MR GUIDED RADIATION THERAPY

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Joint ICTP-IAEA Workshop on Radiation Protection in
Image-Guided Radiotherapy (IGRT)
Trieste, Italy, 7-11 October 2024

UNIVERSITY OF MINNESOTA

Disclosures

- Nothing to disclose
- Any reference to commercial products does not imply endorsement

Outline

- Introduction
- Equipment
- Implementation
- Indications and Contraindications
- Safety
- Summary and Conclusions

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Introduction

- IGRT methods not employing ionizing radiation
  - Surface-Guided Radiation Therapy (Discussed in next talk)
    - Most prevalent, low cost, used primarily for breast and cranial treatments
  - Ultrasound-Guided Radiation Therapy
    - Older method, limited use primarily for prostate and breast treatments, no longer marketed

Introduction

- MR-Guided radiation therapy (MRgRT or MRIgRT)
  - Relatively new
  - High upfront and ongoing cost
  - Slower treatment times
  - Useful for treatments needing soft tissue contrast and adaptive planning

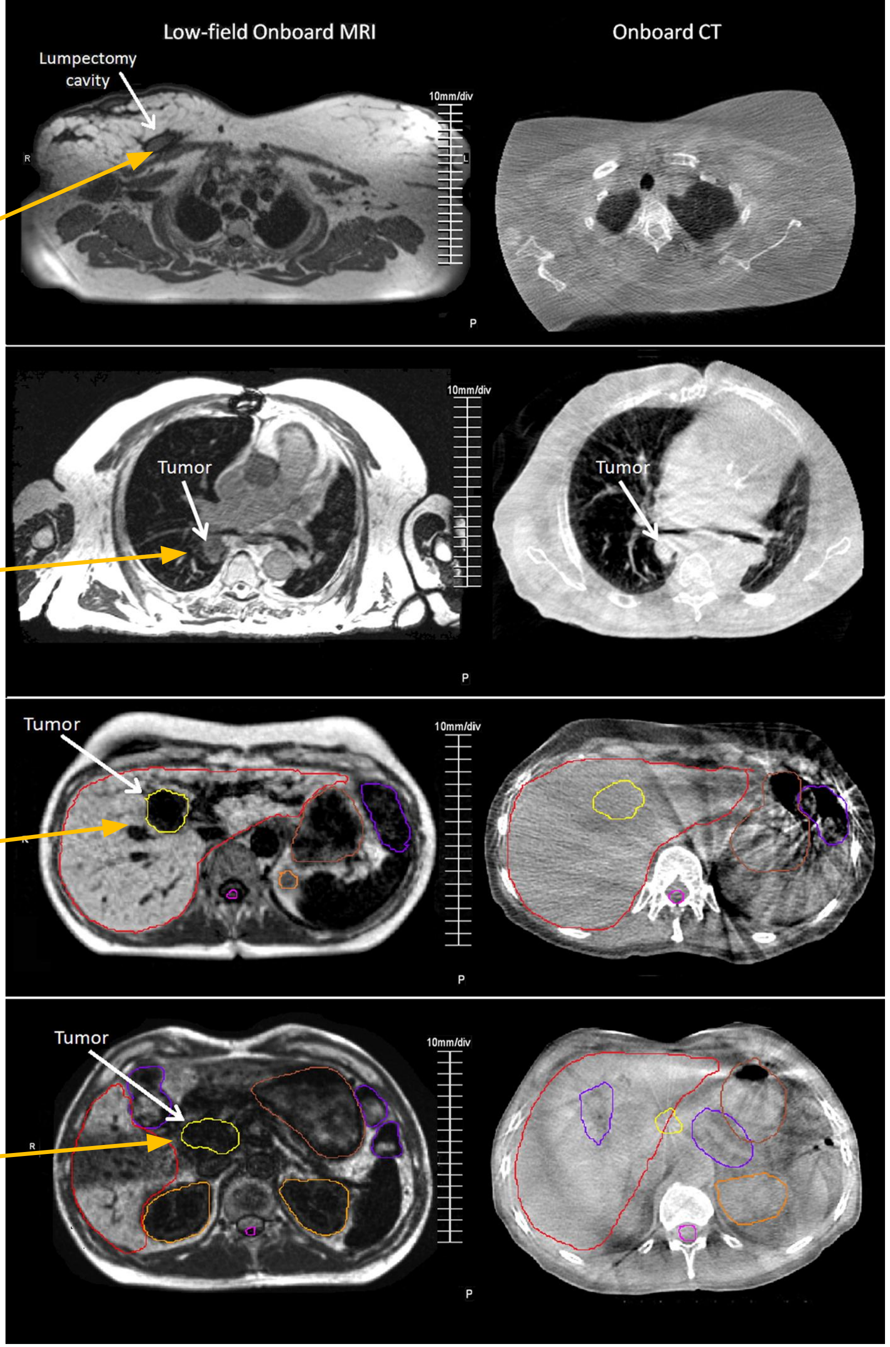
Comparison of on board low-field MRI and CBCT

Lumpectomy cavity

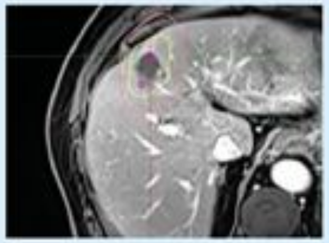
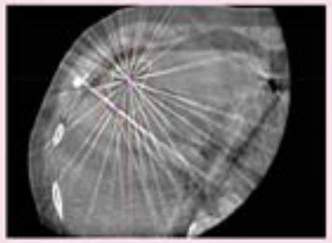
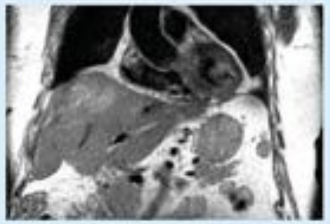
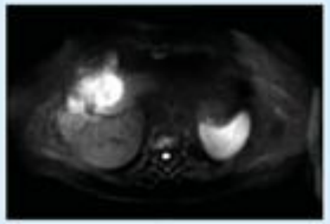
Lung tumor

Liver tumor

Pancreatic tumor



Noel et. al, *Acta Oncol* 54:1474-1482, 2015

	MRI guided	X-ray guided
Pretreatment image-guidance quality	Routinely available. Superior soft tissue imaging: Exquisite visualization of tumor and normal tissue. 	 Routinely available. Generally poorer tumor and normal tissue visualization than MRI.
Imaging during treatment	Routinely available. Limited in spatio-temporal acquisition. 	 Emerging. General reliance on implanted markers as a surrogate for the tumor position.
Functional imaging	Growing availability. 	Not available.

