Stereotactische radiotherapie mbv een MR-Linac

Dr. ir. Rob Tijssen

Klinisch Fysicus Radiotherapie, Catharina ziekenhuis

9 maart 2023

catharina
a santeon hospital

Passion for life.

MR-guided lung SBRT

Dr. ir. Rob Tijssen

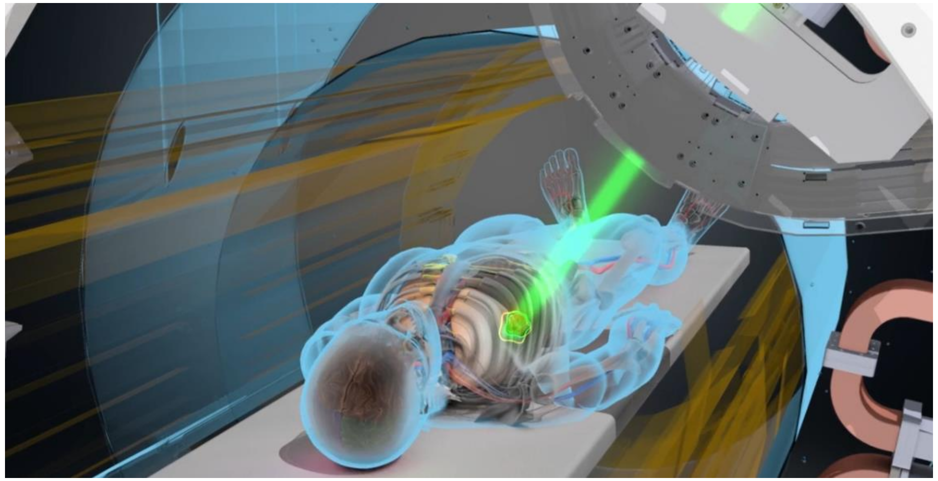
Klinisch Fysicus Radiotherapie, Catharina ziekenhuis

9 maart 2023

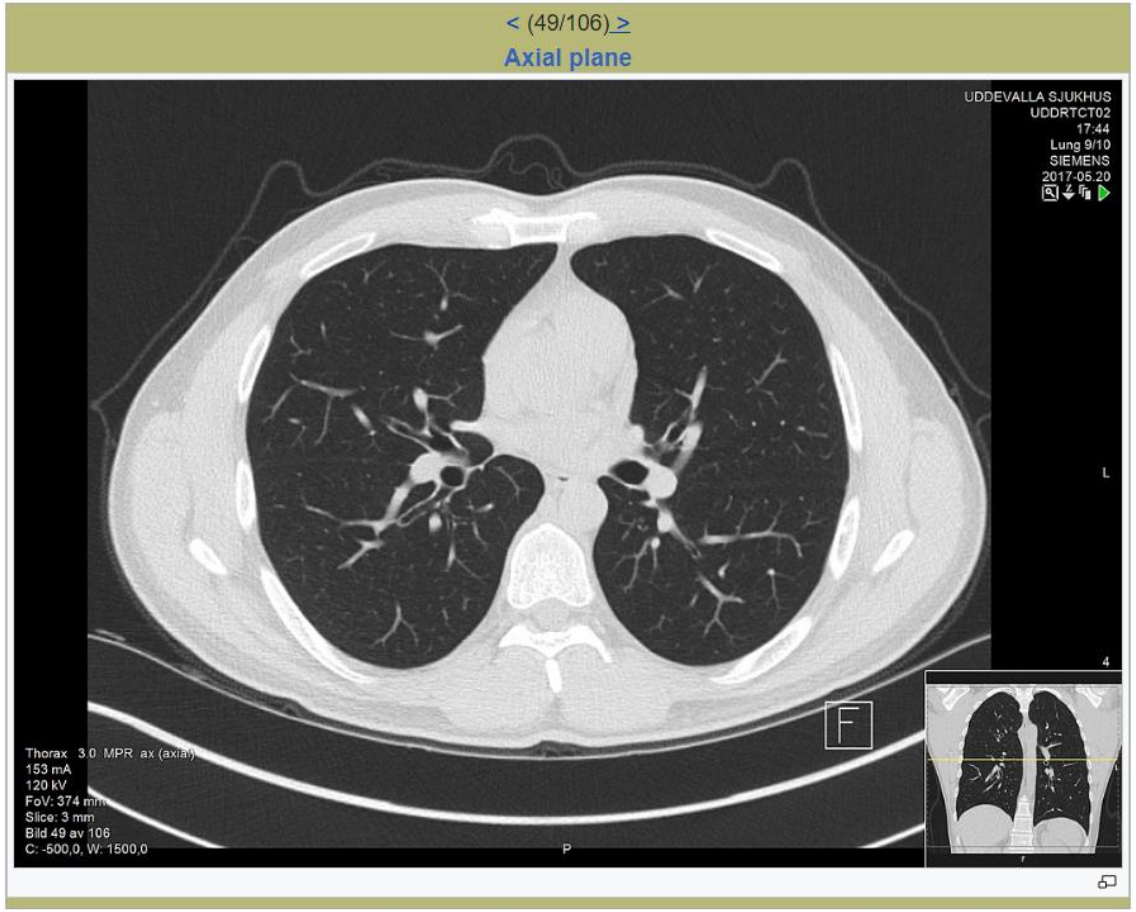
Passion for life.

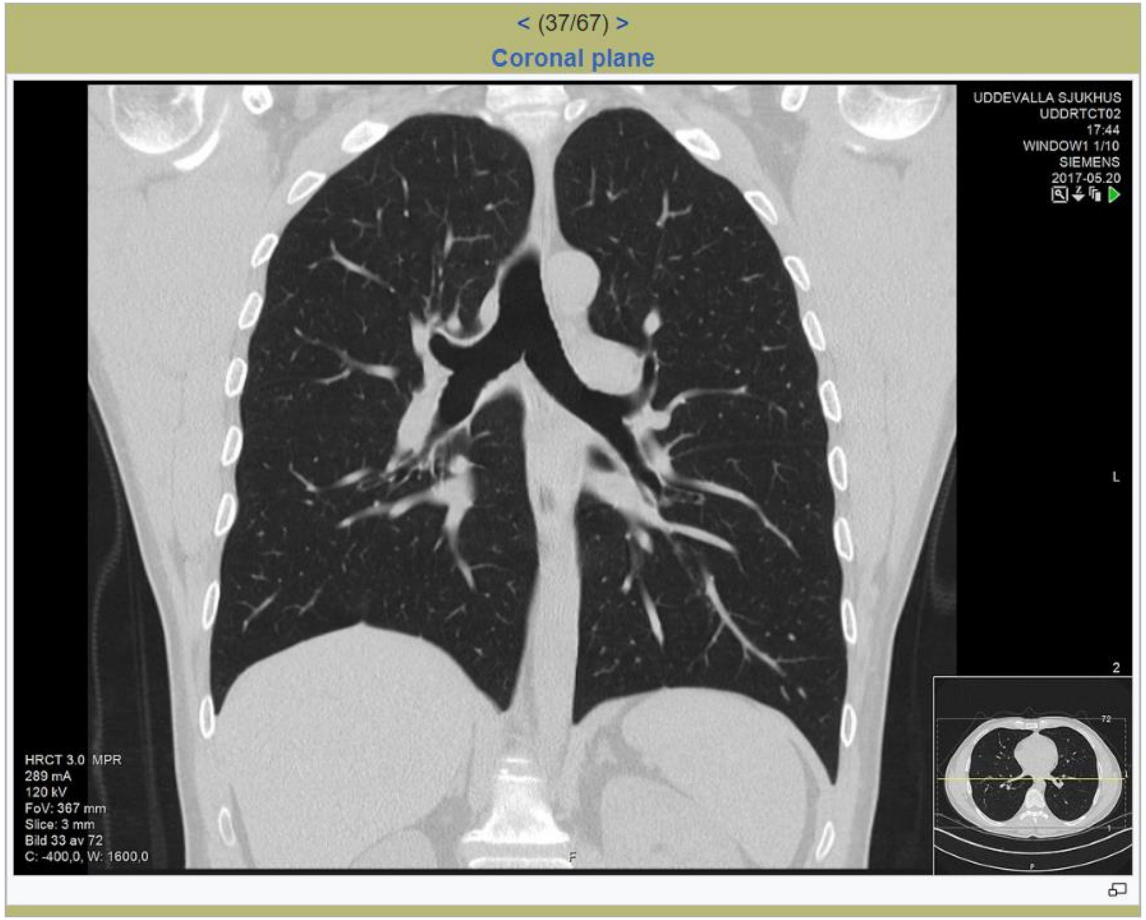
Contents

- Why MRI?
  - Challenges of Lung MRI
- Why MR-Linac?
  - Benefits of MRgRT
  - Differences and similarities between two systems
- Lung MRgRT from a physics perspective
  - Clinical implementation
  - Future outlook



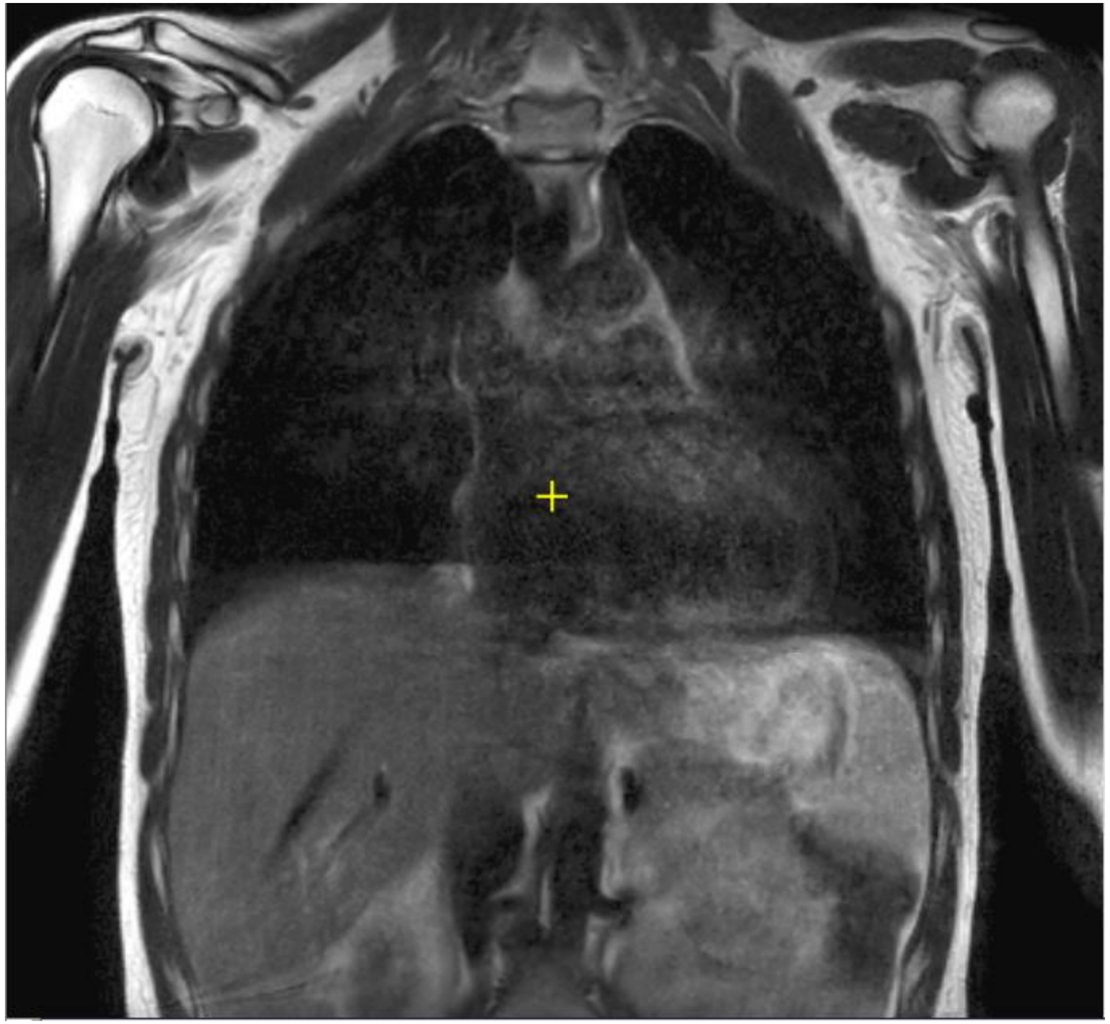
Why MRI?





https://commons.wikimedia.org/wiki/Scrollable_high-resolution_computed_tomography_images_of_a_normal_thorax

Why MRI?

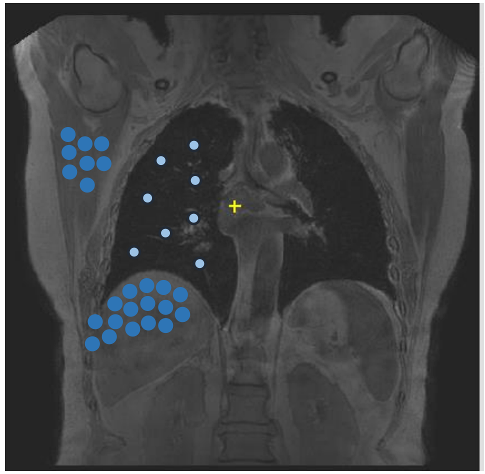


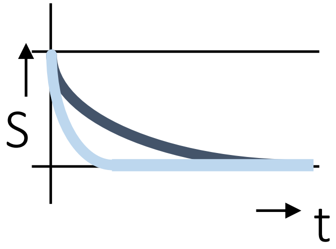
Why MRI?

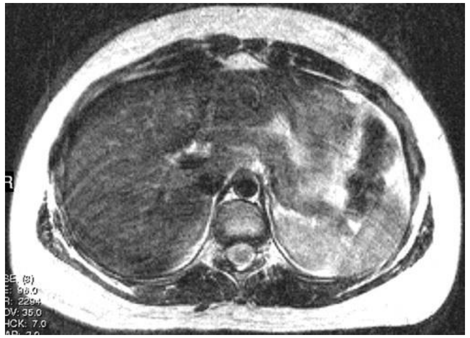
Lung MRI is challenging!

