

# Overview of MRI-Linac Technology



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IN THE HELMHOLTZ ASSOCIATION

Research for a Life without Cancer

# MRI-Linacs : Rationale and Benefits



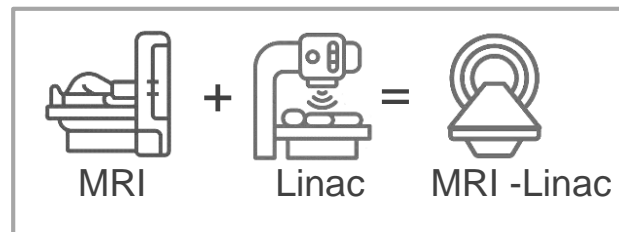
## Radiotherapy (RT):

Delivering optimized dose distribution  
Right dose at the right place.



## Imaging:

Radiotherapy relies on imaging technology



Motivation: Online Adaptive RT

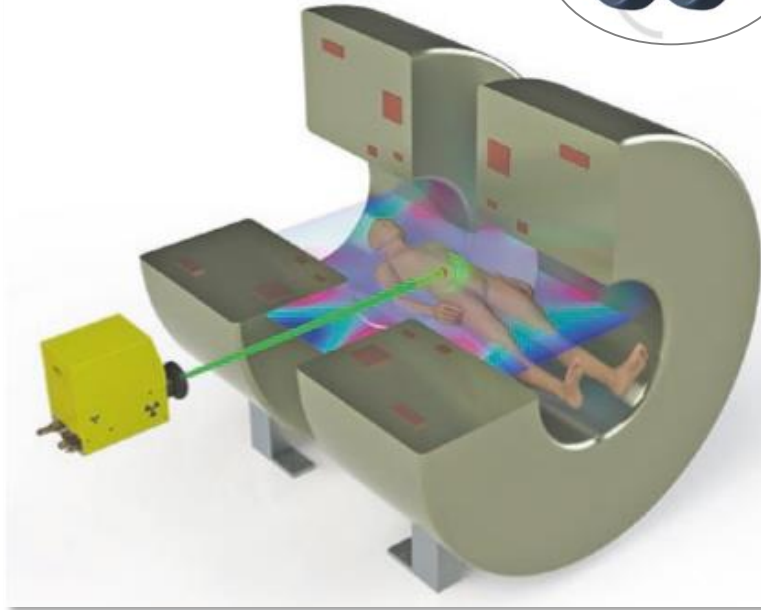
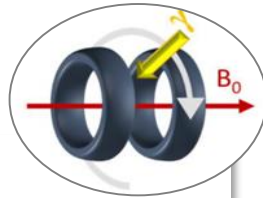
## Image-guided Radiotherapy (IgRT):

- Imaging before and/or during the irradiation:
  - adjustments to patient's position
  - adaption of the treatment plan  
(adaptive radiotherapy, ART)

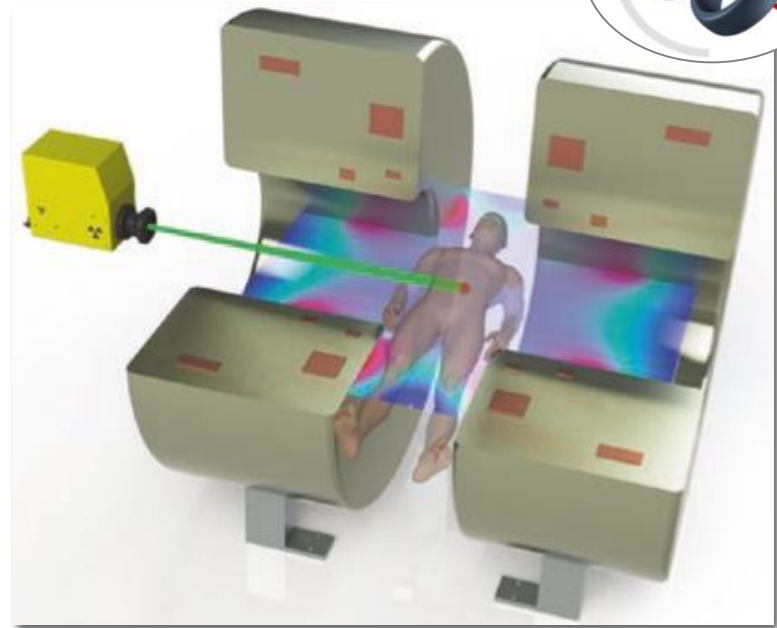
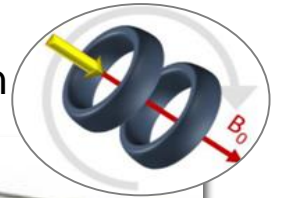
- Advantages:
  - visualizing anatomical changes during RT
  - treatment plan adaptation
  - beam-on motion monitoring : gating/tracking
- Advantages of MRI:
  - high soft tissue contrast
  - no additional imaging dose