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Challenges Associated with combining MRI and Linac

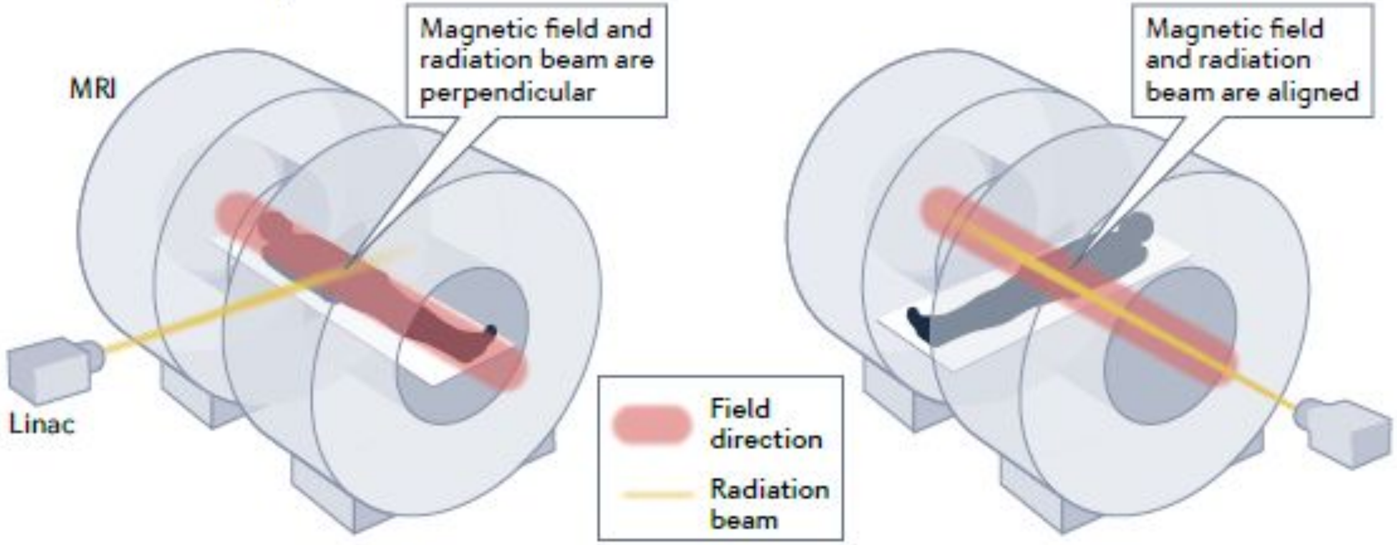
- From the MRI perspective, a Linac is a magnetic source that degrades magnetic field uniformity and is a source of radiofrequency interference which could cause image artefacts

- From the Linac perspective, it must operate within the static magnetic fringe field (the peripheral magnetic filed outside the magnet core) which affects the trajectory of electrons during acceleration

Challenges Associated with combining MRI and Linac

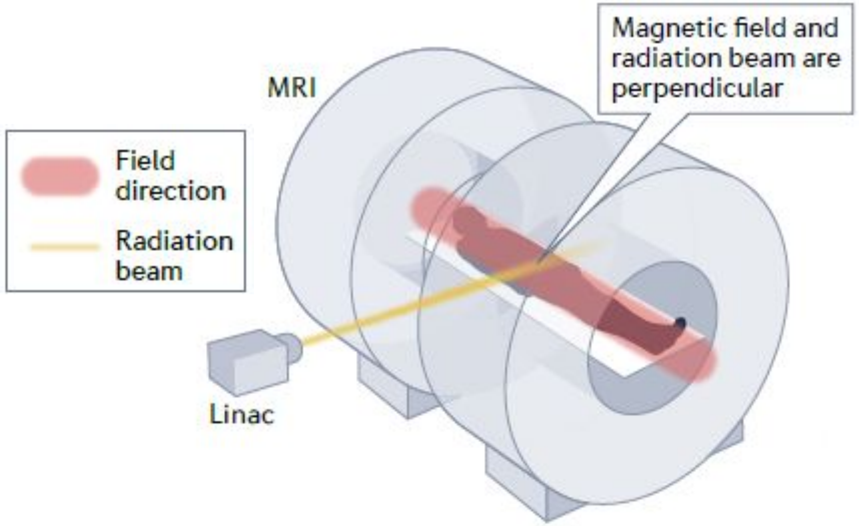
- To overcome these issues, each system has employed magnetic shielding (active or passive) and/or magnet redesign

- Thus the MR-Linac systems tend to have lower performance that stand-alone MRIs and Linacs, including longer scan times and ability to deliver the beams only in co-planar geometry



Configuration	Perpendicular	In line
Effect of field on therapy beam	Major: magnetic field bends charged particles, affecting beam generation and dose in patients	Minor: magnetic fields aligned with particle beam direction
Effect on MRI technology	Minor: close-to-standard hardware can be used	Major: specialized hardware designs are required
Multiple beam angles	Linac can be rotated independently of magnet	Either magnet or patient must be rotated to maintain configuration alignment

Fig. 2 | **Types of MRI–linac systems.** Enabling the simultaneous and integrated operation of two sensitive pieces of equipment, an MRI system and a linear accelerator (linac) system, is an engineering feat. Two main types of MRI-guided linear accelerator (MRI–linac) systems exist depending on whether they have a perpendicular or in-line configuration of the magnetic field and radiation beam. The design differences and implications are shown.