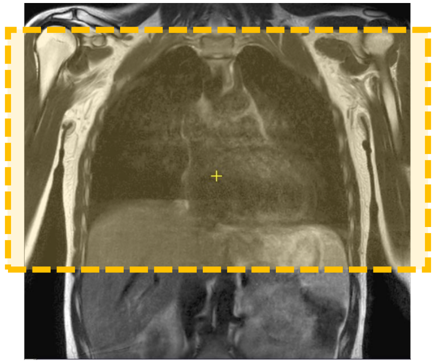
Low proton density | short relaxation times | respiratory motion | cardiac motion | large organ

proton



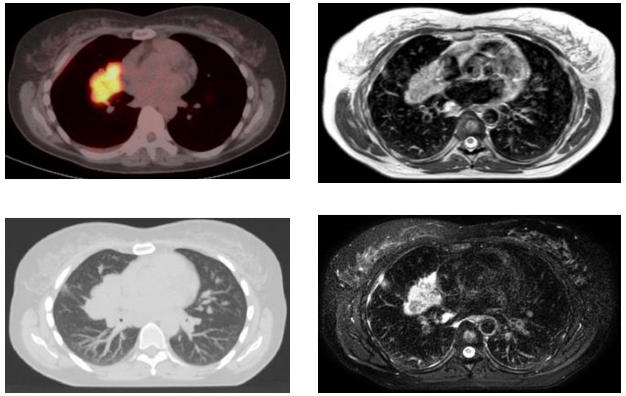


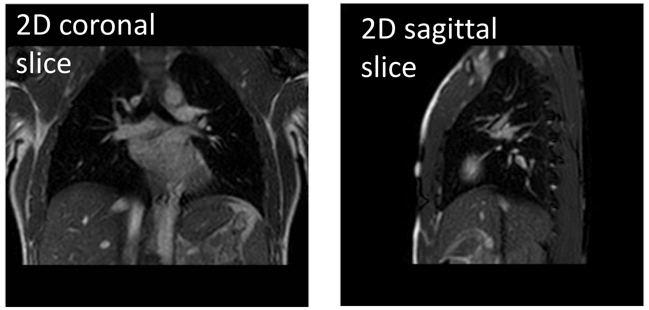


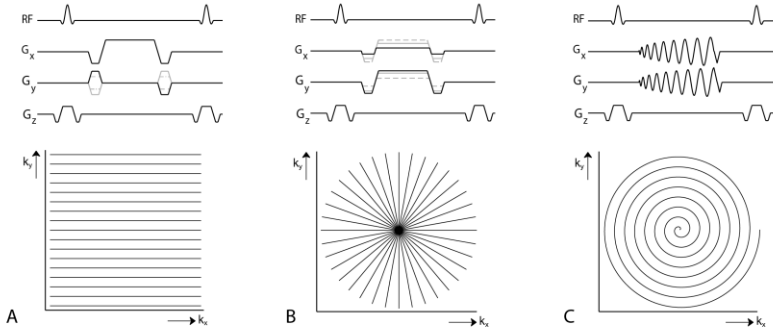


MRI is flexible!

Flexible in contrast | Flexible in orientation | Flexible in acquisition



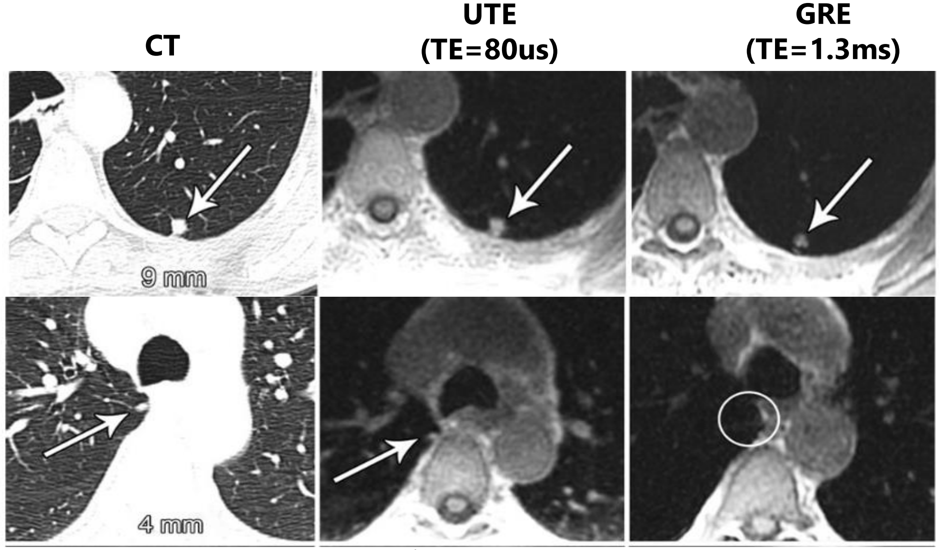




Solutions

Low proton density | **short relaxation times** | respiratory motion | cardiac motion | large organ

1. Reduce Echo Time



[1]Burris et al. Radiology 2016; 278(1):239-46

2. Increased relaxation time

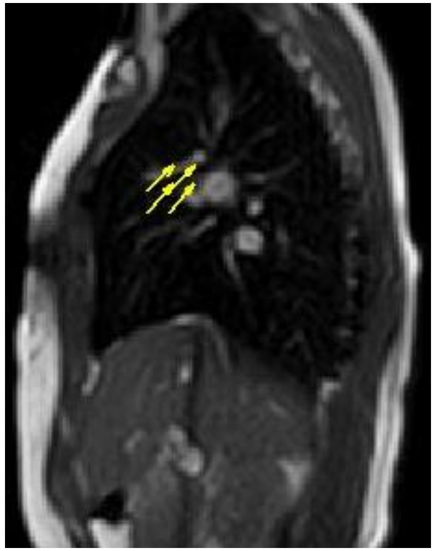
Tissue	T1 (ms)	T2 (ms)	T2* (ms)
Lung			
1.5T	1250	41	1
0.55T	975	60	10

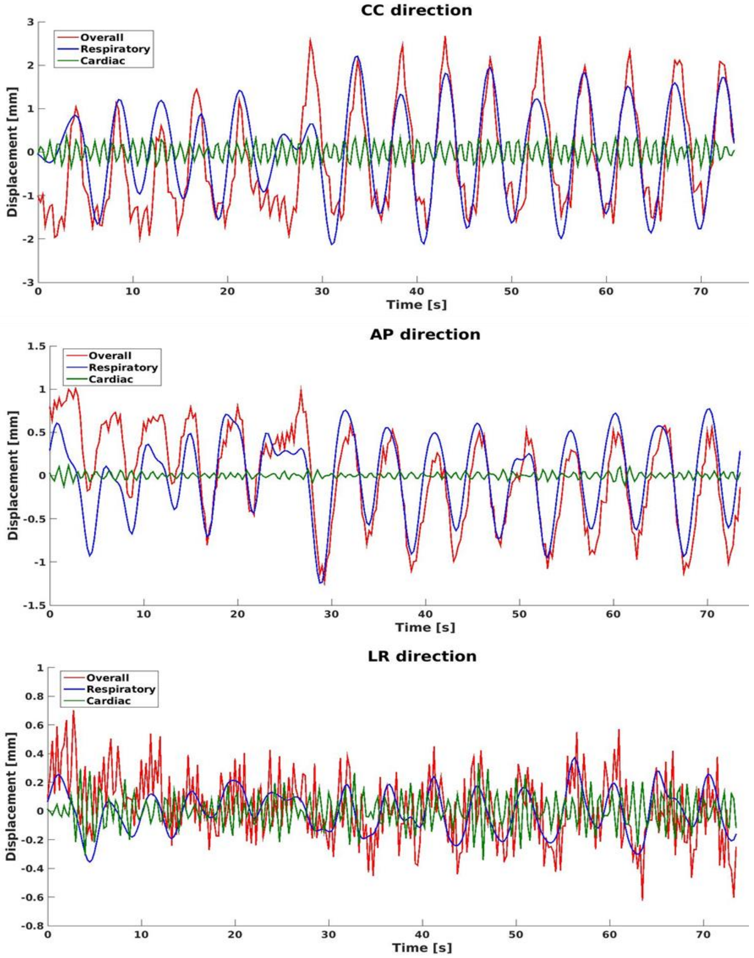
Washburn et al., Radiology 2019; 293:384–393

Solutions

Low proton density | short relaxation times | **respiratory motion** | **cardiac motion** | large organ

Sag cine-MRI

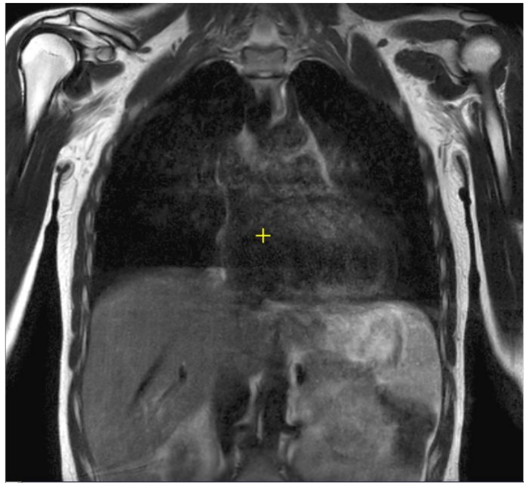




Solutions

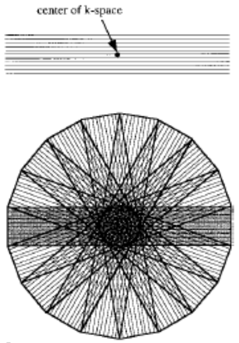
Low proton density | short relaxation times | **respiratory motion** | **cardiac motion** | large organ

T2-TSE w/o triggering

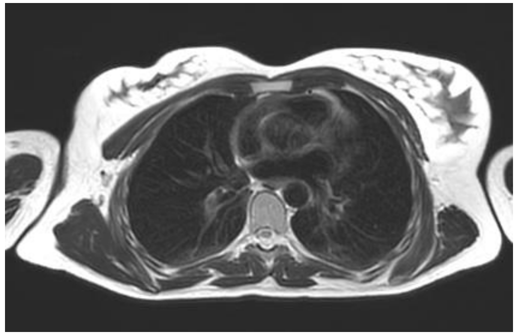


T1-Dixon
cardiac & resp triggering

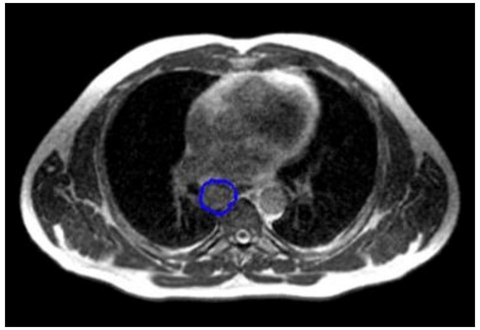
> 10 mins!



T2-TSE propeller (1:03)



breath-hold bSSFP

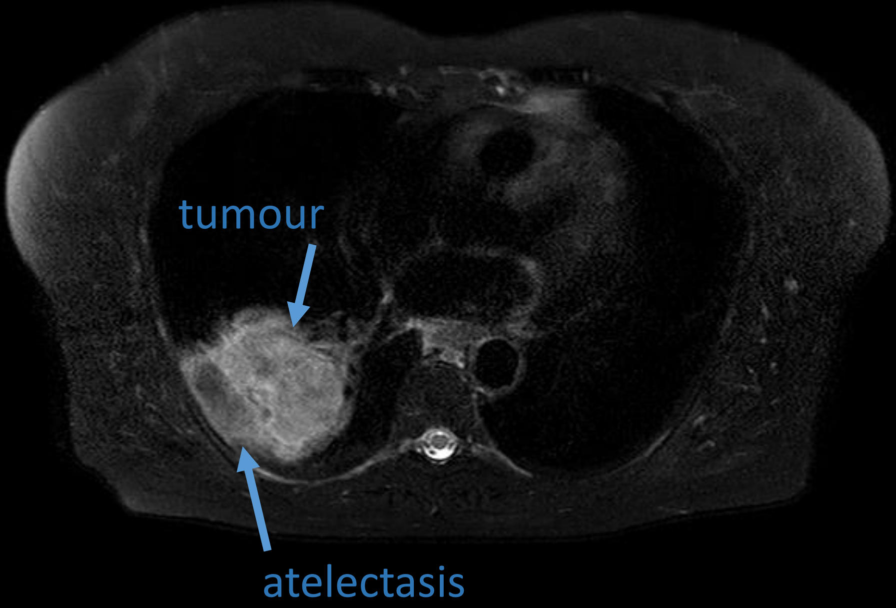


17sec
1.6x1.6x3.0 mm

1. Triggered imaging
2. Propeller / radial readout
3. Breath hold

a few examples..

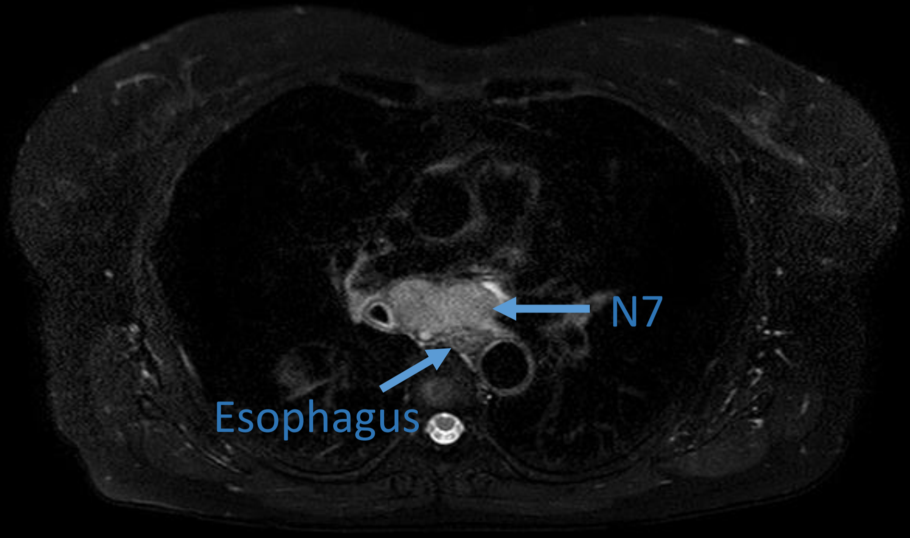
tT2-TSE SPAIR, resp triggered



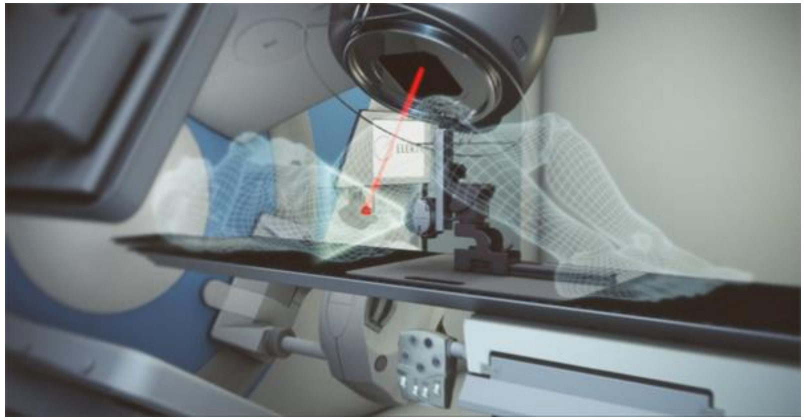
Res: 0.9x1.6x4.0mm
TR=2040ms, TE=100ms
Time/resp: 2040ms
Acq-time: 6.00min

a few examples..