# MRI-Linac : possible configurations

perpendicular configuration



parallel (in-line) configuration



Paganelli et al., 2018

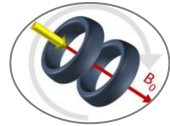
# MRI-Linac : parallel (in-line) configuration

## MagnetTx Aurora RT™



6 MV/0.5 T

- Rotating magnet
- FDA clearance (May 2022)

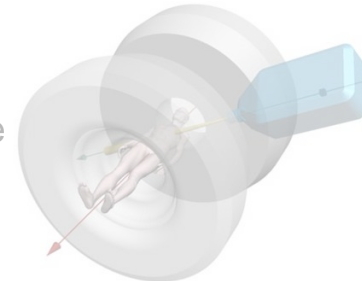
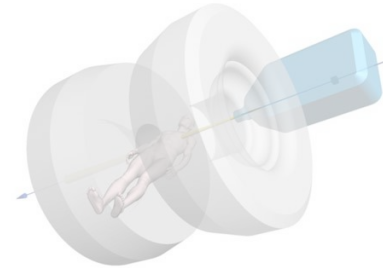


## The Australian MRI-Linac



6 MV/1.0 T

- Both perpendicular and in-line orientation possible
- Research prototype



Keall et al., 2014

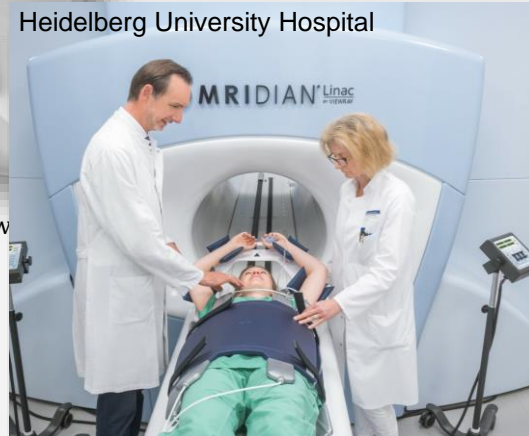
# MRI-Linac : perpendicular configuration

ViewRay MRIdian Linac



view  
6 MV/0.35 T

Heidelberg University Hospital



In clinical use: since 2014 using  $^{60}\text{Co}$   
since 2017 using a 6 MV Linac