Effect of field on therapy beam	Major: magnetic field bends charged particles, affecting beam generation and dose in patients
Effect on MRI technology	Minor: close-to-standard hardware can be used
Multiple beam angles	Linac can be rotated independently of magnet

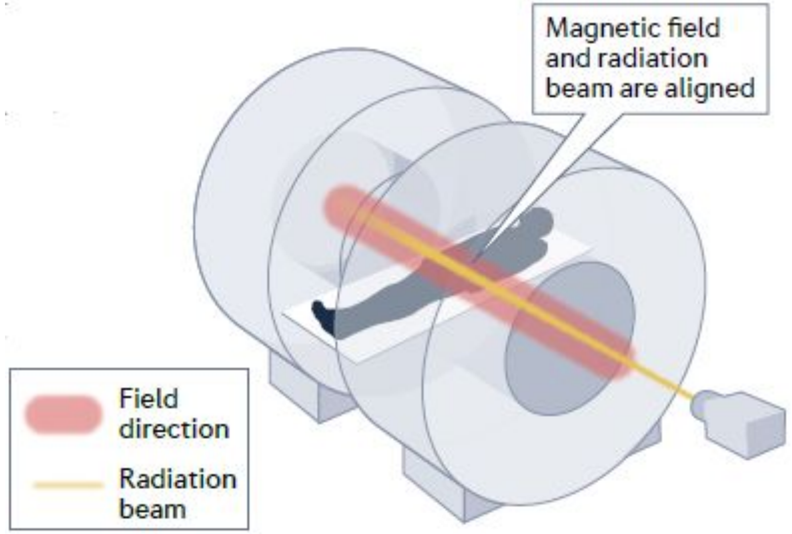
Perpendicular Configuration:

Magnetic field bends charged particles, affecting beam generation and patient dose

Minimal effect on MRI by Linac

Linac can be rotated independently of magnet

Keall et al., *Nat Rev Rad Onc* 19, 458-470 (2022)



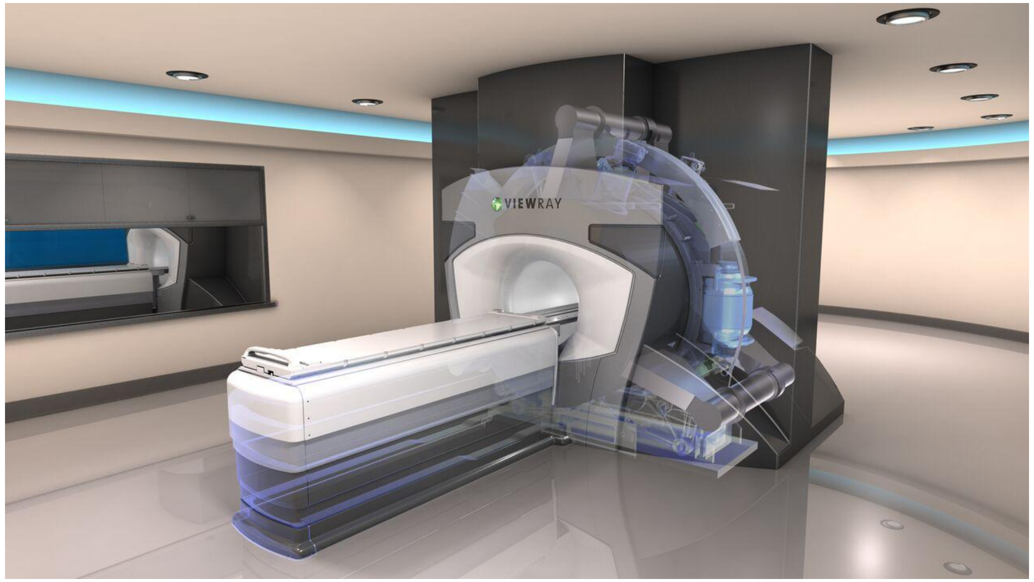
Effect of field on therapy beam	Minor: magnetic fields aligned with particle beam direction
Effect on MRI technology	Major: specialized hardware designs are required
Multiple beam angles	Either magnet or patient must be rotated to maintain configuration alignment

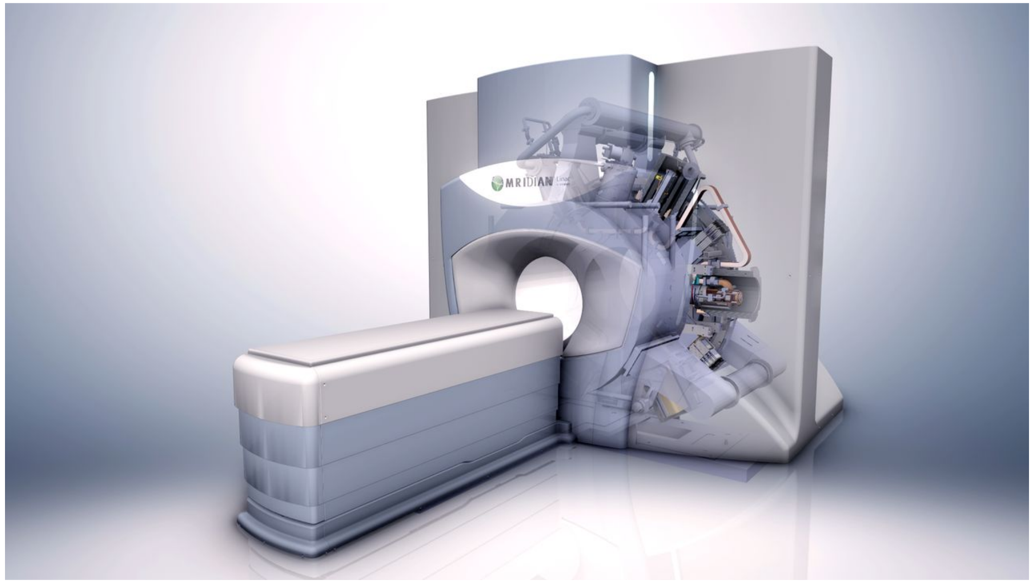
Inline Configuration:

Minor effect on beam generation by magnet

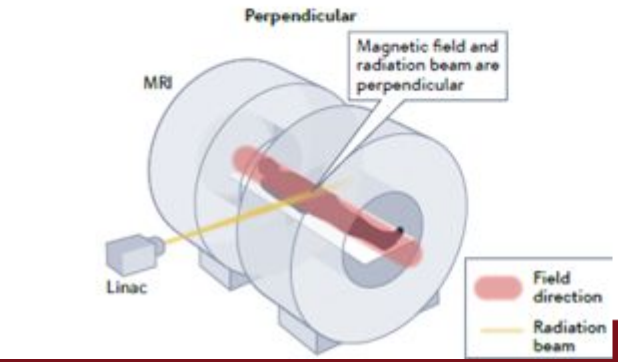
Major effect on MRI by Linac

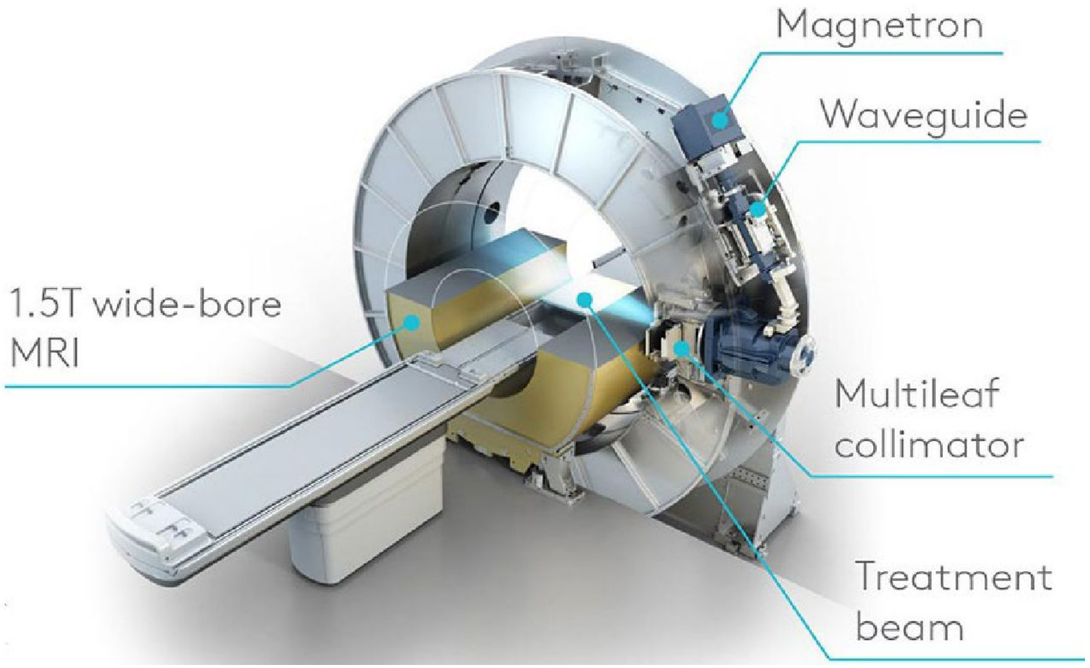
Either magnet or patient must be rotated



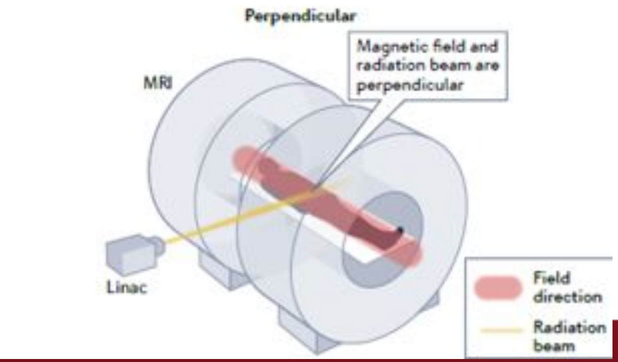


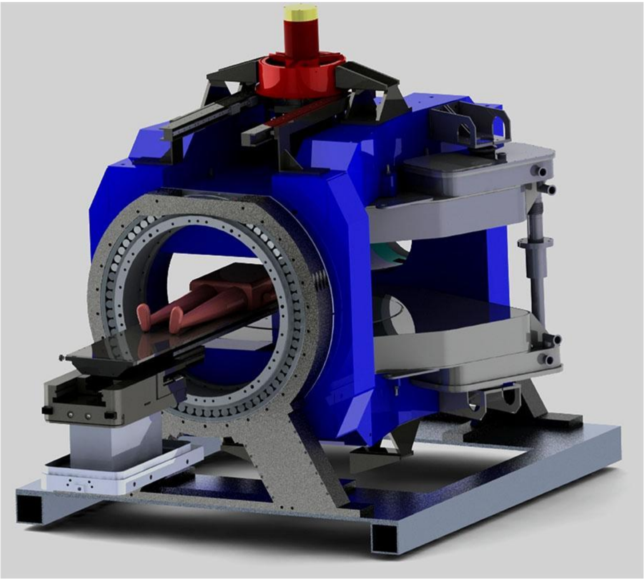
ViewRay, MR-Cobalt & MR-Linac (MRIdian), 6 MV FFF beam mounted on a 0.35 T split superconducting magnets with a 28 cm gap between the two halves, SAD: 90 cm, field size of 27.4 x 24.1 cm





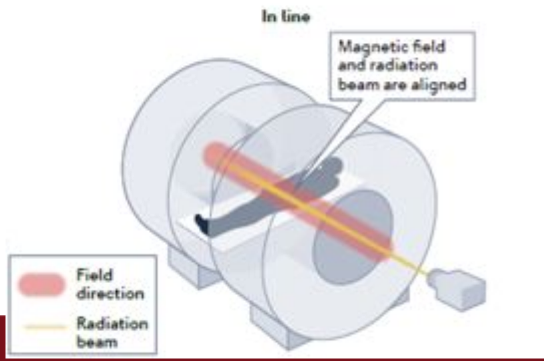
Elekta Unity: 7 MV FFF linear accelerator mounted in a ring around a 1.5 T closed superconducting magnet, SAD: 145 cm, field size of 55 x 29 cm