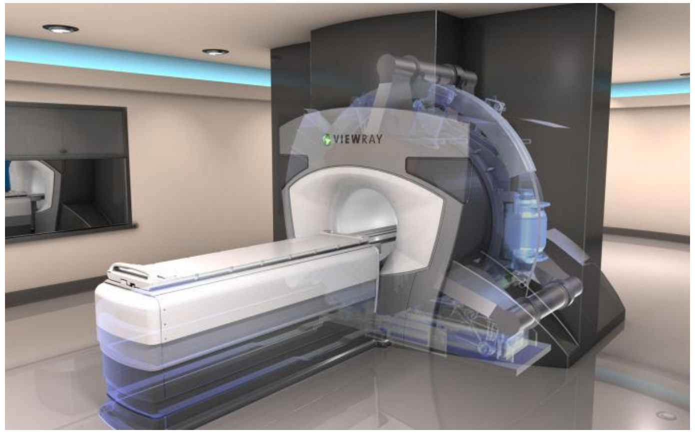
tT2-TSE SPAIR, resp triggered



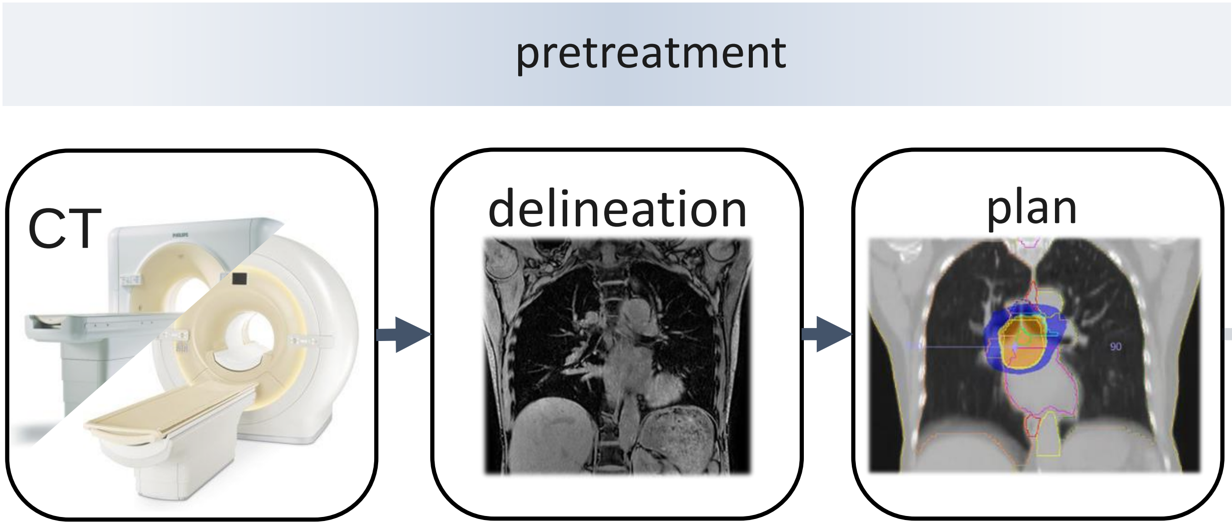
Res: 0.9x1.6x4.0mm
TR=2040ms, TE=100ms
Time/resp: 2040ms
Acq-time: 6.00min

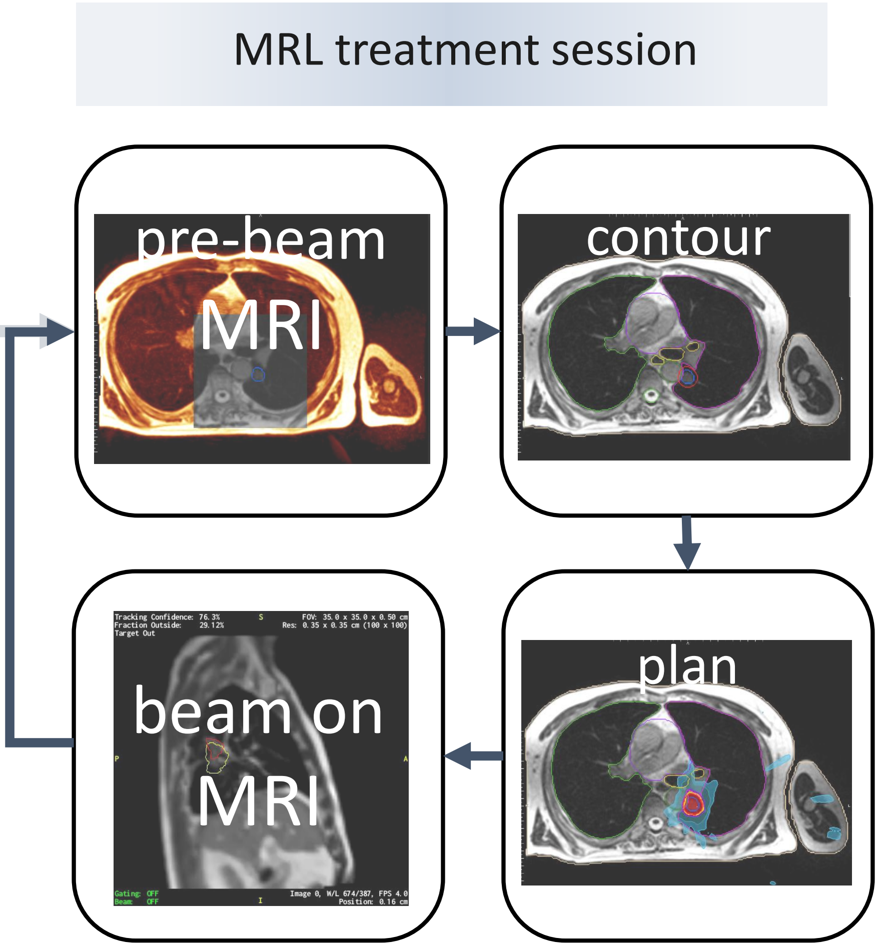


Why MR-Linac?



Why MR-Linac





Adaptive RT
- Inter-fraction anatomical changes
- Intra-fractional motion management

Adaptive MRI
- MRI = flexible (in terms of contrast)
- MRI = independent of beam angle

Two MRgRT systems available

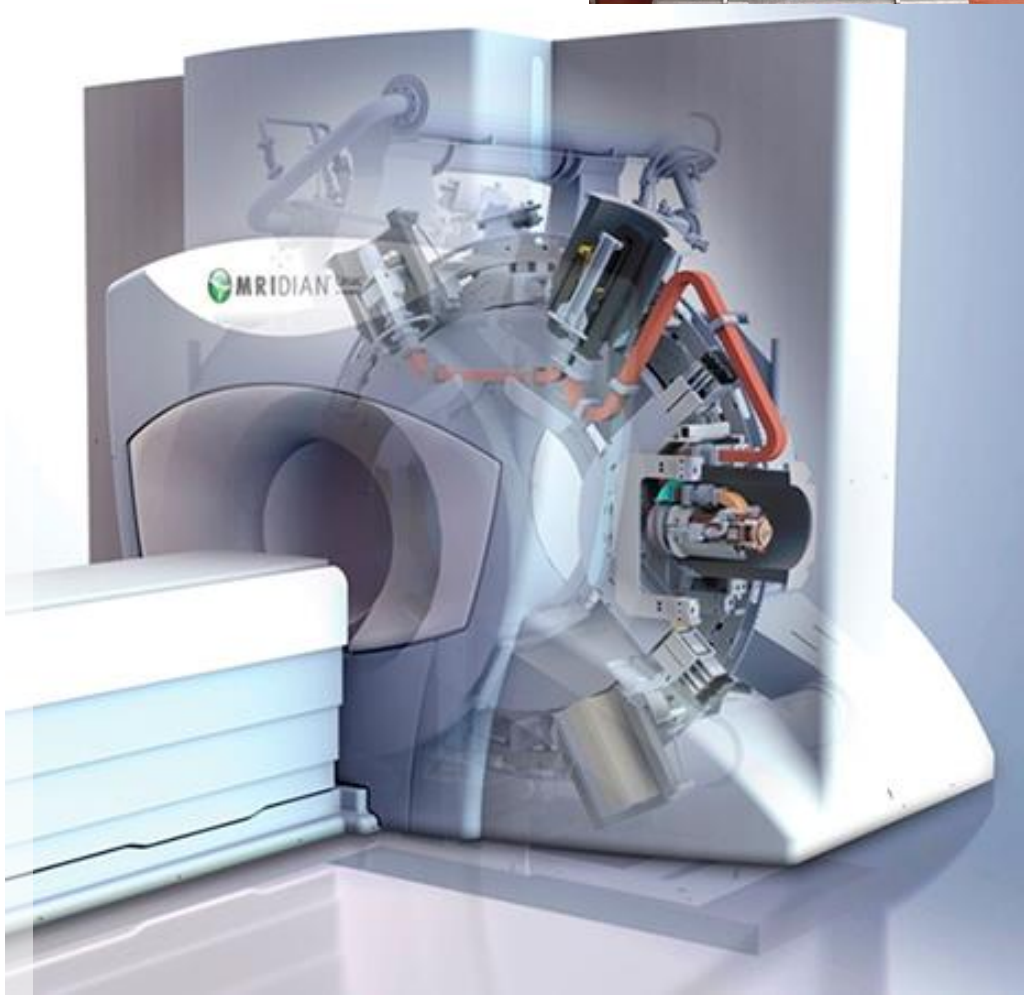
BASE
1.5T or 0.35T wide bore scanner

GANTRY
Around or in between cryostat

GRADIENTS
Split gradient design (similar)

RECEIVER COILS
Radiolucent coil array (similar)

SHIELDING
Wrap around or buckets



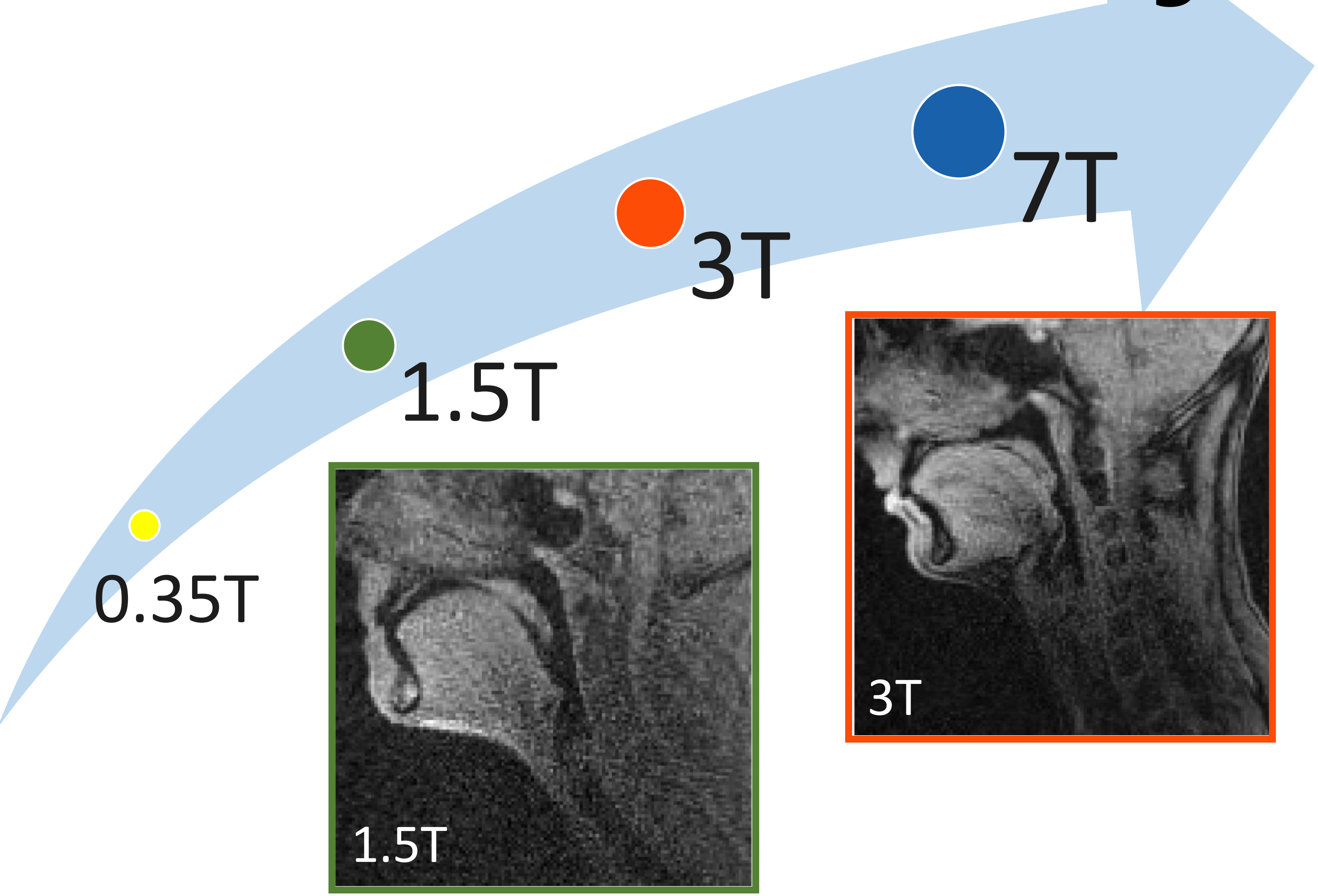
1.5T Elekta Unity

0.35T ViewRay MRIdian

Field strength

- Image accuracy
  - SNR
  - Geometric distortion
  - SAR
- Dosimetry
  - Lorentz force
  - Electron return effect

The Effect of Field strength



SNR scales with

- field strength
- voxel size
- 1/receiver bandwidth (=speed)

Higher field strength also gives:

- better functional contrast (BOLD, DWI)

but also,

- Longer T_1 relaxation rates
- higher SAR
- higher susceptibility effects
- different ERE/EFE effects

SAR (tissue heating) is always an issue at ‘ high’ field strength..!