Elekta Unity



elek  
7 MV/1.5 T

Utrecht University Hospital



In clinical use since 2017

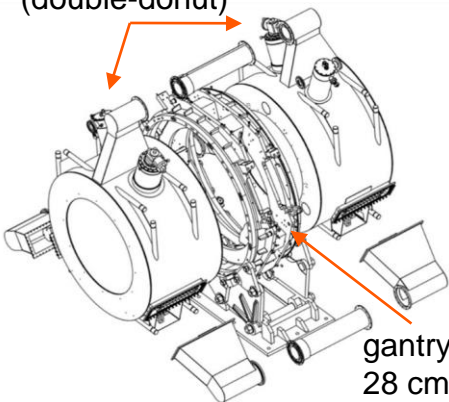
# Shielding between MRI and Linac

## ViewRay MRIdian: split magnet

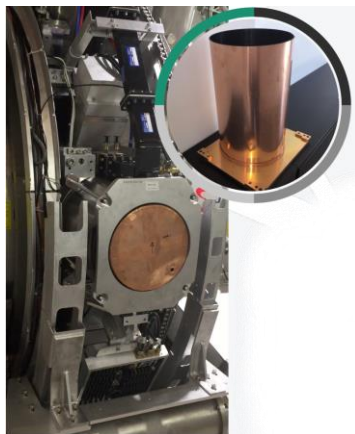
Cryostat-/Coil-Attenuation: ca. 10.0%

- Irradiation through gap in split magnet
- Passive MF shielding
- gantry contains buckets that shield both MF and RF

split magnet  
(double-donut)



gantry in  
28 cm gap between magnet halves

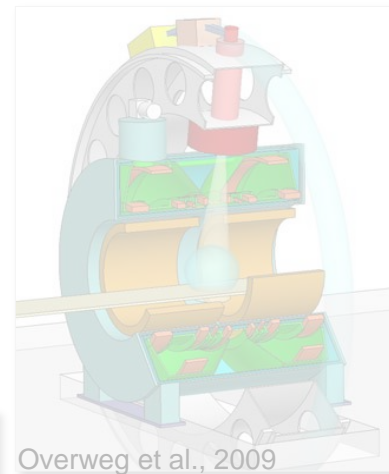
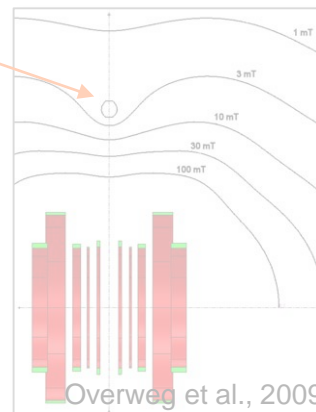


## Elekta Unity : non-split magnet

Cryostat-/Coil-Attenuation: ca. 56.3%

- Irradiation through cryostat with split coils
- Active MF shielding (shield coils with opposite polarity)
- RF shielding: cryostat in Faraday cage

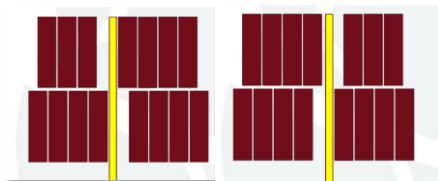
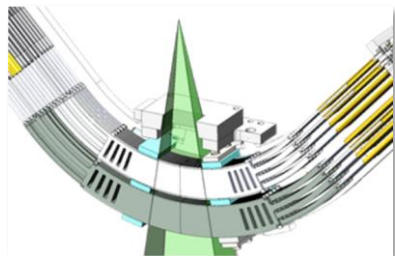
Linac in  
near zero  
MF area



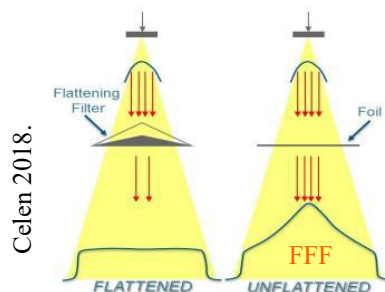
# Beam characteristics

## ViewRay MRIdian Linac

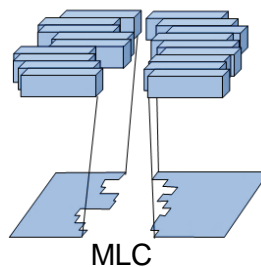
- 6 MV FFF Linac with 6 Gy/min @ 90 cm SAD
- double stacked / double focus MLC
- stacks are shifted by half a leaf width
  - max. field size (27.4 x 24.1) cm<sup>2</sup>
  - min. field size (0.2 x 0.415) cm<sup>2</sup>



Two different MLC configurations for a 4.15mm wide beam

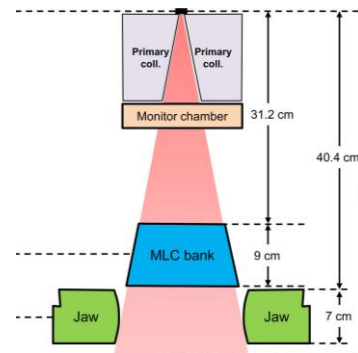


Celen 2018.



