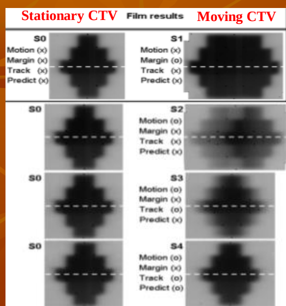
M. Reynolds, B.G. Fallone, S. Rathee, *Dose Response of Selected Ion Chambers in Applied Homogeneous Transverse and Longitudinal Magnetic Fields*, Medical Physics, 40(4), 042102(7 pp), (2013).

Courtesy of G. Fallone

Concurrent Auto intra-fractional contouring, tracking & irradiation

SEEING TREATING ADAPTING

www.linac-mr.ca



Large PTV
Current RT

CTV moves over
Radiation Field

Tracking CTV
without Prediction

**Tracking CTV with
Prediction= EXACT**

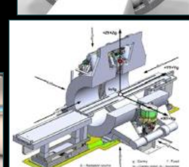
Courtesy of G. Fallone

J. Yun, K.Wachowicz, M. Mackenzie, S. Rathee, D. Robinson, B. Gino Fallone, *First demonstration of intrafractional tumor-tracked irradiation using 2D phantom MR images on a prototype linac-MR,* Medical Physics, 40(5), 051718 (12 pp), (2013).

ViewRay system implementation, Washington Univ, St. Louis

Viewray system

- MR scanner: 0.35 T, split-ring bore
- 3 x Co-60 teletherapy heads & MLCs
- DR: 550 cGy/min
- Rotating gantry assembly
- Room: 5.8 x 7.5 x 2.9 (m)
- Installation through maze | He vent
- FDA Clearance

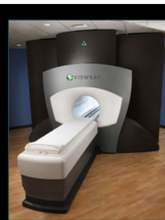


www.viewray.com

Semin Radiat Oncol 24:196-199

Viewray system

- First patients treated - Jan. 2014
- Siteman Cancer Center & Wash U
- Ongoing: breast, bladder, lung, pancreas, stomach, palliative