SAR (specific absorption rate) well monitored by all commercial systems, incl MR-linacs

At 1.5T no real limitation for most real-time imaging methods

However, be careful with foreign objects (e.g., interventional MRI w/ guidewire)

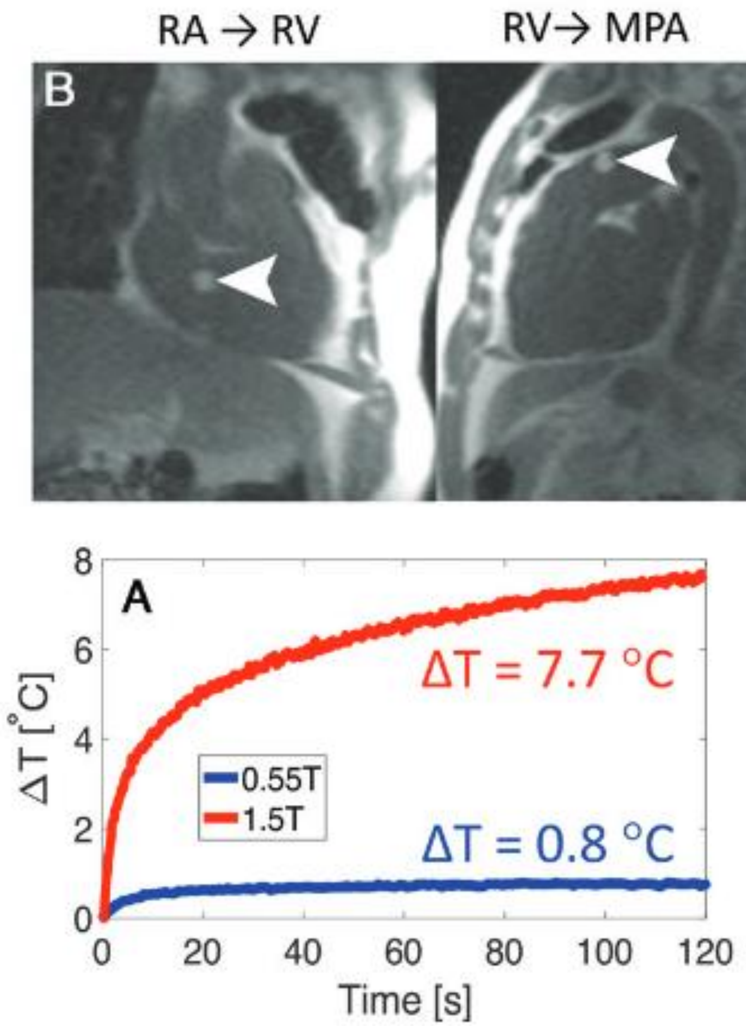
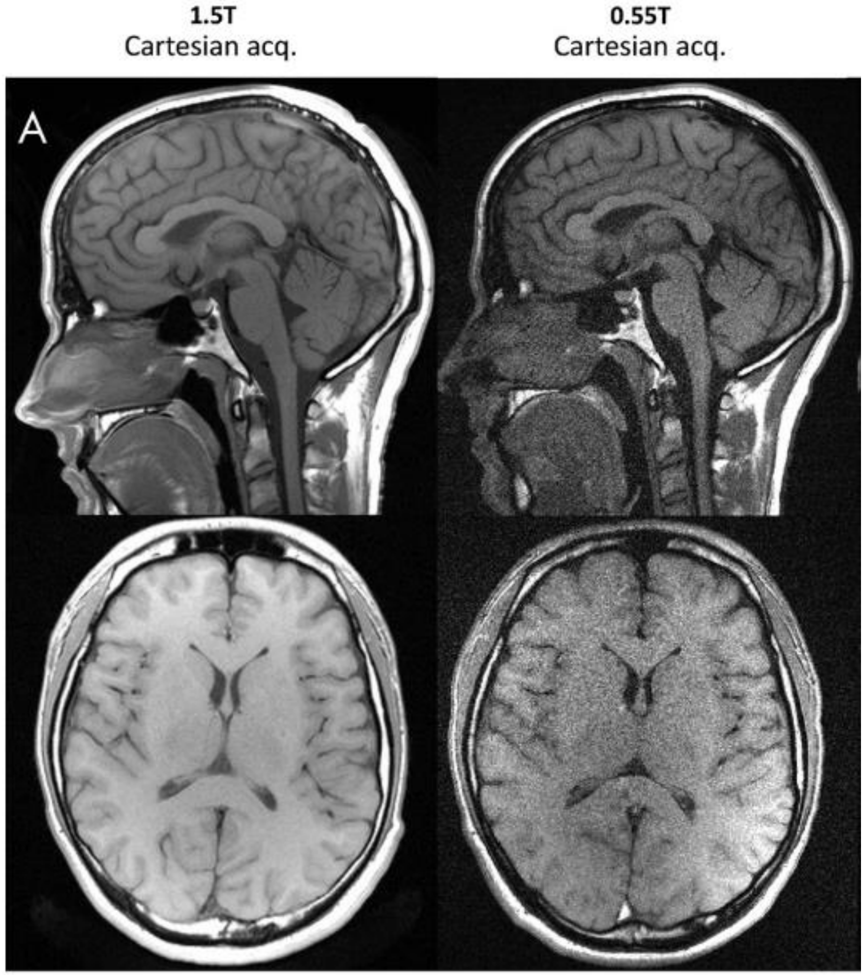
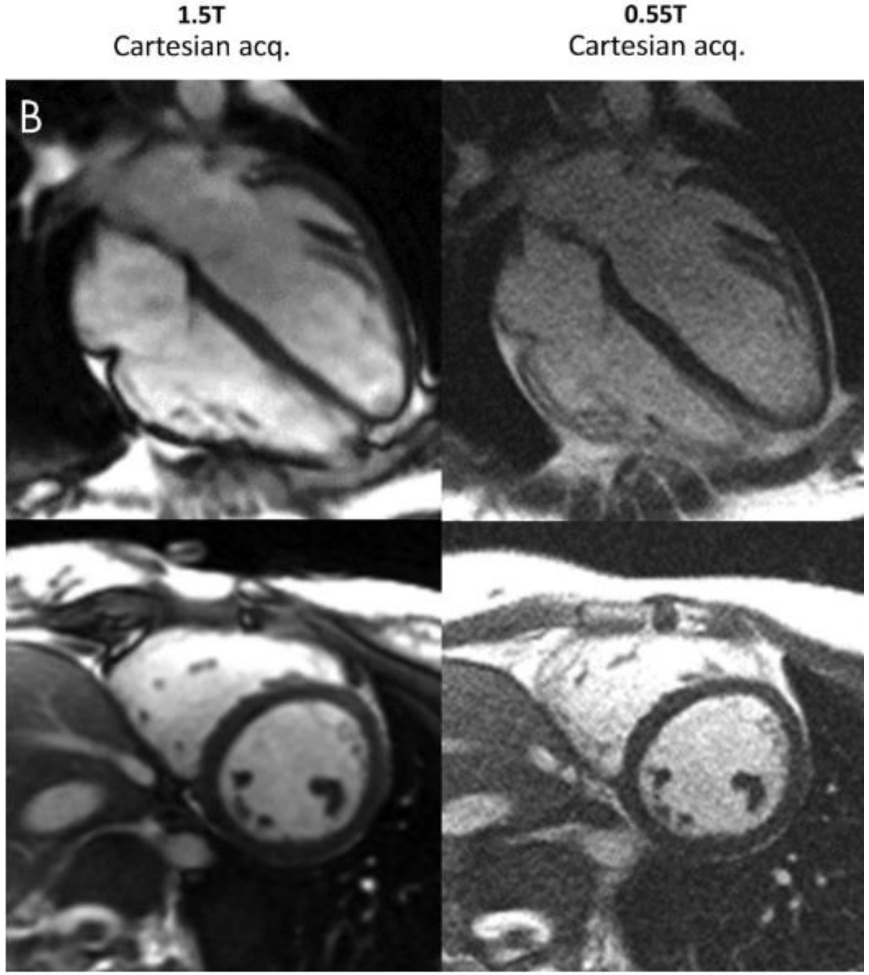


Figure: two minute real-time balanced SSFP using commercial guidewire with gadolinium filled balloon

Washburn et al., Radiology 2019; 293:384–393

SNR is much better at higher field strength..!





Washburn et al., Radiology 2019; 293:384–393

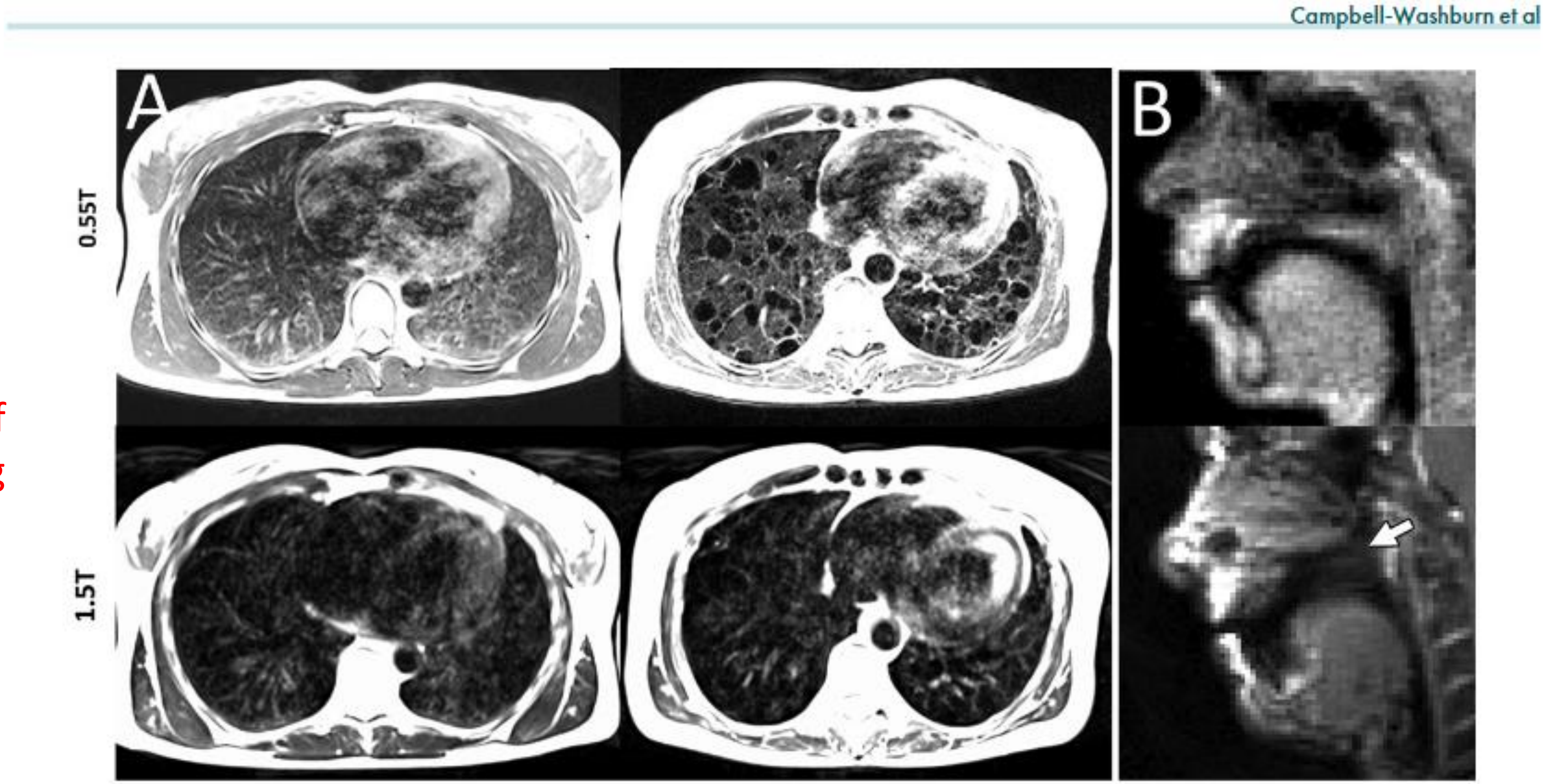
Field strength: effect on SNR

MRI signal depends on:

Amount of polarisation

Amount of signal dephasing

- high field strength: $T_2^{(*)}$ of lung tissue is extremely short
- Low field strength: less signal dephasing around air tissue interfaces



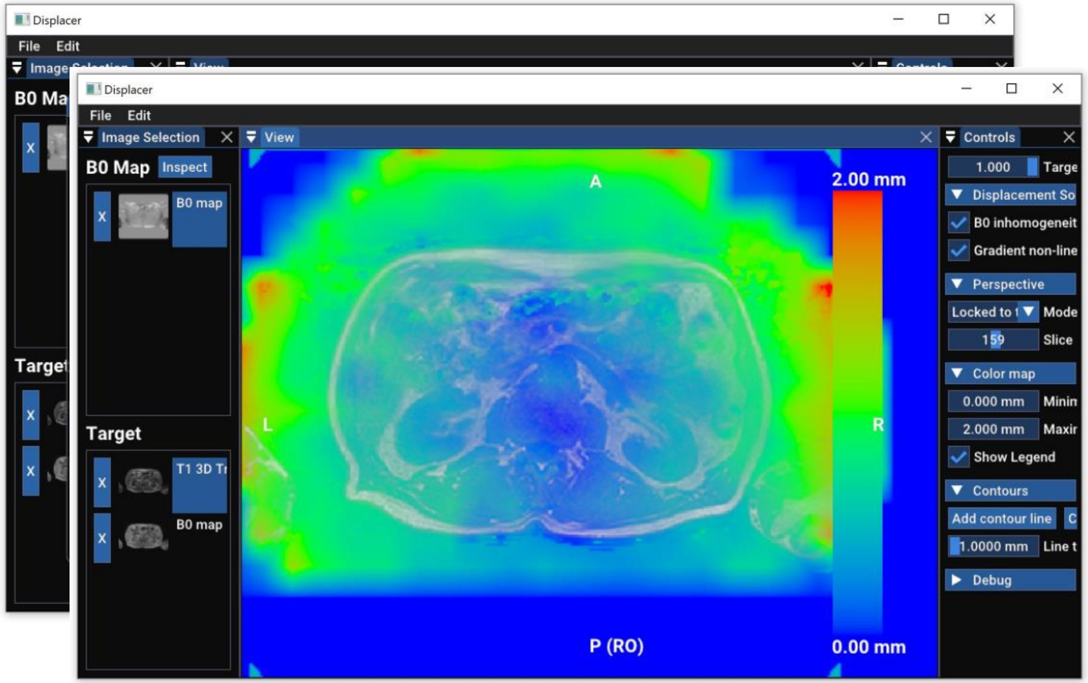
Healthy lung

lymphangioleiomyomatosis

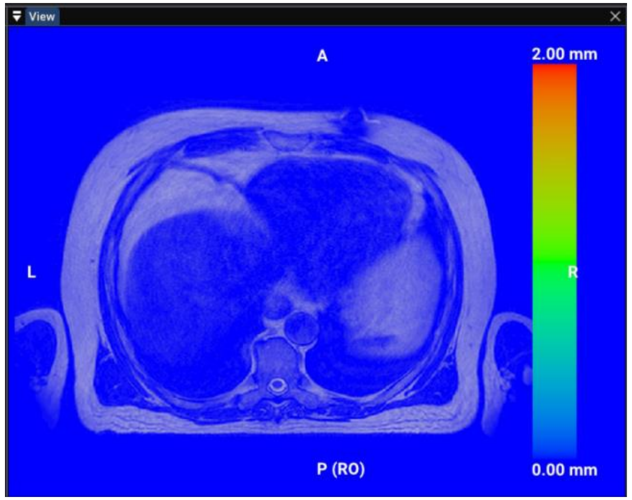
Real-time speech MRI

Washburn et al., Radiology 2019; 293:384–393

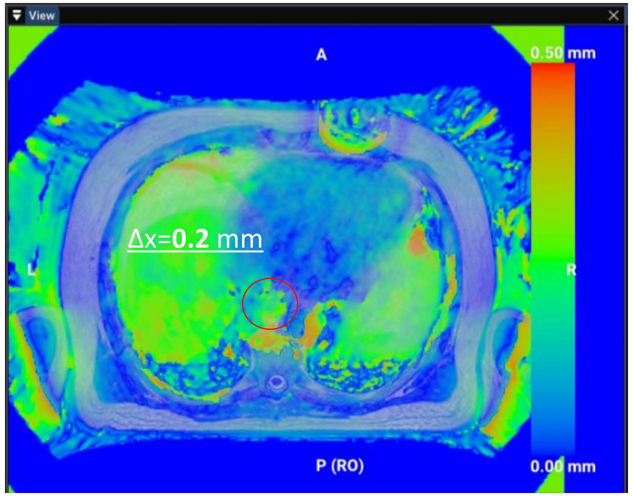
Too much distortion at high field strength..!



anatomical



B_0 induced distortion



Yes, susceptibility (and thereby distortion) scales with field strength.