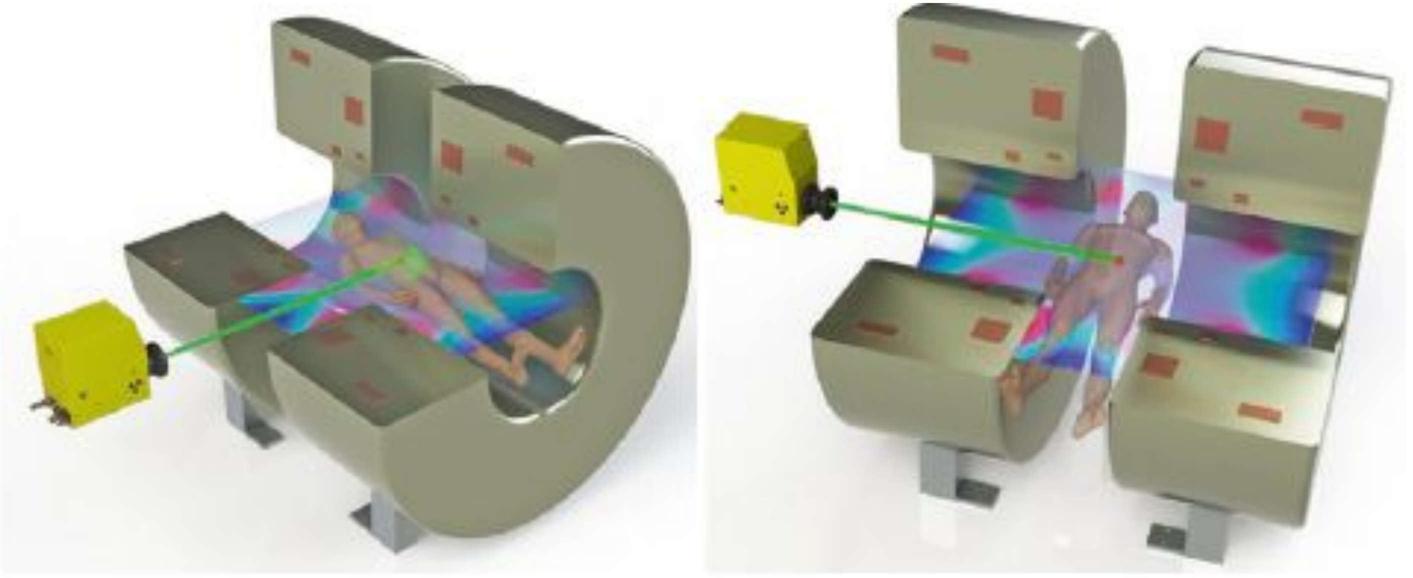




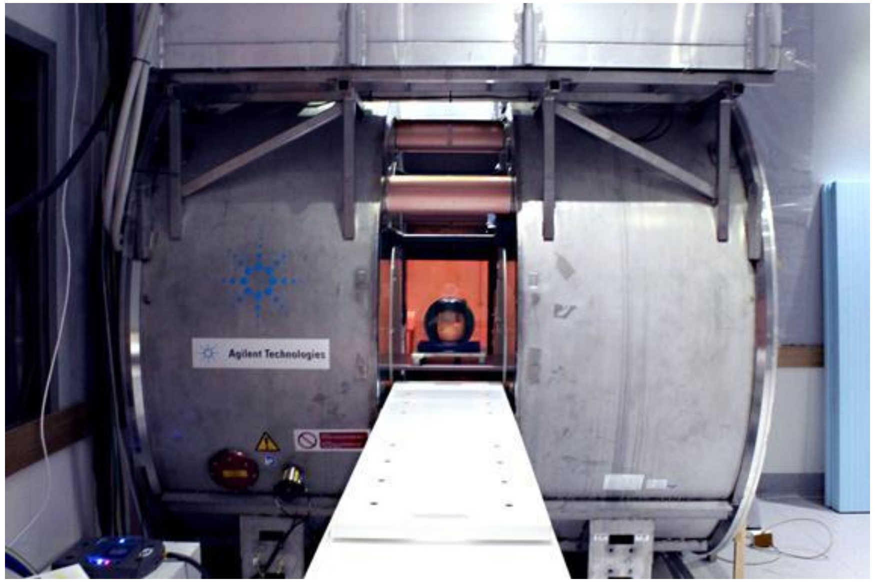
http://mp.med.ualberta.ca/linac-mr/photo_gallery.html

MagnetTx Aurora-RT, 6 MV FFF linear accelerator mounted inline with a 0.5 T biplanar superconducting magnet, SAD: 120 cm



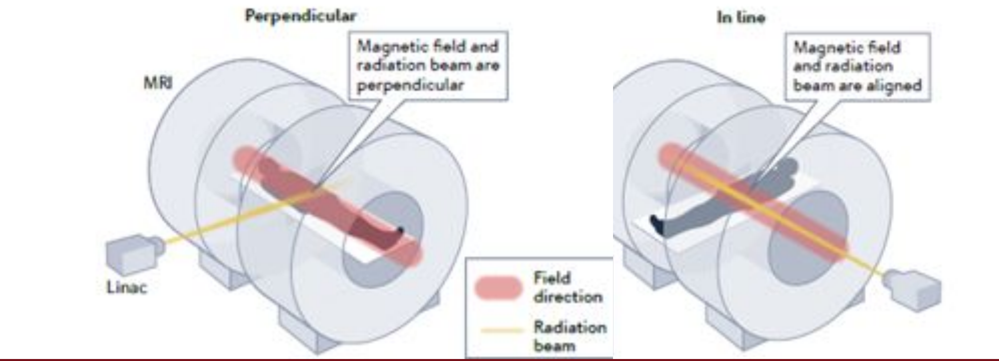


Paganelli et al. 2018



https://image-x.sydney.edu.au/mri-linac/

Australian MR Linac, 4/6 MV FFF linear accelerator mounted inline or perpendicular on a 1.0 T magnet, 180 cm SAD (fixed beam, rotating patient)



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Implementation of MRgRT

- Out of the over 13,000 radiotherapy machines globally (2013 data), ~1% are MRgRT systems

	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries
Radiotherapy departments	5075	1972	590	40
Total megavoltage machines	8911	3115	1014	62
Linear accelerators	8300	2371	523	25
^{60}Co units	611	744	491	37
Modelled capacity (fractions per year)	75 879 000	32 995 000	10 660 000	650 000

Data are n, unless otherwise specified. The number of fractions that can be delivered with this equipment each year was modelled according to the nominal activity-based model.