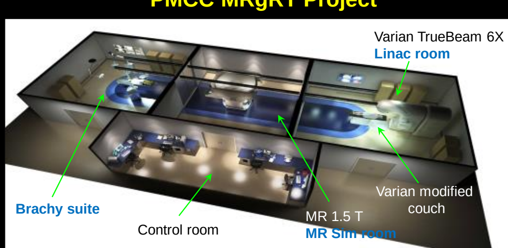


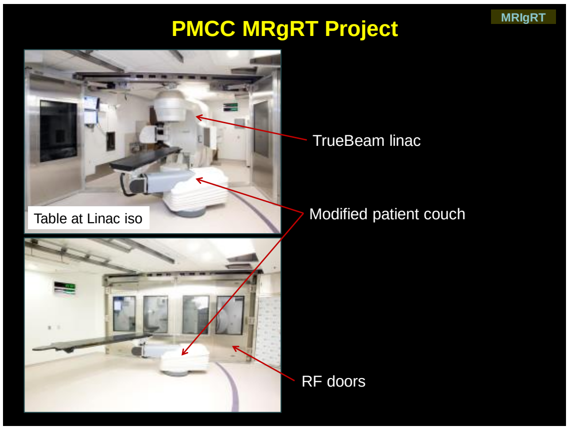
Semin Radiat Oncol 24:196-199

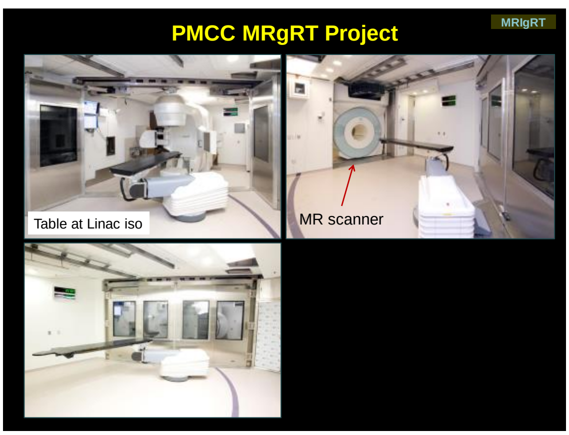
PMCC, Toronto, Canada

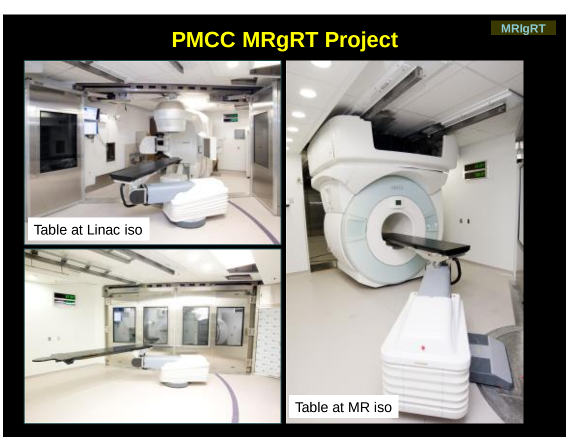
MRIgRT

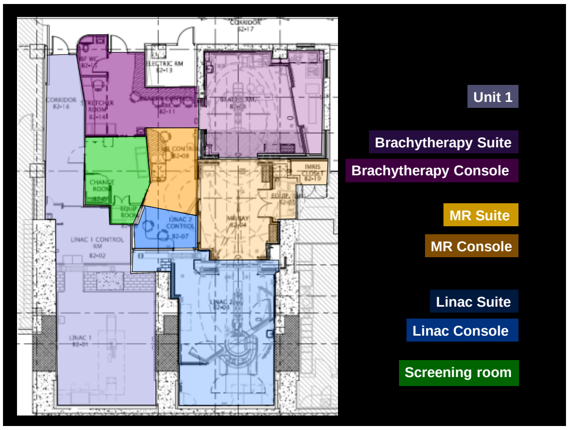
PMCC MRgRT Project

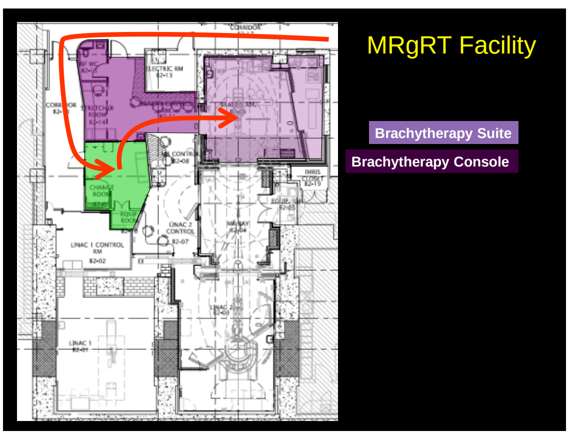


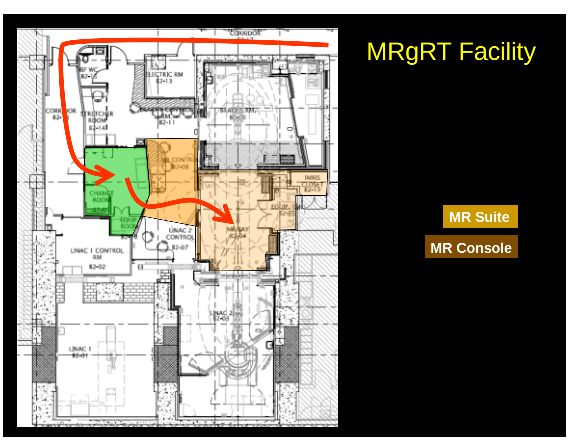

PMCC MRgRT Project
MRIgRT
TrueBeam linac
Modified patient couch
Table at Linac iso
RF doors


PMCC MRgRT Project
MRIgRT
Table at Linac iso
MR scanner

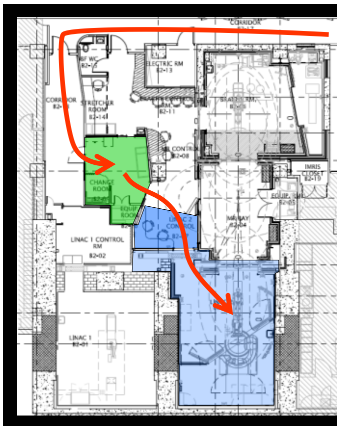

PMCC MRgRT Project
MRIgRT
Table at Linac iso
Table at MR iso


Unit 1
Brachytherapy Suite
Brachytherapy Console
MR Suite
MR Console
Linac Suite
Linac Console
Screening room