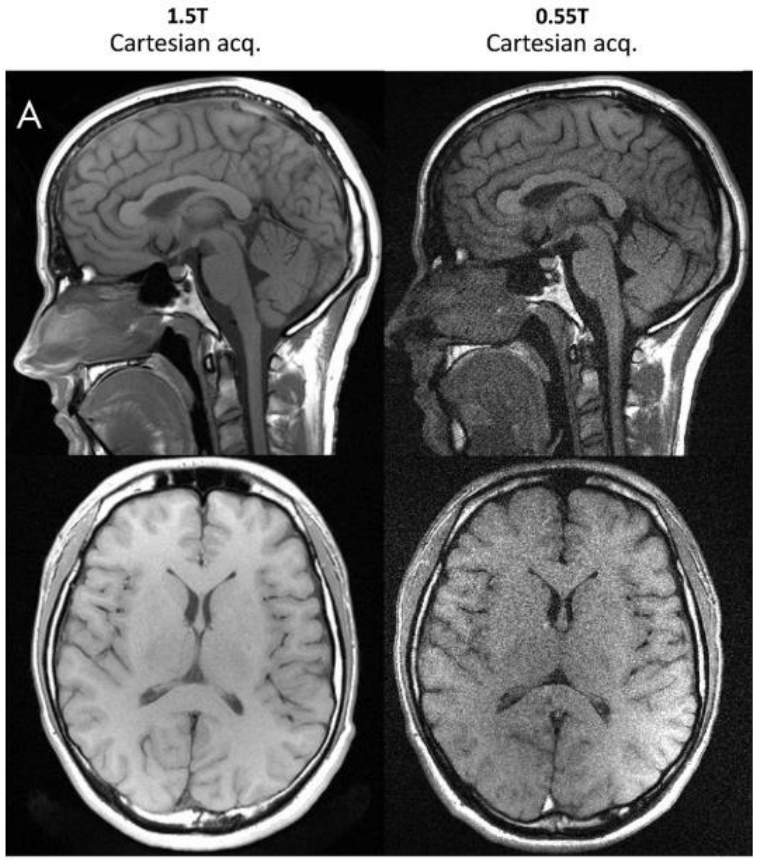
Yes, susceptibility effects 4x larger at 1.5T compared with 0.35T

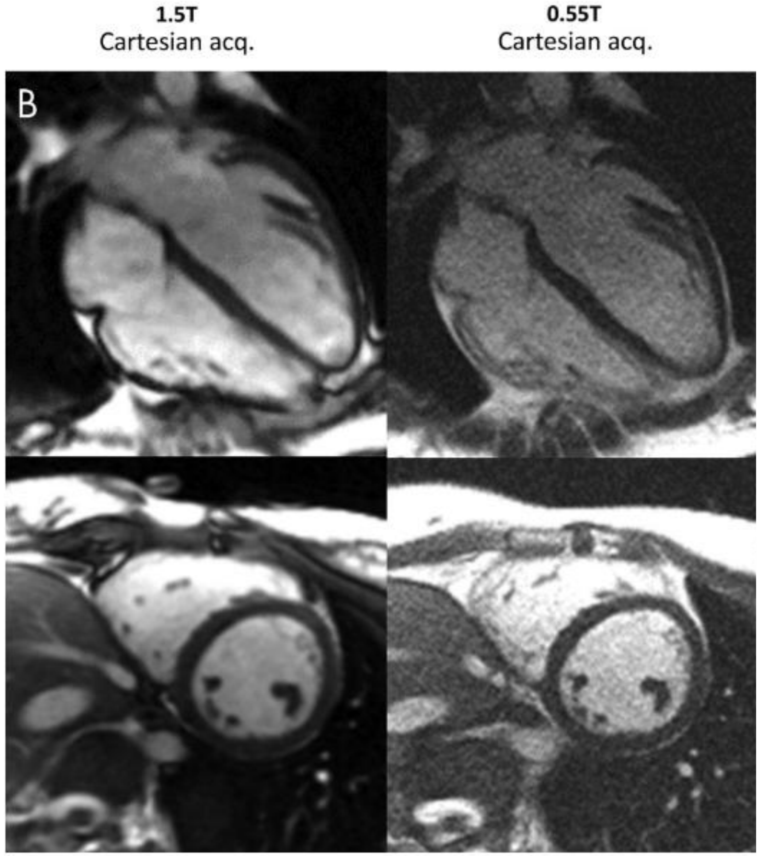
However, effects effectively supressed by using high BW imaging

Real difference: longer, more efficient, readouts (e.g., spiral) easier at lower field strength

Tijssen et al., MR in RT, 2019

~~SNR is always better at higher field strength..!~~



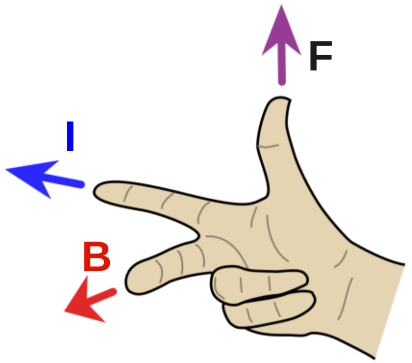


Washburn et al., Radiology 2019; 293:384–393

Field strength

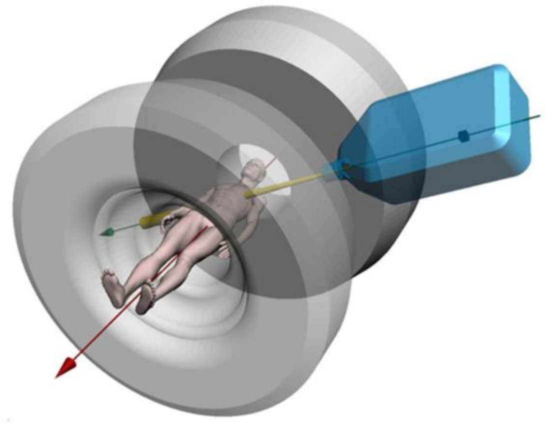
- Image accuracy
  - SNR (polarisation VS short relaxation times)
  - Geometric distortion (susceptibility)
  - SAR
- **Dosimetry**
  - Lorentz force
  - Electron return effect

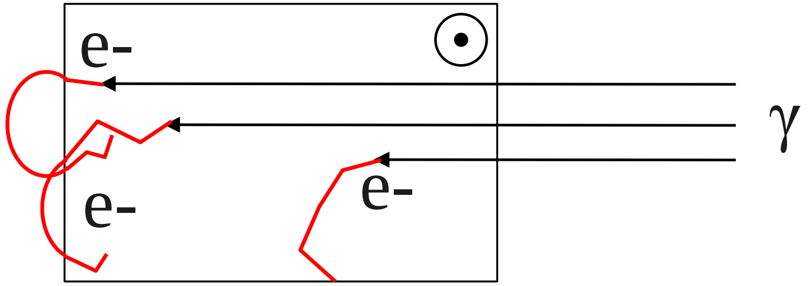
B_0 field exerts a Lorentz force on e^-

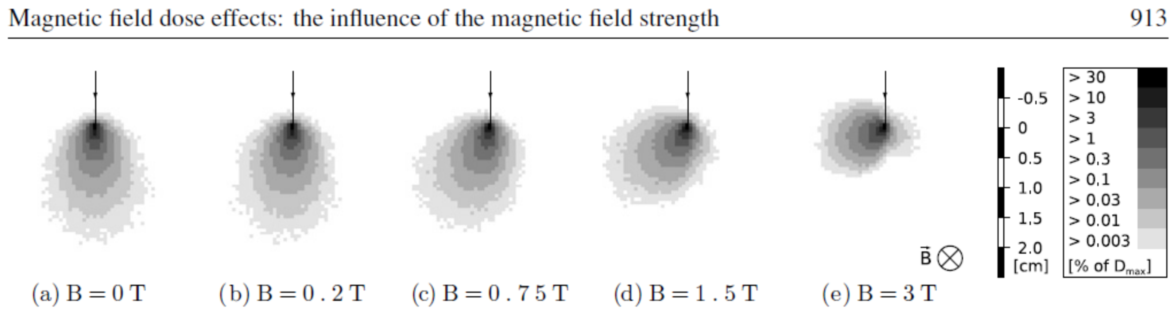


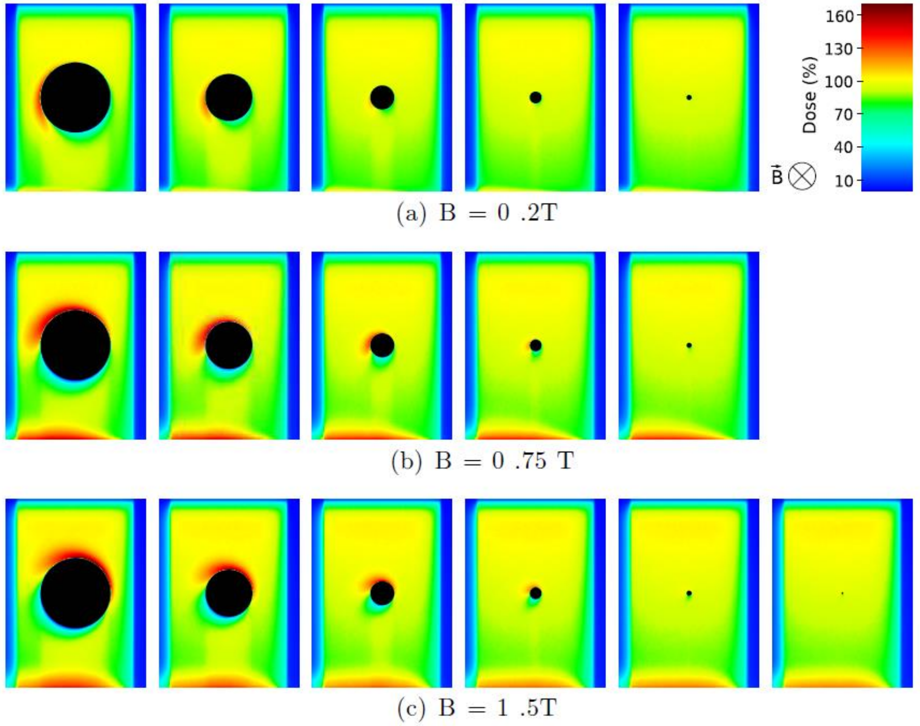
$$F = q\vec{v} \times B$$

The resulting electron return effect (ERE) depends on the <u>size</u> and orientation of B_0 with respect to the incident beam