Table 4: Radiotherapy resources and modelled capacity, 2013

Expanding global access to radiotherapy

Rifat Atun, David A Jaffray, Michael B Barton, Freddie Bray, Michael Baumann, Bhadrasain Vikram, Timothy P Hanna, Felicia M Knaul, Yolande Lievens, Tracey Y M Lui, Michael Milosevic, Brian O'Sullivan, Danielle L Rodin, Eduardo Rosenblatt, Jacob Van Dyk, Mei Ling Yap, Eduardo Zubizarreta, Mary Gospodarowicz

Implementation of MRgRT

- Most radiation therapy departments have limited expertise in safely introducing MRIs
- Safety training should include various MR safety trainings and professional bodies are beginning to address these
- Hence many departments recruit or involve staff with MRI experience

Implementation of MRgRT

- Two international guidelines have been introduced on the use of MRI in radiation therapy

Task group 284 report: magnetic resonance imaging simulation in radiotherapy: considerations for clinical implementation, optimization, and quality assurance

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(Received 30 June 2020; revised 12 December 2020; accepted for publication 16 December 2020; published 27 July 2021)

IPEM Topical Report: an international IPEM survey of MRI use for external beam radiotherapy treatment planning

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rsity Hospital), Firenze, Italy
, France
University and Northern Centre for Cancer Care, Newcastle upon Tyne
ited Kingdom

Task Group No. 352 - MR-guided Radiotherapy Systems: Considerations for clinical implementation and quality assurance (TG352)

Implementation of MRgRT

- Considerations of cost-effectiveness of MRgRT:
  - It is significantly more expensive than linac-based IGRT
  - It involves longer treatment times
  - It requires substantial structural and staffing costs
  - There is lack of data on clinical effectiveness

- In contrast:
  - Conventional radiotherapy is highly cost effective

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Clinical Advantages of MRgRT

- Superior anatomical definition translates into better target definition for soft tissue tumors
- Intrafraction cine-MR allows for gating and target tracking for moving organs
- This is particularly relevant for hypofractionated treatments
- Ability for real-time adaptive radiotherapy

Limitations of MRgRT

- No rotational movement of the couch to account for all six degrees of freedom
- Necessity of evaluating image quality, specially for the presence of motion artefacts
- Complexity of introducing on-line adaptive radiation therapy, low patient throughput

Indications Treated by MRgRT

- Abdomen
  - MRgRT enables delivery of higher radiation doses, particularly to upper abdominal cancers
  - Pancreatic cancer patients treated with MRgRT showed a significant correlation between dose and survival
- Lung
  - MRgRT might provide optimal solution for hard-to-treat lung cancers

Disease Site	Enhanced Soft Tissue Visualization	Motion Management	Inter-Fraction Adaptive Re-Planning	Margin Reduction	Facilitate Dose Escalation
Prostate	✓			✓	
Pancreas	✓	✓	✓		✓
Liver	✓	✓	✓		✓
Breast	✓	✓		✓	
Lung		✓	✓		
Oligometastases	✓	✓	✓	✓	✓
Cardiac Ablation	✓	✓			

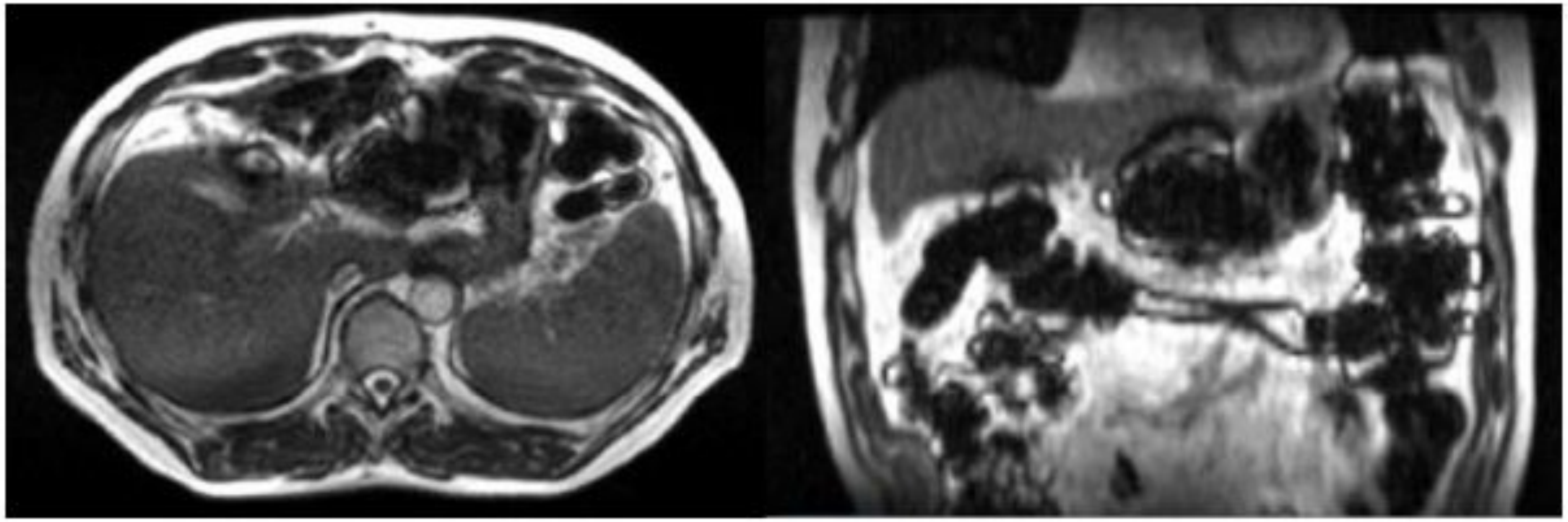
Contraindications

- Implantable medical devices (safety and image artefacts)
- Ferromagnetic materials (implants ad prosthesis, clips, staples, …)
- Patient size (limited FOV)

- Patient diet prior to treatment

Contraindications

- Case report: Metal artefacts caused by iron-fortified breakfast cereal consumed shortly before treatment



Susceptibility artefacts, image distortion due to magnetic field inhomogeneity from ferrous materials