MRgRT Facility
Brachytherapy Suite
Brachytherapy Console


MRgRT Facility
MR Suite
MR Console

MRgRT Facility

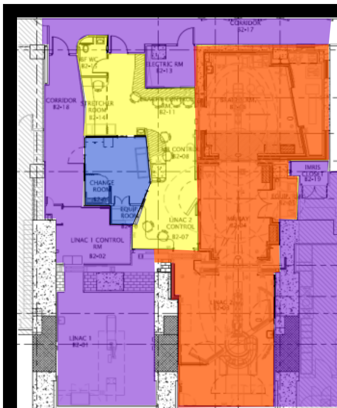


Linac Suite

Linac Console

MRgRT Facility

MR Safety



Zone I
- Freely accessible

Zone II
- Access to other zones
- Screening area

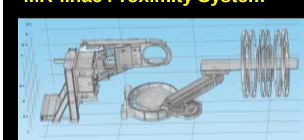
Zone III
- Magnetic field present
- Access restricted
- Supervised by MR staff
- Control for ferromagnetic objects

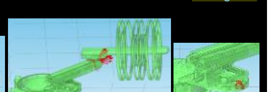
Zone IV
- Magnet room
- Very strong fields

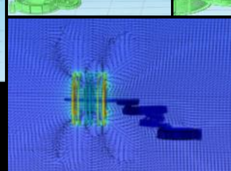
ACR Guidance Document on MR Safe Practices
JMRI 37:501–530 (2013)

MRIgRT

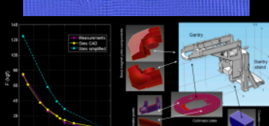
MR-linac Proximity System







System performance & Safety:
- System simulation CAD & FEM
- Experimental validation (B-field, forces)
- Couch performance
- Couch safety testing for B-field forces
- Beam testing after MR in the RT room
- MR shimming at 2 imaging positions
- End-to-end performance



Application Sites for MR-guided External Beam

Site	Support	Type
SBRT Liver	++++	IG
SBRT Paraspinal Mets	++++	IG
RT for Cancer of the Cervix	++++	IG/A/R
RT for Partial Breast Irradiation	+++	IG/A
RT for Head and Neck (Oro)	++	IG/A
RT Prostate	+	IG/B
…		

IG – Online Image Guidance; A – Adaptive;
R – Response Assessment; B- Boost

D. Jaffray

UMC, Utrecht, Netherland

UMC Utrecht

Imaging Division

MRI, therapy & oncology

MR-guided Radiotherapy

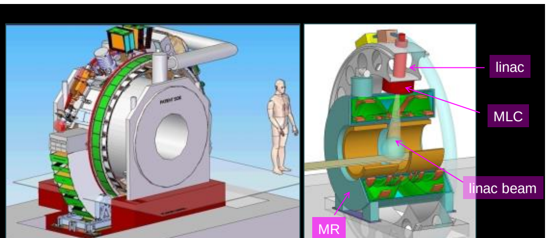
Jan Lagendijk, Bas Raaymakers, Marco van Vulpen

Courtesy of J. Lagendijk

Vision

- Develop Centre of Image Guided Oncological Interventions
- Improving local cancer therapy and making this therapy non-invasive

Courtesy of J. Lagendijk



System specs - Stereotactic MRI accelerator (MRL):
MR scanner: 1.5T (Philips)
Linac: 6X (Elekta)

- Gantry assembly: rotation in both directions - 10 rpm (slip ring) | 0.1° accuracy
- MLC field size 24 x 56 cm2 – 7 mm leaves at iso
- 1 mm spherical volume as target at iso
- Simultaneous irradiation and MR imaging

Adapted from J. Lagendijk

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Adapted from J. Lagendijk

Building and installing the MRI linac at the UMCU

Courtesy of J. Lagendijk

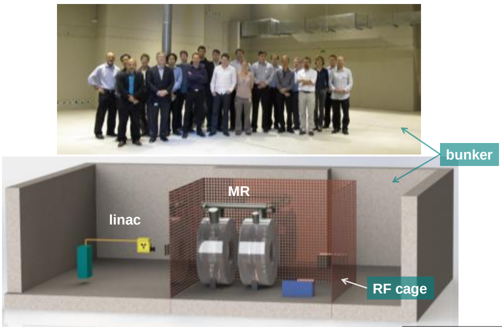
Radiotherapy UMC Utrecht goes MRI

- Tumour characterization
- MRI simulation: delineation
- MRI guidance
  - MRI treatment guidance external beam
  - MRI guided brachytherapy
  - MRI guided HIFU
  - MRI guided protons
  - MRI guided radioembolization
- MRI treatment response assessment