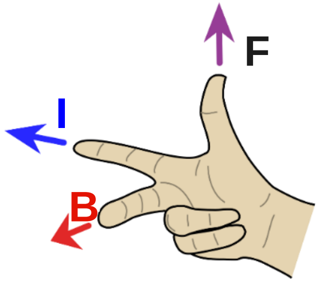




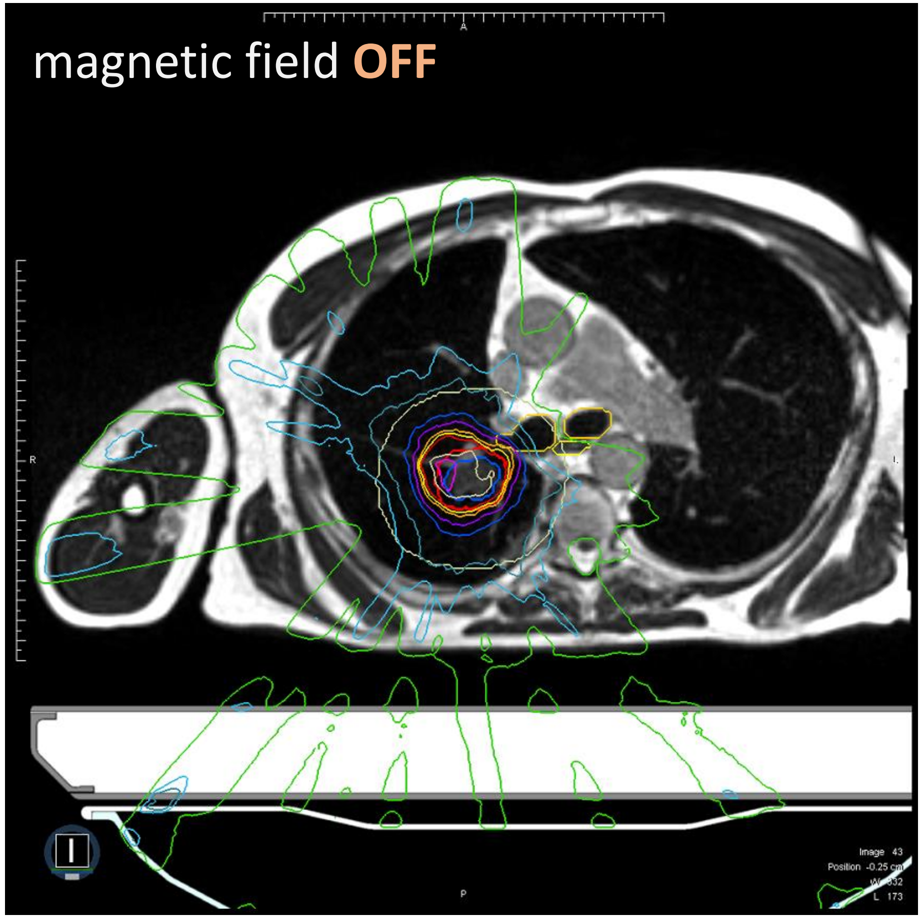


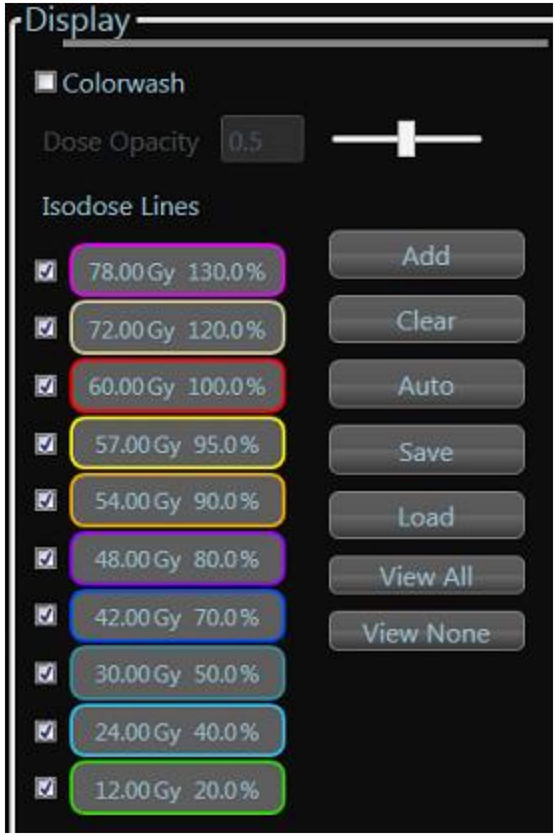
Raaijmakers et al., PMB 2005

Electron Return Effect @0.35T

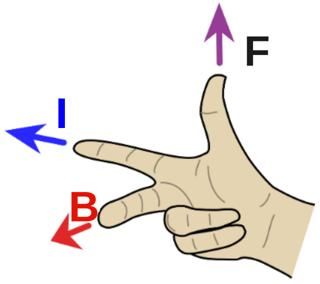


$F = q\vec{v} \times B$

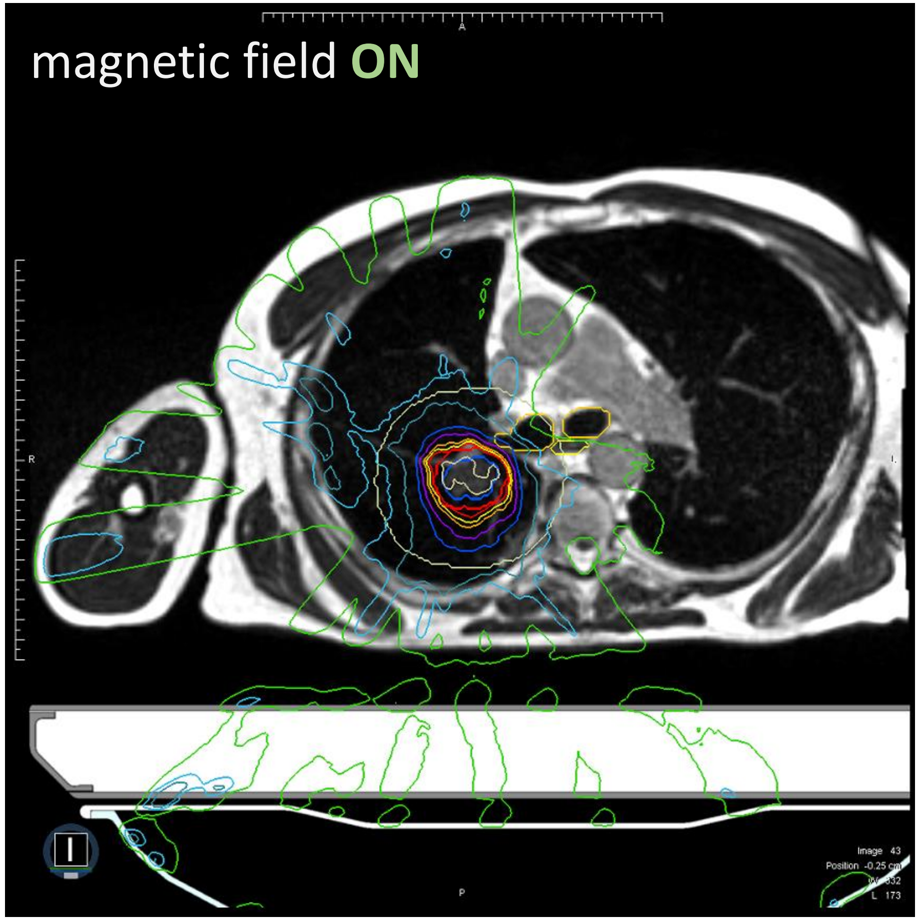


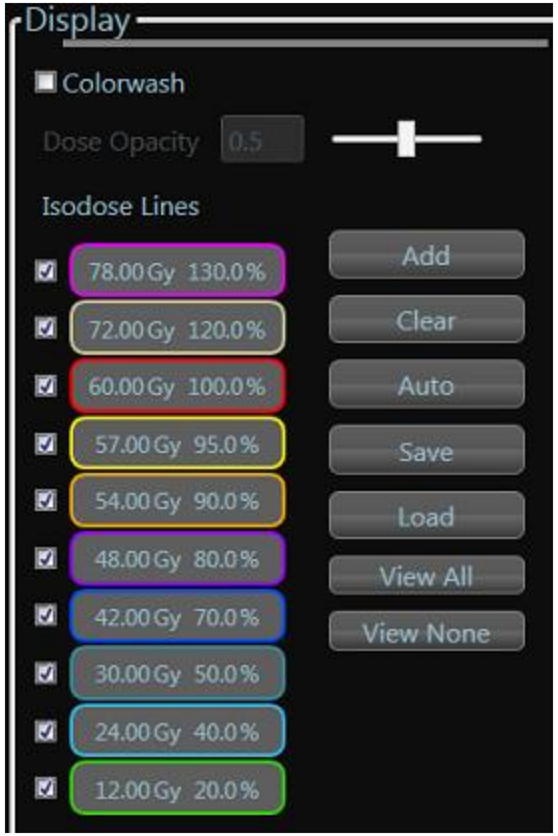


Electron Return Effect @0.35T



$F = q\vec{v} \times B$

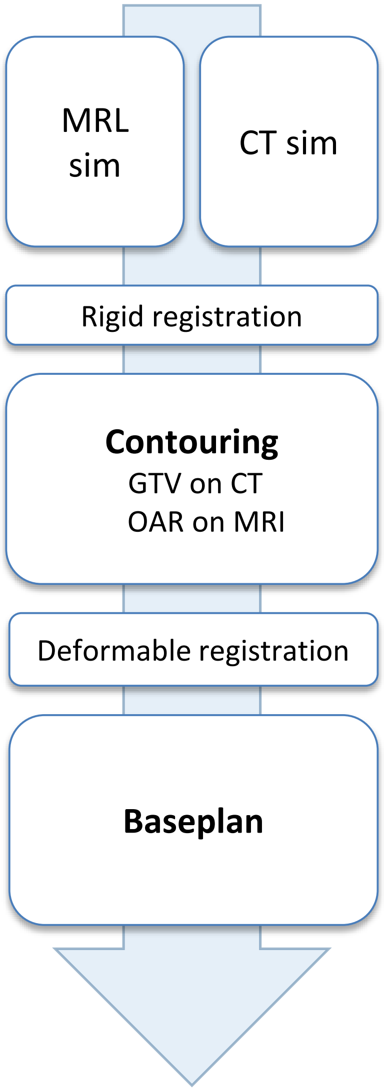




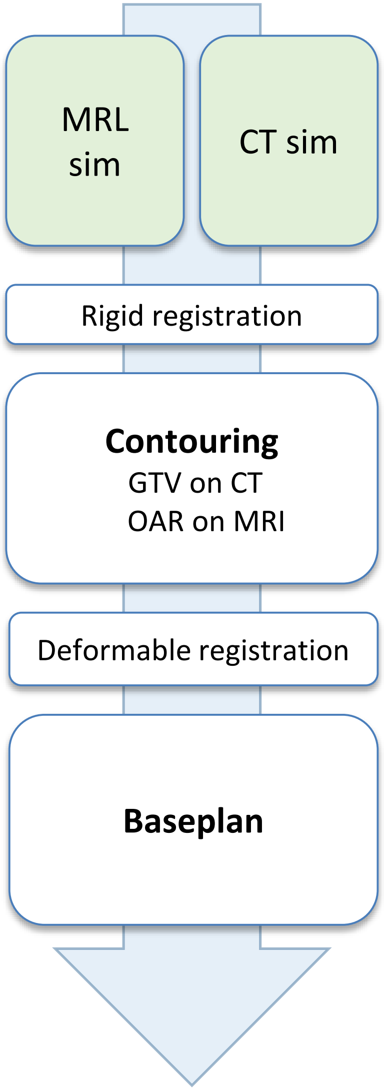
Clinical implementation
practical considerations

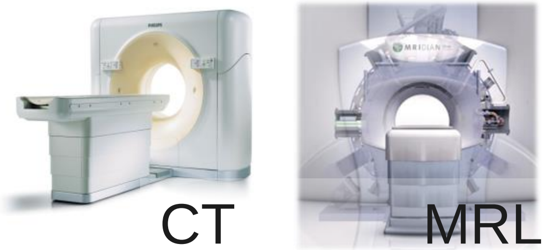
- Susceptibility effect
  - Delineation in areas with short relaxation time
- Planning strategies
  - Robustness
- Motion management
  - Gating
  - Compensating drift
- Patient feedback monitor
- 4D QA