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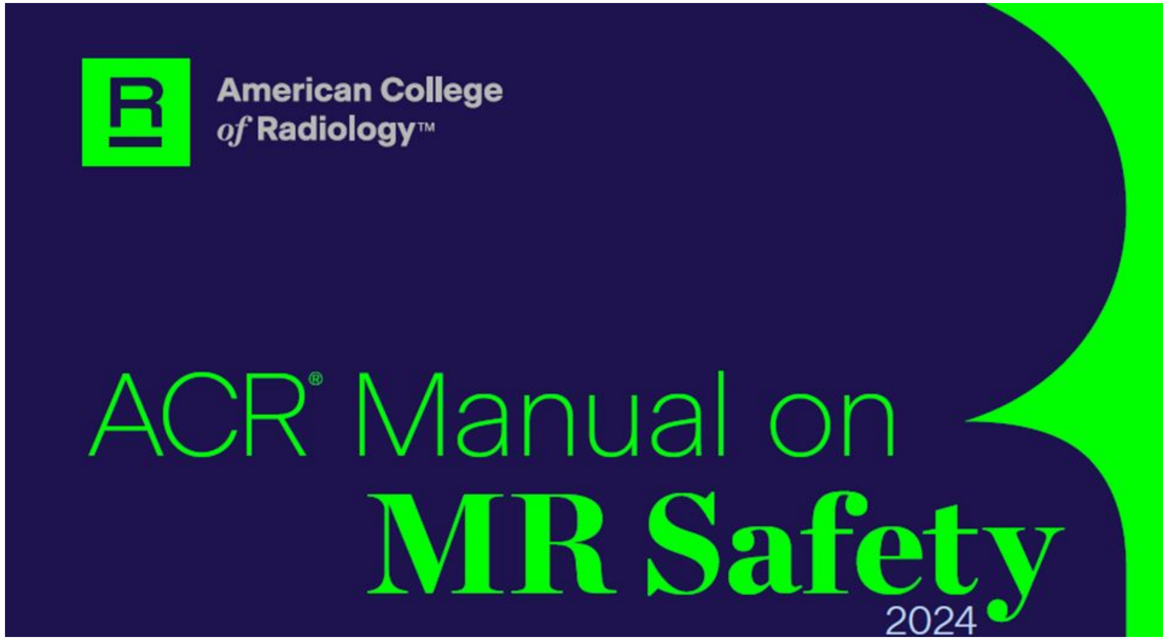
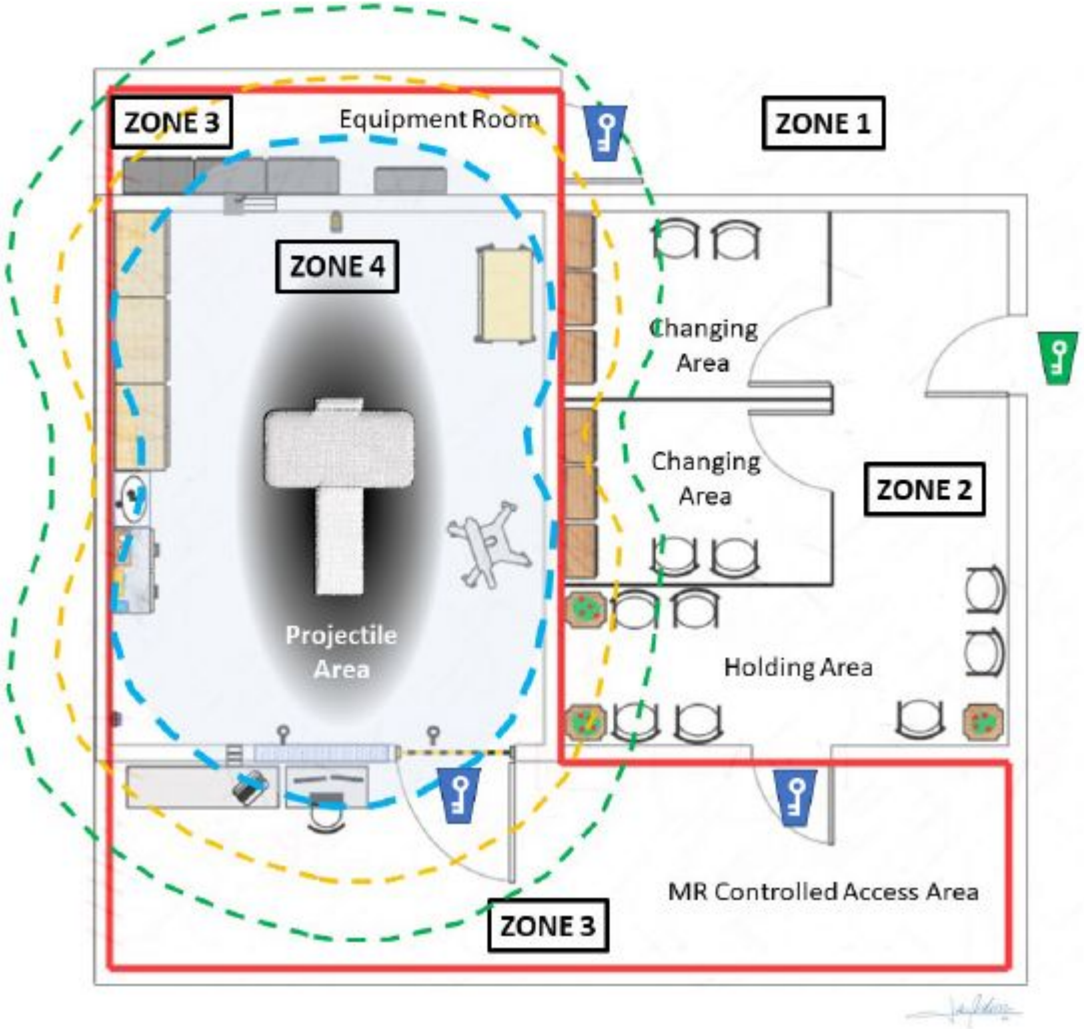
Safety

- All MRI safety issues are applicable to MR-Linacs
  - MR safety zones
  - MR personnel
  - MR screening
  - …



Safety



Items like these must be removed prior to entering Zone IV.

Examples of RF field-associated burns are provided in Figure 14.