Courtesy of J. Lagendijk

Univ. of Sydney, Sydney, Australia

The Australian MRI-Linac Program



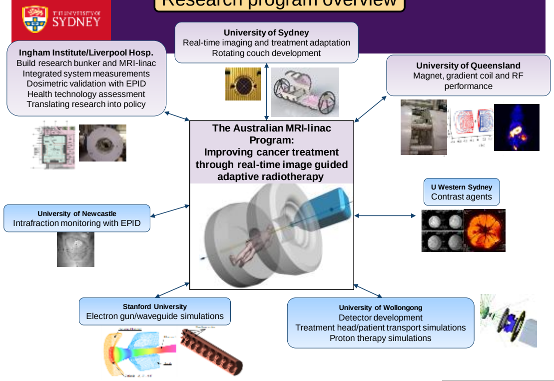
Courtesy of P. Keall

EQUIPMENT STATUS

Item	Status
Bunker	Crookes construction: ~14x12x5m^3, completed
Magnet	Agilent: 1T split bore, actively shielded with low field in linac region, delivery ~11/14,
Linac and MLC	Varian Linatron and Millennium MLC, delivered, installation ongoing
Spectrometer	Siemens, delivery ~12/14
Gradient coil system	Tesla, delivery ~11/14
RF system	Magnetica, delivery ~11/14

Courtesy of P. Keall

Research program overview

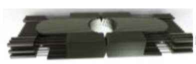


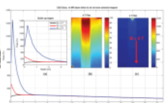
Courtesy of P. Keall

THE UNIVERSITY OF SYDNEY

KEY SCIENTIFIC ACHIEVEMENTS

Message	Source
The electron gun can be modified to operate in magnetic fields	Constantin Med Phys 2011, 2014
Real-time image guidance via template matching is feasible	Bjerre Phys Med Biol 2013
The MLC will not inhibit MRI image quality; if sufficiently separated	Kolling Med Phys 2013
Real-time MLC tracking is used for patient treatments	Keall Med Phys 2014
Skin dose is really high inline; but can be reduced	Oborn, Med Phys 2014





Courtesy of P. Keall

MRIgRT

MR in RT Symposium

May 22-23, 2014

HOME • REGISTRATION • MEETING PROGRAM • ORGANIZING BOARD • ABSTRACTS • SPONSORSHIP • ACCOMODATIONS

Location
Washington University
School of Medicine
Saint Louis, Missouri

Registration Dates:
January 15, 2014
thru
May 10, 2014

SITEMAN CANCER CENTER

Washington University in St. Louis
School of Medicine

HOME

Meeting Objectives

MRI has both an established as well as several rapidly evolving roles in the clinical practice of Radiation Therapy. While MRI has been used for nearly 3 decades as an adjunct to precision treatment planning due to superior soft tissue contrast, recent developments including recommendations for Brachytherapy treatment planning, rapid expansion of MRI systems primarily directed to Radiation Therapy utilization, integration of MRI as embedded technology for daily and live treatment guidance, and growing evidence of the potential of more advance MRI-derived quantitative information such as diffusion and perfusion measurements to impact individualized treatment planning, modification and assessment have brought to the forefront several needs for the clinical radiotherapy community. It is important for Radiation Oncology professionals to have a deeper understanding of the fundamentals, benefits, and potential limitations of MRI, and at the current nascent stage of broad adoption, it is critical to provide a dedicated forum where advanced research can be discussed and common solutions debated and discussed. This workshop will address some of these needs. Major foci of the workshop will include:

- Education of the community on MRI-specific issues (technology, imaging hardware and sequence optimization, quality assurance)
- Helping define the current and evolving roles of MRI utilization in Radiation Oncology, including current evidence of clinical benefit of MRI utilization
- Provide focused discussions on research in critical areas, including:

http://radonc.wustl.edu/mrinrt/

MRIgRT

Seminars in RADIATION ONCOLOGY

- Introduction: Magnetic Resonance Imaging Comes of Age in Radiation Oncology
- The Value of Magnetic Resonance Imaging for Radiotherapy Planning
- Magnetic Resonance Imaging Acquisition Techniques for Radiotherapy Planning
- Point: Principles of Magnetic Resonance Imaging Integration in a Computed Tomography–Based Radiotherapy Workflow
- Counterpoint: Opportunities and Challenges of a Magnetic Resonance Imaging–Only Radiotherapy Work Flow
- Introduction: Systems for Magnetic Resonance Image Guided Radiation Therapy
- Magnetic Resonance Imaging of the Tumor Microenvironment in Radiotherapy: Perfusion, Hypoxia, and Metabolism
- Clinical Applications for Diffusion Magnetic Resonance Imaging in Radiotherapy
- Magnetic Resonance–Guided Adaptive Radiotherapy: A Solution to the Future

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