Treatment preparation



Treatment preparation





Treatment preparation

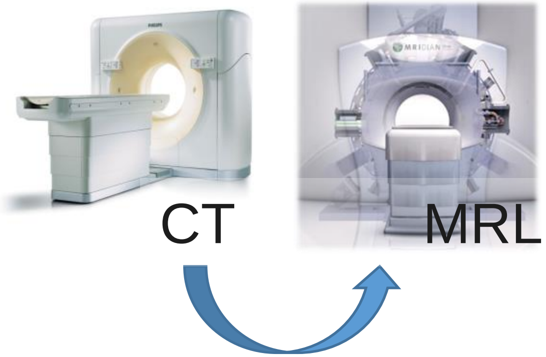
CT sim | MRL sim

Rigid registration

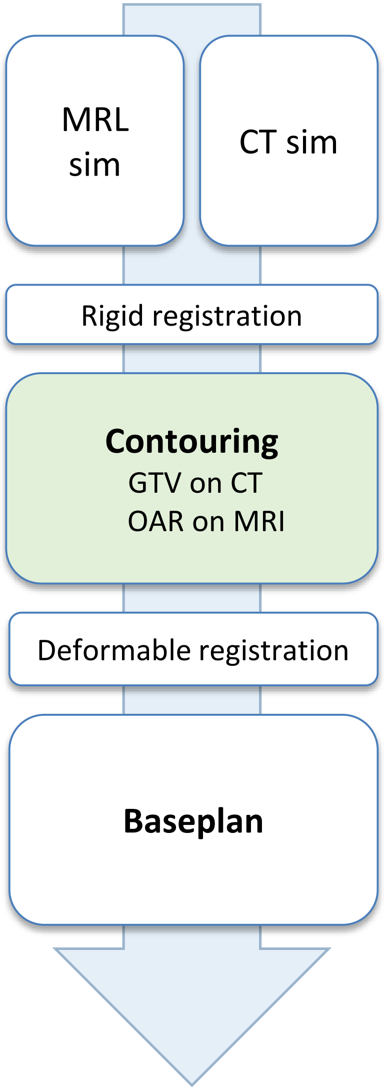
Contouring
GTV on CT
OAR on MRI

Deformable registration

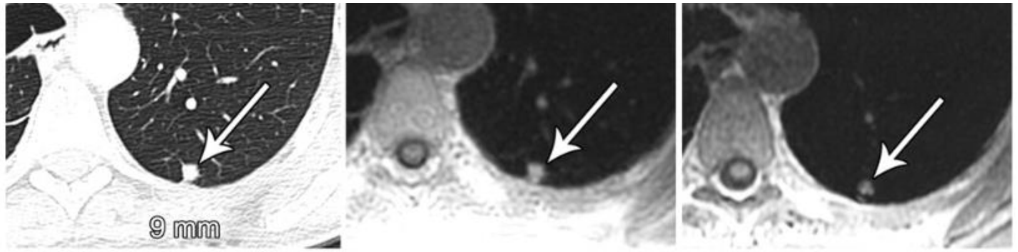
Baseplan



Treatment preparation

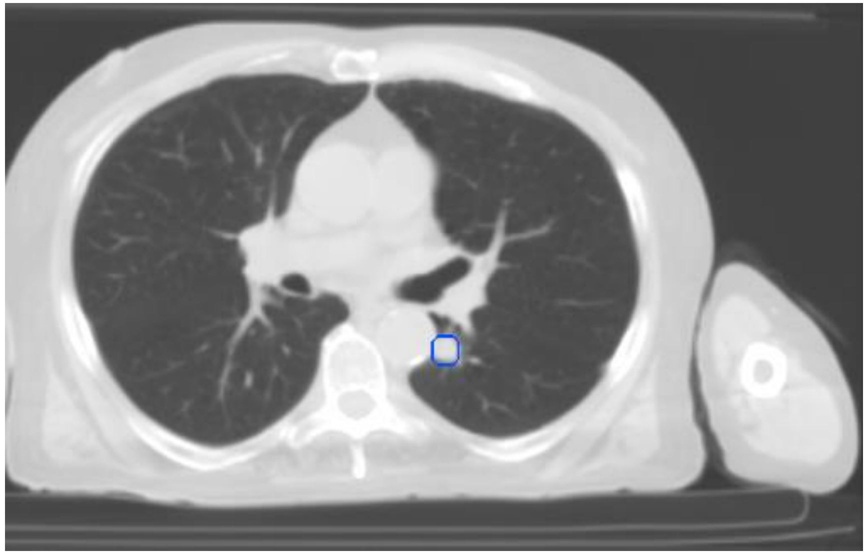


CT | **UTE (TE=80us)** | **GRE (TE=1.3ms)**

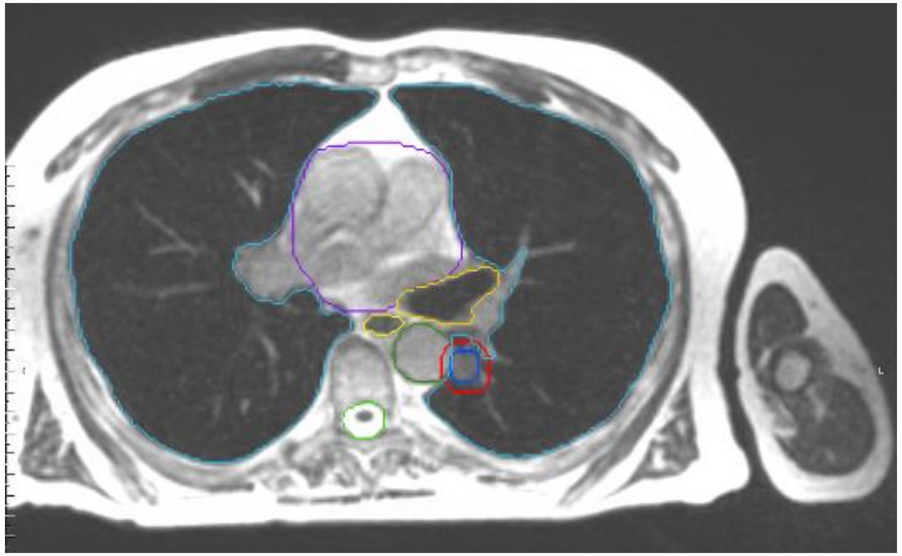


[1]Burris et al. Radiology 2016; 278(1):239-46

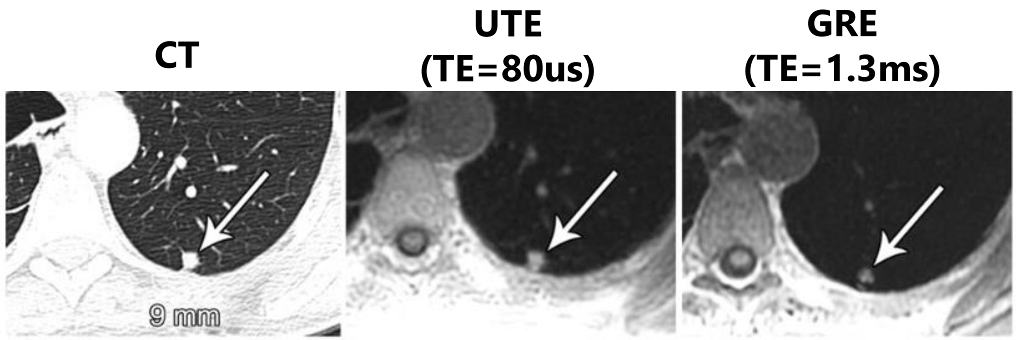
GTV delineation on CT



AOR delineation on MRI



Treatment preparation



[1]Burris et al. Radiology 2016; 278(1):239-46

MRL sim

CT sim

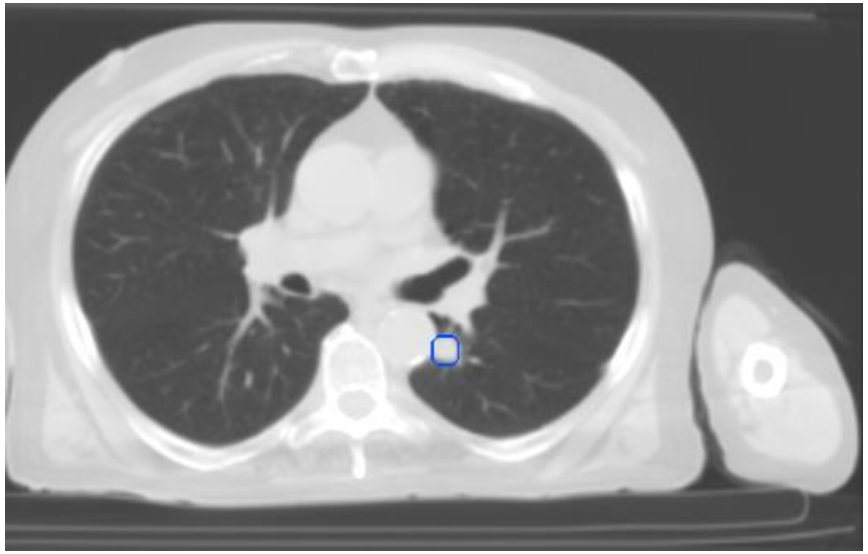
Rigid registration

Contouring
GTV on CT
OAR on MRI

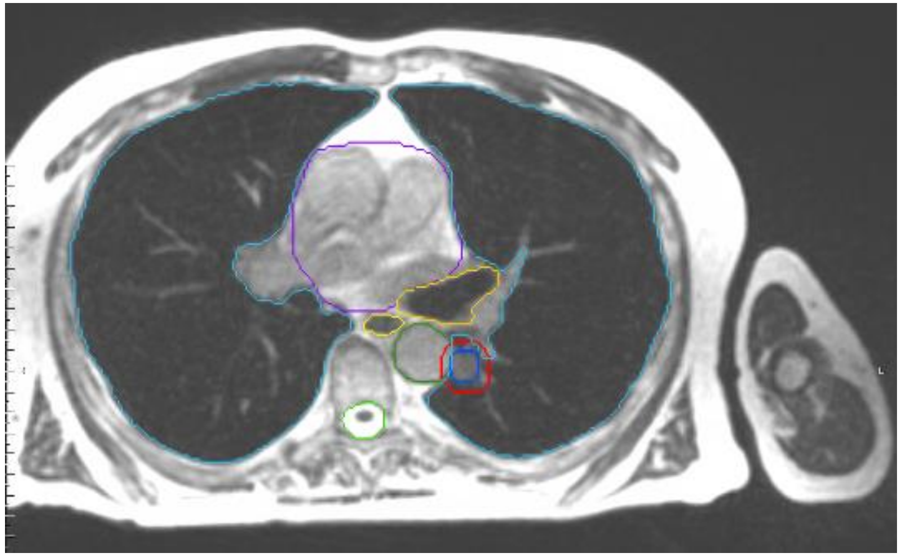
Deformable registration

Baseplan

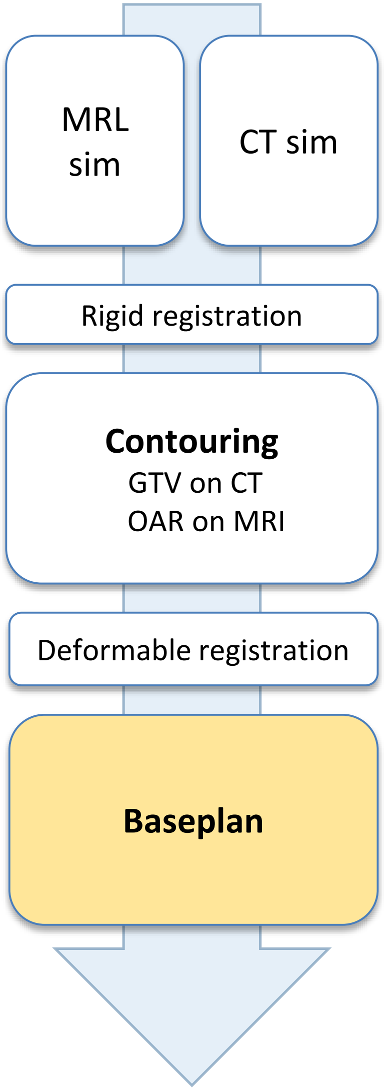
GTV delineation on CT

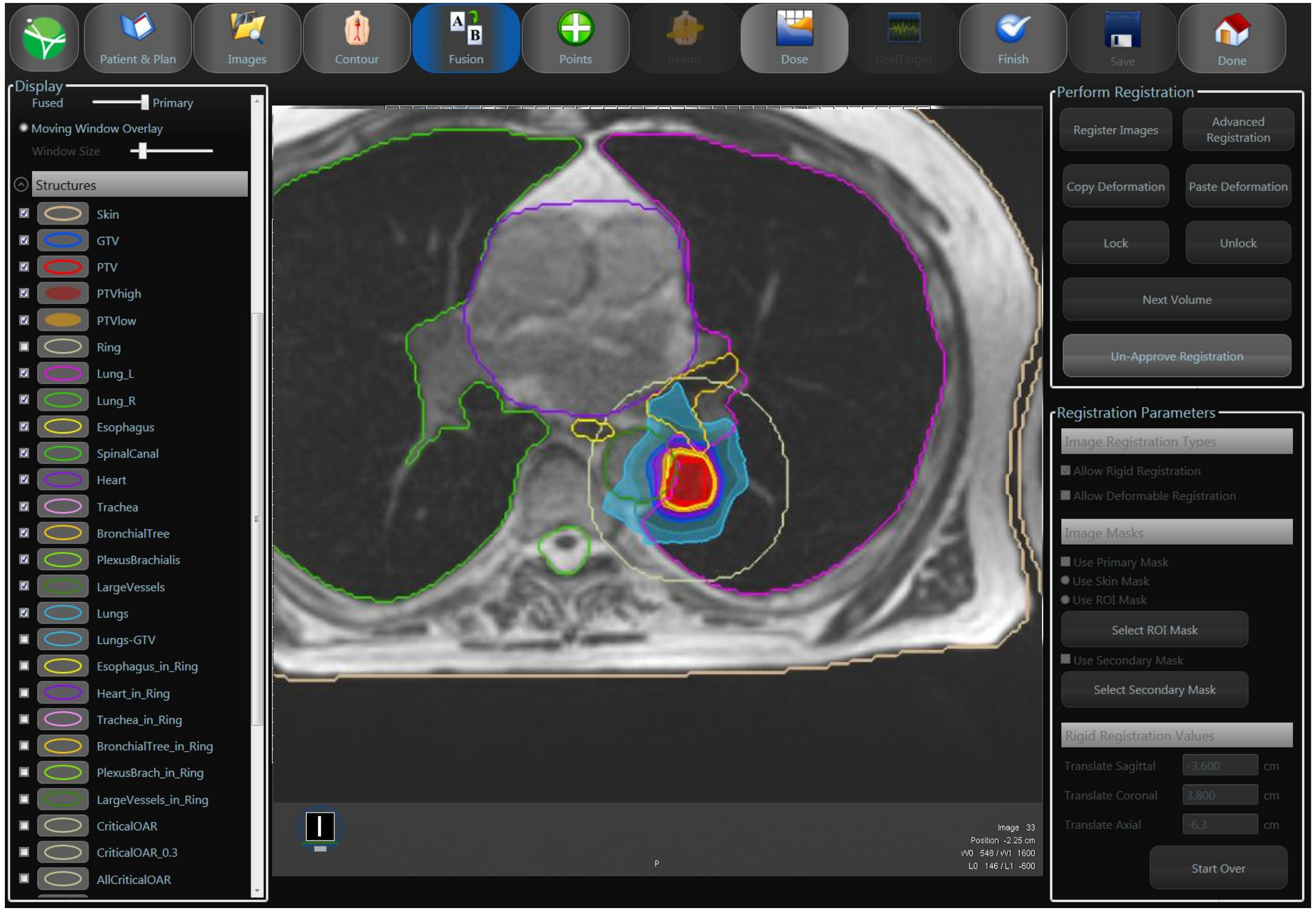


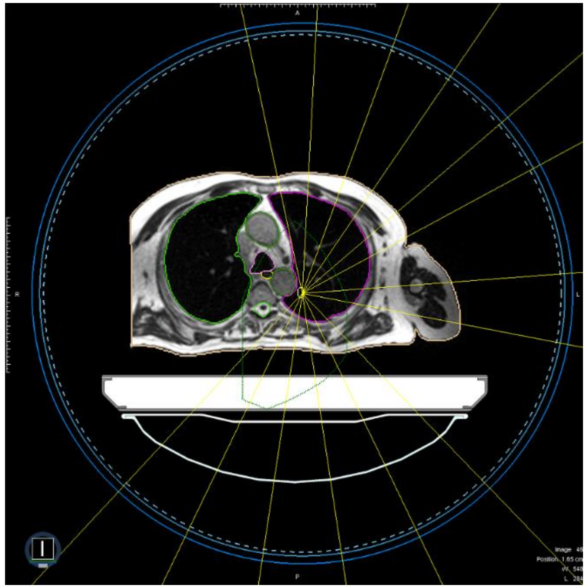
AOR delineation on MRI



Treatment preparation



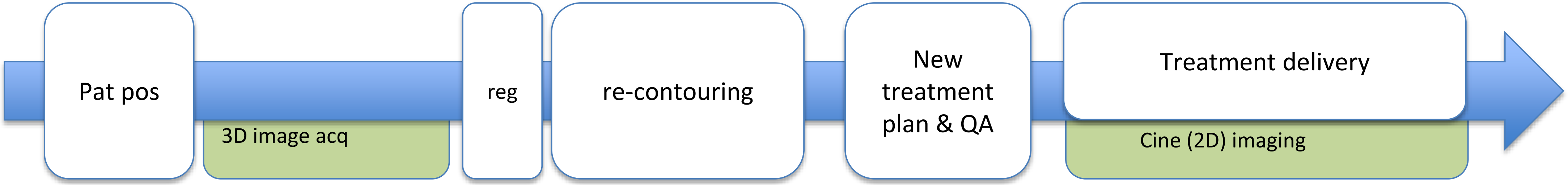




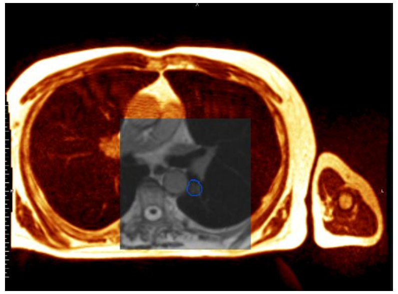
Beam setup

PTVhigh: area able to receive prescribed dose
PTVlow: overlap with AOR (natural dose fall-off)