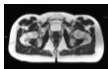
## Elekta Unity

- 7 MV FFF Linac with 4 Gy/min @ 143.5 cm SAD
- single focus MLC + jaws
  - max. field size (57.4 x 22.0) cm<sup>2</sup>
  - min. field size (0.5 x 0.5) cm<sup>2</sup>



Graves et al. 2019

# MR imaging



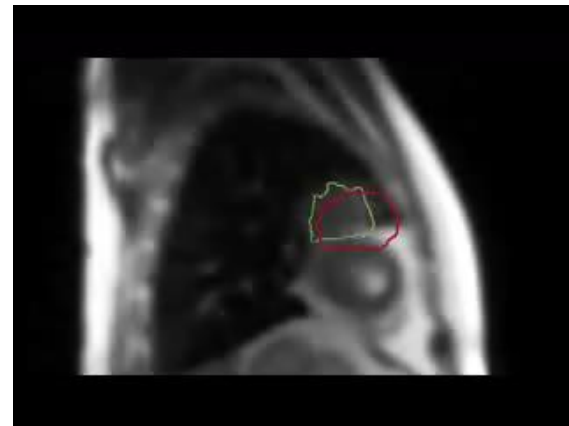
MRI is used for patient positioning and treatment planning

ViewRay MRIdian Linac **0.35 T**

Elekta Unity **1.5 T**

- Higher MF:
  - Higher signal-to-noise ratio
  - Higher MF effects on dose distribution
- MRI-coils included in the immobilization process

Cine MR  
real time imaging during treatment



→ can be used for automated beam gating

S.Klueter, Heidelberg ViewRay MRIdian

Cuccia et al. 2021

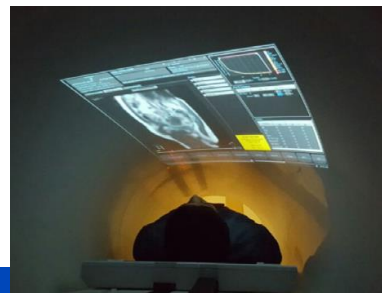


Elekta Unity

MR-coils

ViewRay MRIdian

Med. Phys. 44 (9), September 2017



Kim et al.: Patient-controlled gating system for MR-IGRT

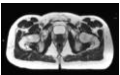


# Plan adaptation workflow

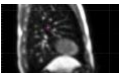
## Simulation



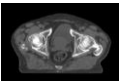
Patient immobilization at MR-Linac



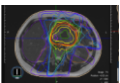
3D MR-Scan at MR-Linac



[2D Cine MR-Scan]



CT-Scan ➤ Electron density



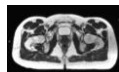
Treatment planning



Plan verification

Adapted from S. Klueter and S. Dorsch, Heidelberg University Hospital ViewRay MRIdian

## Treatment



Daily MR-Scan

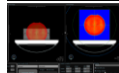
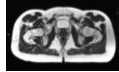


Image registration + determination of setup error



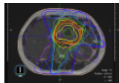
Setup correction by couch movement



Verification MR-Scan



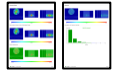
Deformable image registration, contour checks



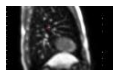
Dose prediction based on the daily image



Plan adaption



Online plan QA



[Definition of gating structure and margins]



Irradiation [with cine MRI-gating ]