Safety

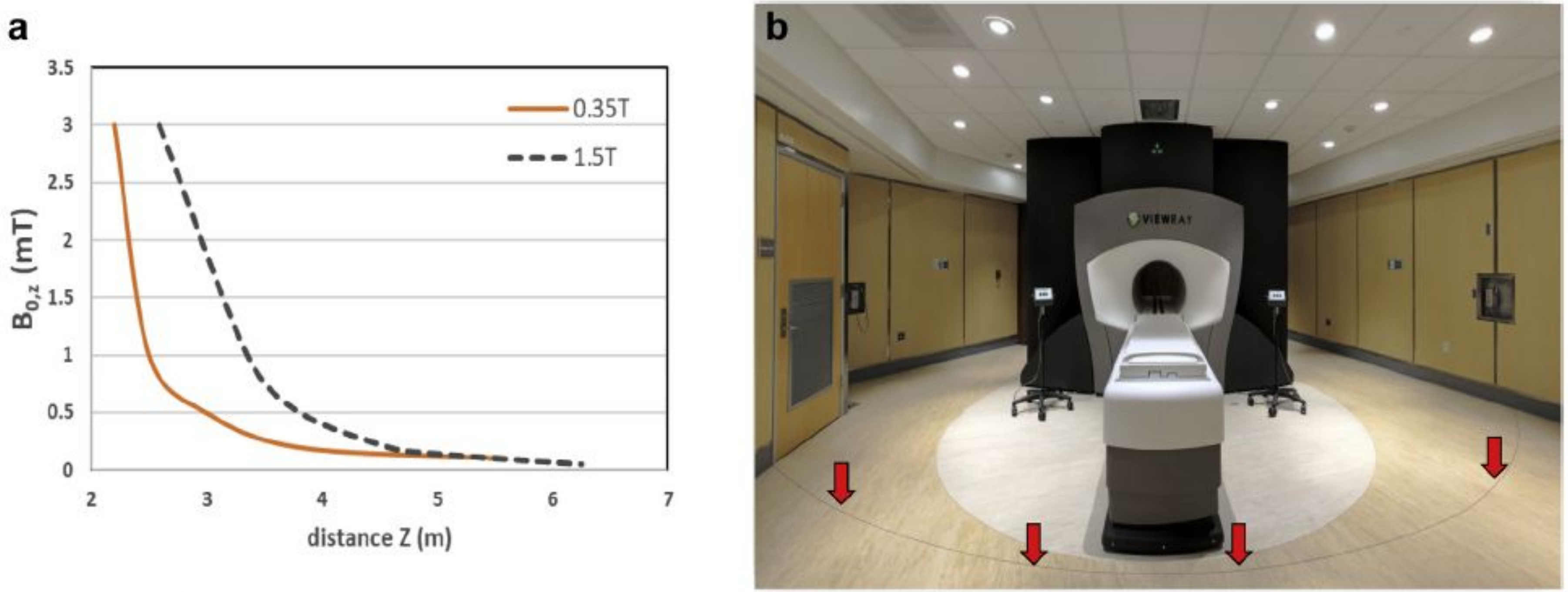


Figure 1 (a) Fringe field strength of 0.35T and 1.5T magnetic resonance imaging along the B_0 direction as a function of the distance from isocenter. (b) Picture of a magnetic resonance-guided radiation therapy vault with the 5 Gauss line clearly marked on the floor as being a potential hazard.

Safety

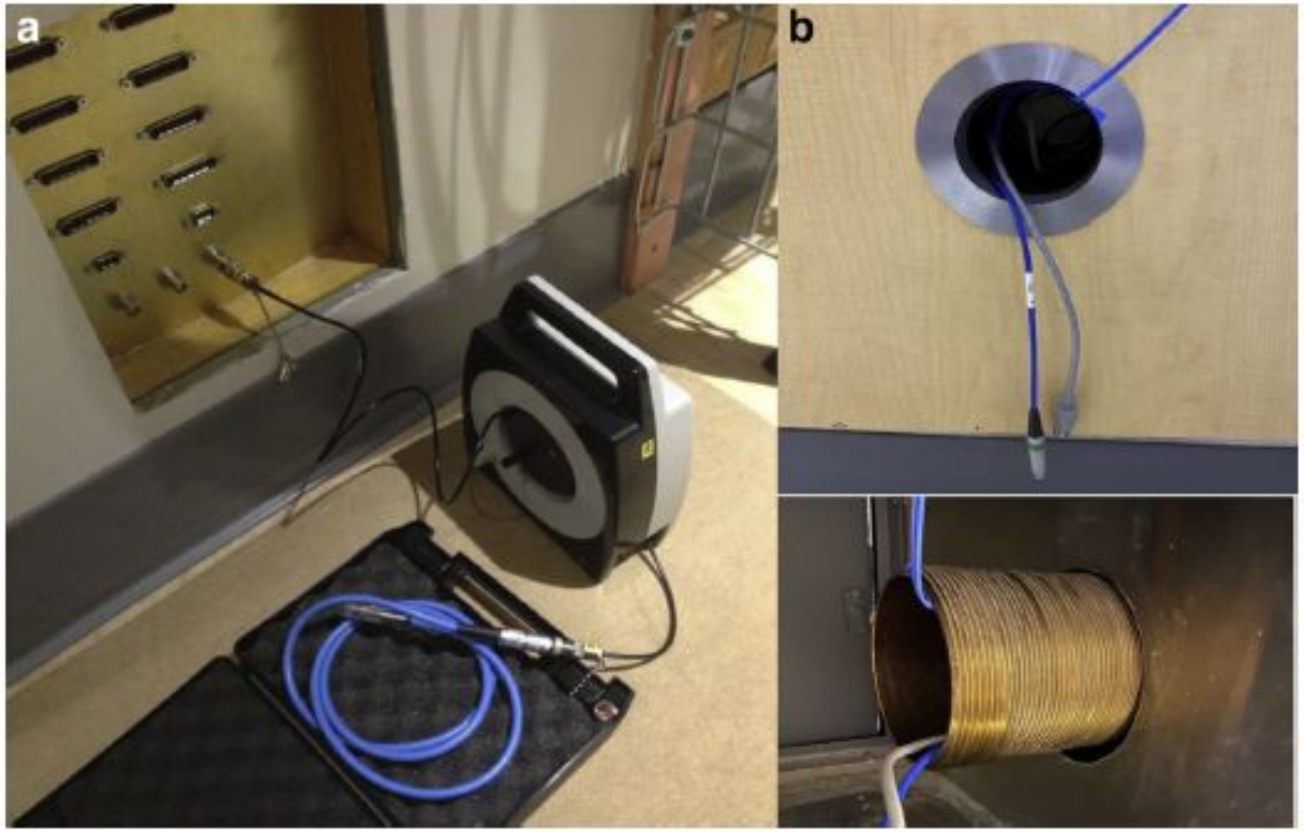


Figure 2 (a) Radiofrequency filter panel designed specifically for triaxial and coaxial cable used for dosimeters such as ion chambers. (b) Waveguide conduit for cables that do not need radiofrequency filter.

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Summary and Conclusions

- MRgRT has clear advantages in treating certain indications requiring soft tissue contrast
- It also enables real-time adaptive radiation therapy
- It eliminates the imaging dose burden of patients

Summary and Conclusions

However;

- It has high upfront and ongoing costs
- It requires significant safety measures and staff training
- It is a slower treatment delivery option, especially if adaptive planning is employed


Questions?