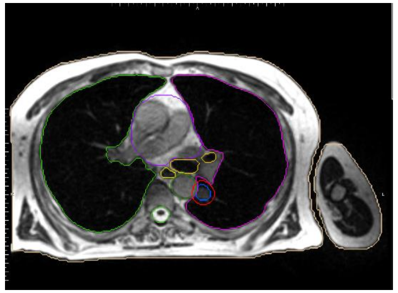
Online workflow



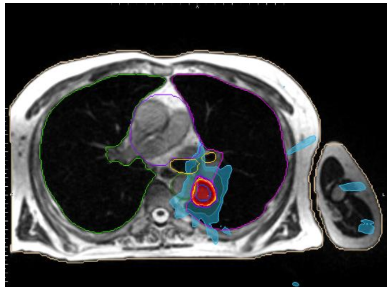
5min



5min



15min

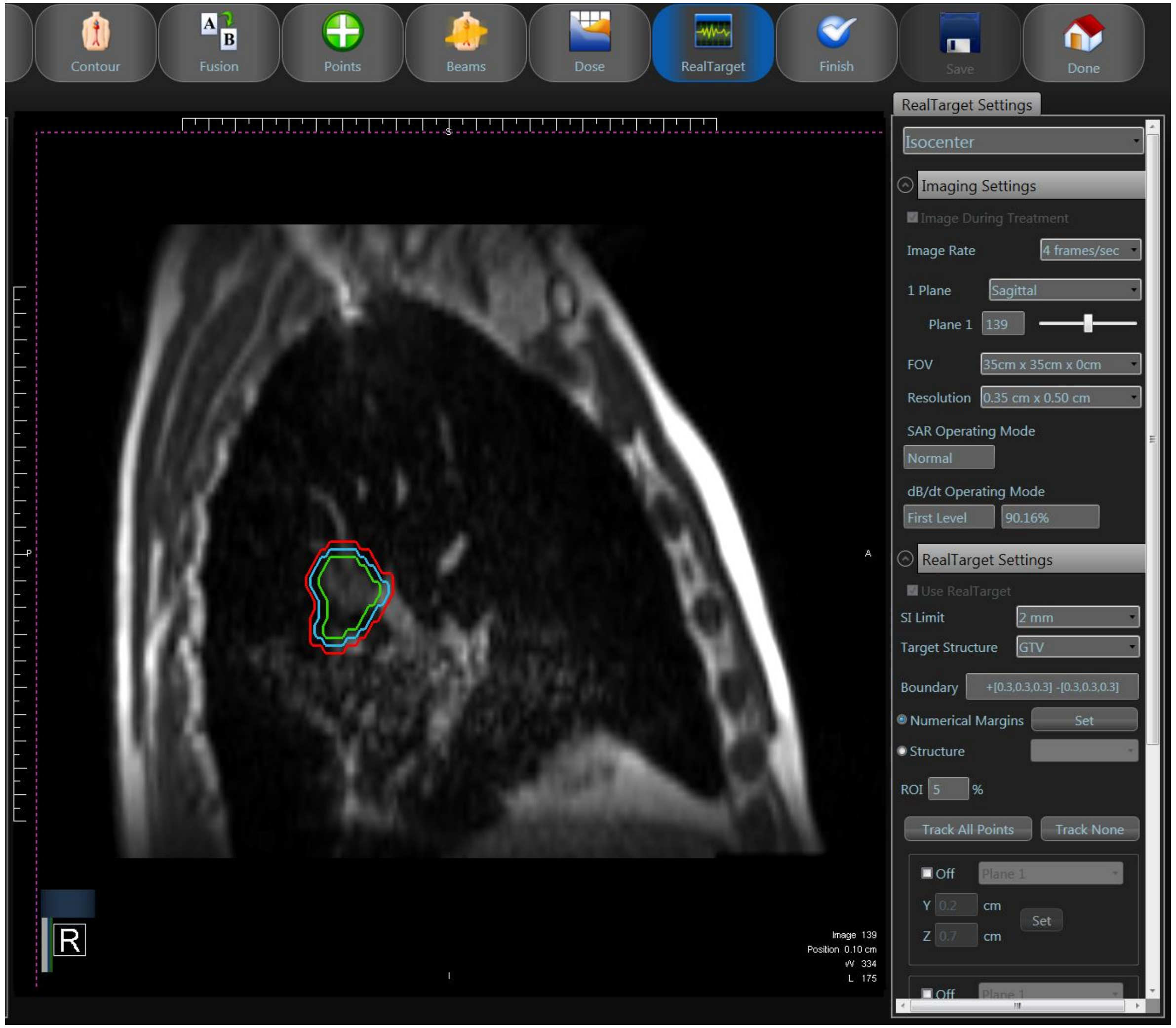


5min

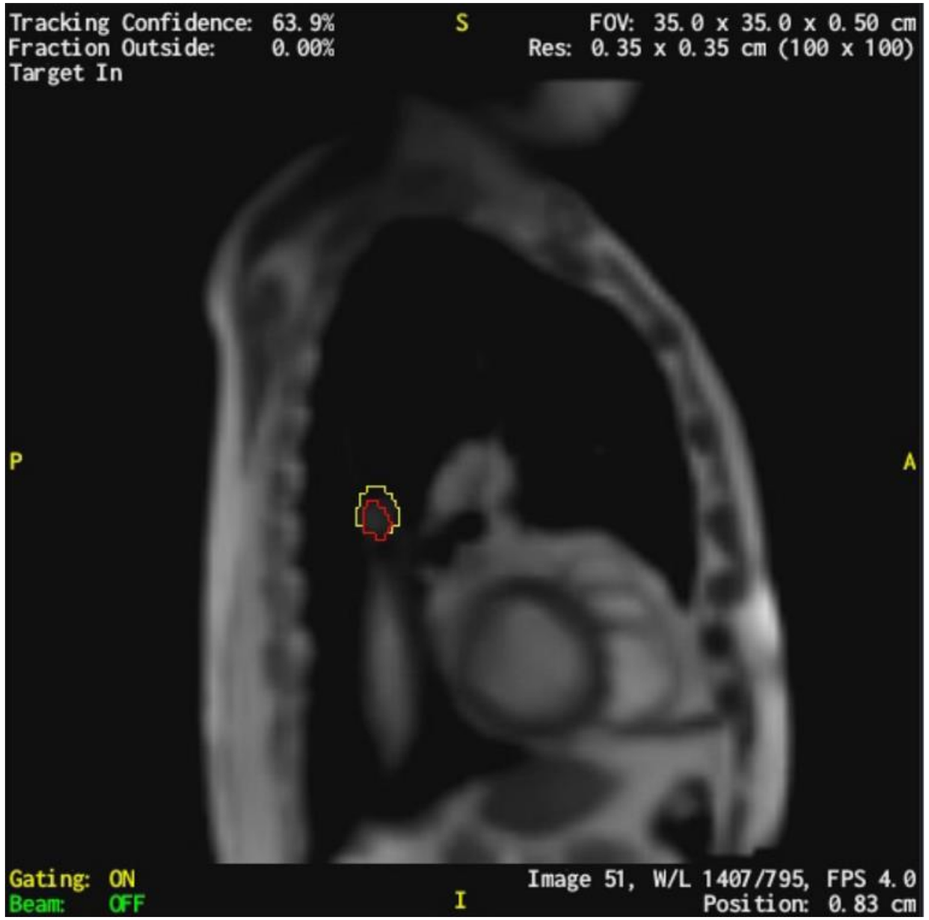
Total: 45 min

Motion management on MRIdian

- Target
  - Region of anatomy to be tracked
  - GTV or surrogate
- Boundary
  - Numerical expansion of the target
  - PTV or less
- Gating threshold parameters
  - Percentage area outside boundary
  - Confidence value



Cine imaging; 4 or 8 frames per second



4 fps, Cartesian readout
Resolutie lower, no artefacts
(tracking goes well)

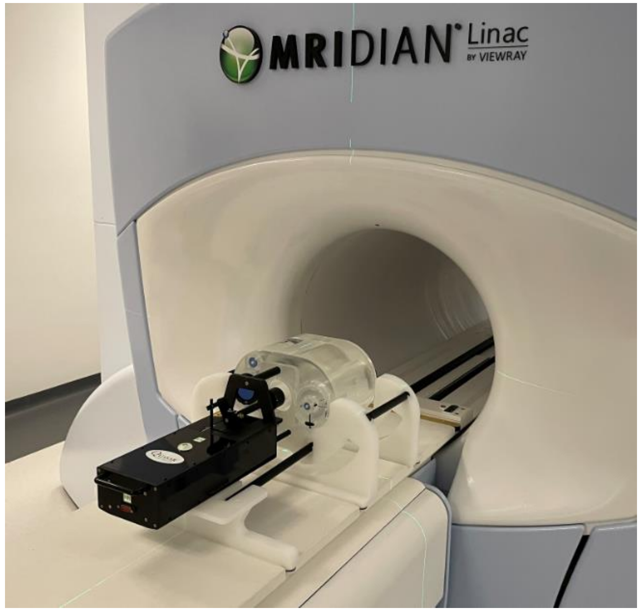
8 fps, Radial readout
Resolutie lower, streaking artefacts
(tracking goes well)

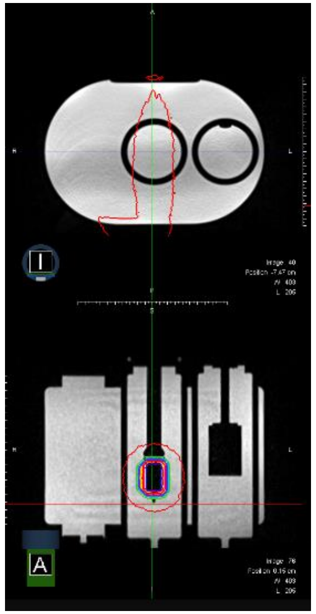
Motion management
Quality Assurance

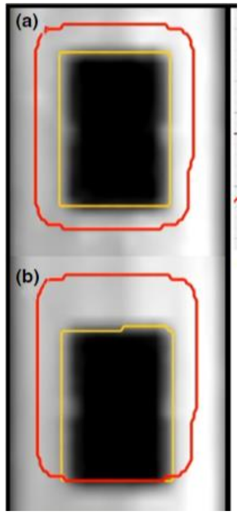
- Measurements performed using MRI safe and compatible 4D motion phantom
- Latency (delay) dependent on imaging protocol
- Soon to be pulished guideline by NCS (report 36) => annual test + after system updates/upgrades

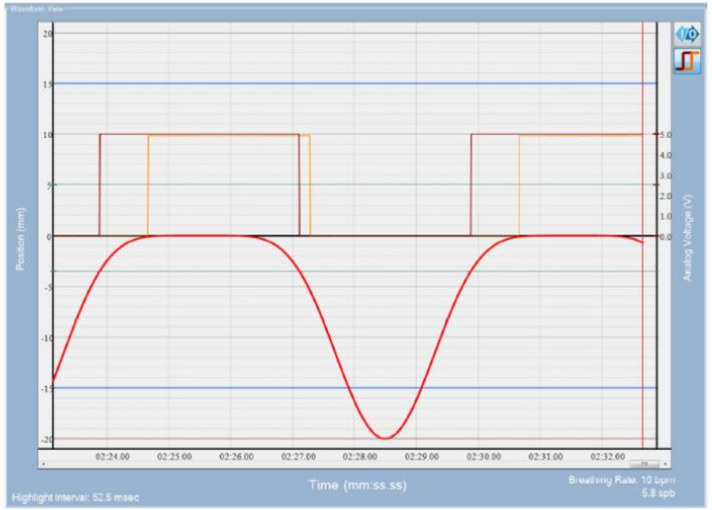
Limits

Criteria (constancy over time)	Acceptable	Critical	Applications	Minimum interval
Total latency	±50 ms	±100 ms	-,-,-,4	Annually









	4 fps		8 fps	
	Beam on data	Beam off data	Beam on data	Beam off data
Aantal metingen	21	21	23	23
Gemiddelde [ms]	700.6	216.9	736.3	187.0
Stdev [ms]	175.0	72.6	44.0	42.5

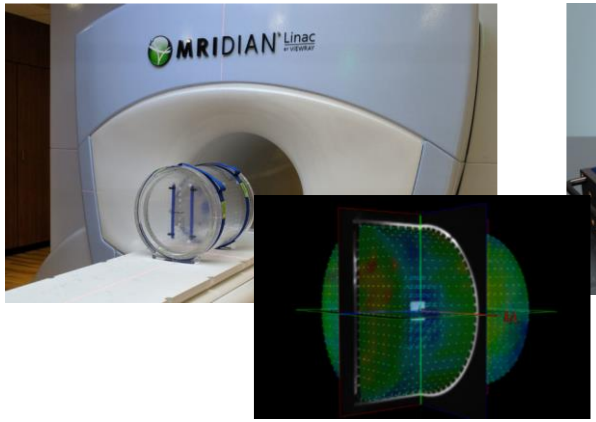
NCS report: https://radiationdosimetry.org/ncs/reportsk

Data: commissioning results CZE, 2022

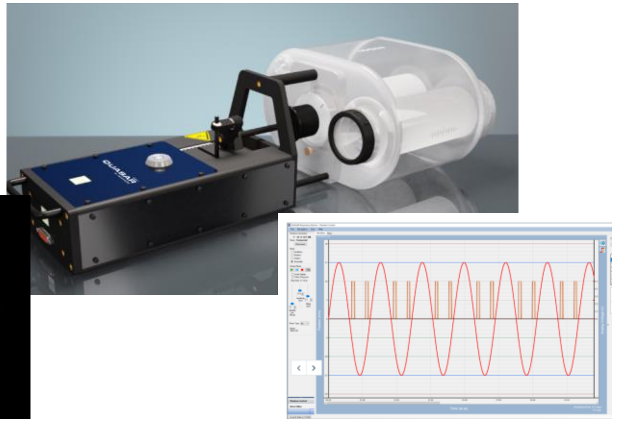
Things to consider

- PTV margins
  - Delineation on MR or CT? ..Accuracy?
  - System inaccuracies
    - MR-MV isocentricity
    - MRI geometric fidelity
    - Gating performance (latency)
- Patient compliance
  - Breath hold instructions
  - Feedback monitor
  - When drift compensation (couch shift)
- Logistics
  - Daily schedule
  - Team members / responsibilities

Geometric fidelity

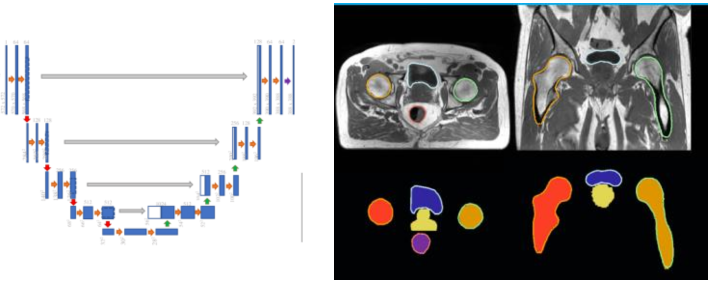


Gating performance

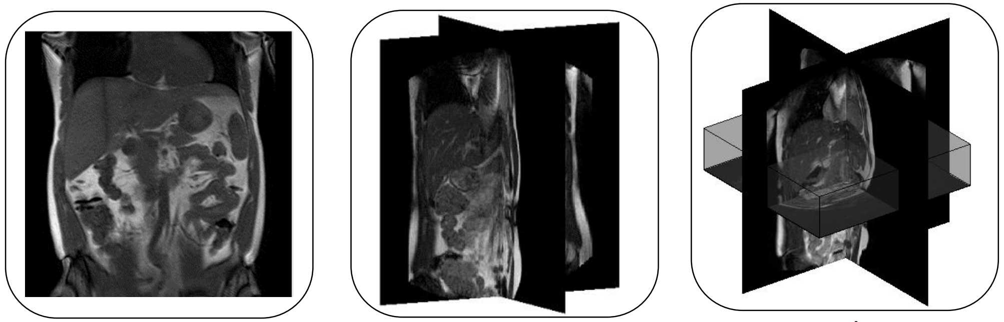


MRgRT in the future

- More automation
  - Auto-segmentation
- More imaging
  - 3D cine during radiation
- More functionality
  - dose accumulation
- More insight.. !



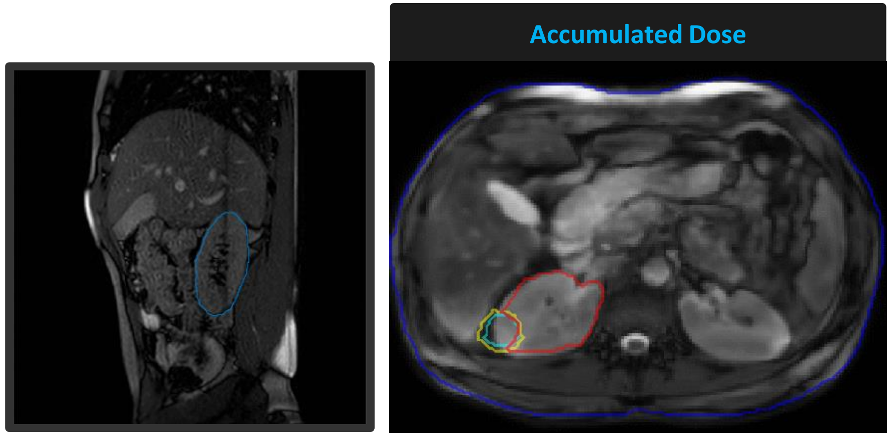
Savenije MHF et al Radiat Oncol. 2020



Single-slice Multi-slice 3D volume

Stemkens & Tijssen

Data science



Bourque & Tijssen, Contaxis & Glitzner

catharina
a santeon hospital

Bedankt
en blijf gezond

Passion for life.