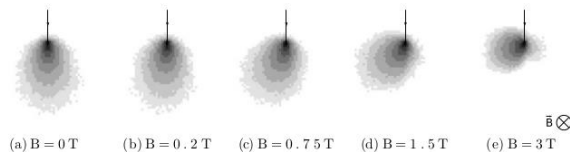
# MRI-Linacs: Challenges

- MR safety measures



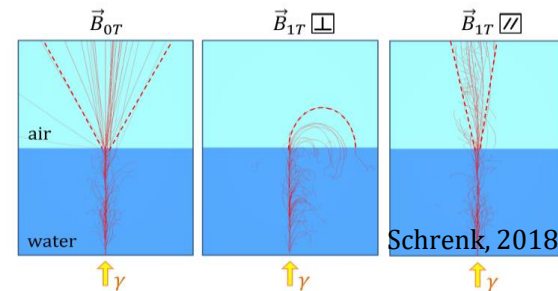
- Clothing?, Tattoos?, Piercings?
- (Medical) implants

- Double training of staff
- Room shielded for both MRI and RT
- Limited space within the MRI bore
- Long treatment time (up to 1.5 h)
- Dosimetry in MF – the main challenge
  - MRI compatible devices
  - Positioning of the water phantom



Raaijmakers et al. 2008

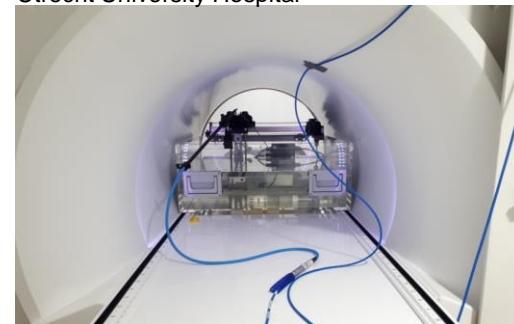
## Electron return effect



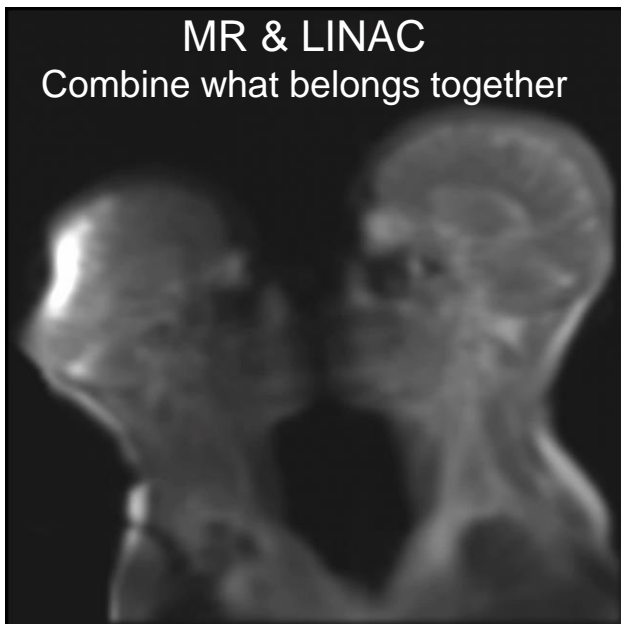
ViewRay MRIdian  
Heidelberg University Hospital



Elekta Unity  
Utrecht University Hospital



# Thank you!



	<b>ViewRay MRIdian</b>	<b>Elekta Unity</b>
Energy	6 MV, FFF	7 MV, FFF
Cryostat-/Coil-Attenuation	ca. 10.0%	56.3%
SAD	90 cm	143.5 cm
Dose rate	6 Gy/min	4 Gy/min
Field size	27.4 cm(LR) x 24.1 cm(IS)	57.4 cm(LR) x 22 cm(IS)
MLC	8.3 mm, stacked, double focus	7.1 mm, single focus
MLC Orientation	Cross-plane	In-plane
Table positioning	3D	1D
EPID for MV Imaging	No	Yes
Treatment planning system	ViewRay	Monaco

Adapted from S. Dorsch, Heidelberg University Hospital