Broadening of Magnetic Resonance Imaging Guided Linear Accelerator (MRI-LINAC)

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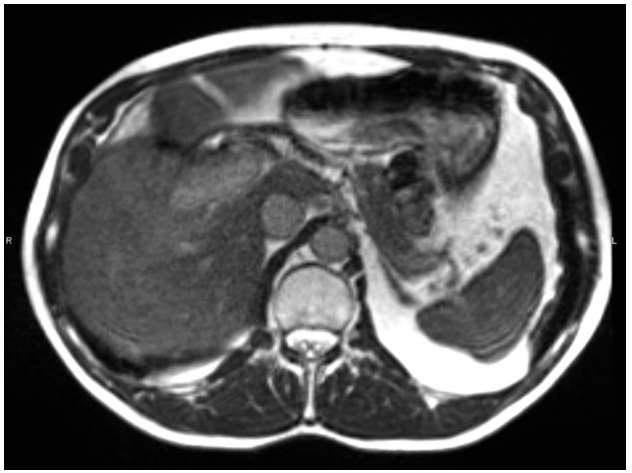
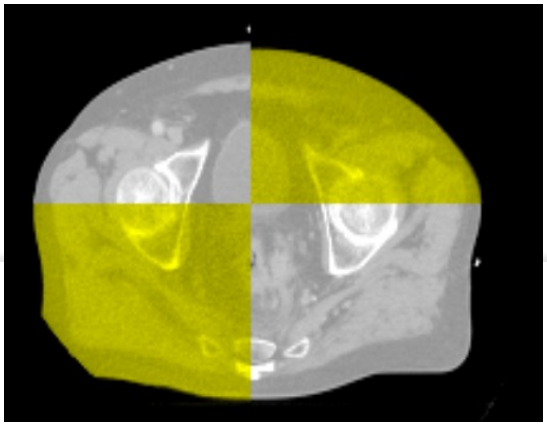
Innovations in image-guided radiotherapy

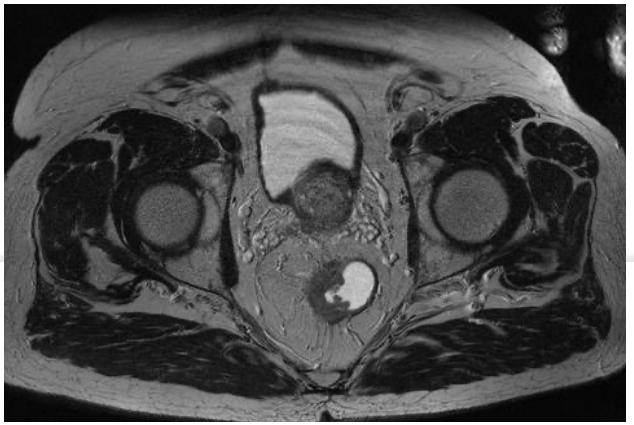
Dirk Verellen, Mark De Ridder, Nadine Linthout, Koen Tournel, Guy Soete and Guy Storme

A logical next step is to introduce MRI in IGRT as it offers superior soft tissue contrast compared with radio- graphic imaging. At the University of Utrecht a proto- type is being designed that combines a linac mounted on a ring-based gantry and a 1.5 Tesla MRI device[113]. The approach is inherently limited by interaction of the radio-frequency signal that is used for MRI with the radio-frequency pulses that are required for electron acceleration in the linac, and the influence of the strong magnetic field from the MRI on the dose-absorption process. To cope with these limitations, a 0.3 T MRI has been designed combined with three ^{60}Co-sources that are equipped with multi-leaf collimators (MLC) for IMRT mounted on a ring-based gantry (J. Dempsey, personal communication). Both MRI concepts are promising but are still in the development phase.

IGRT







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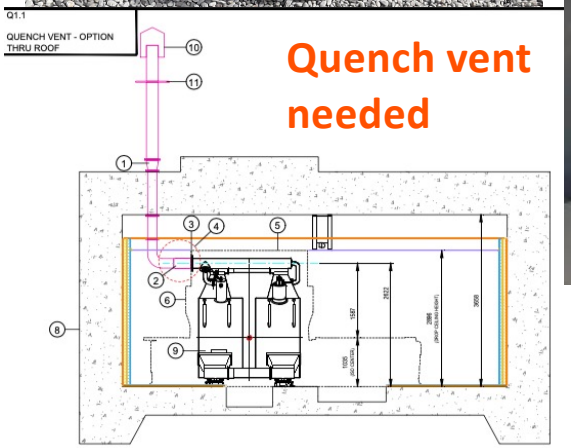
MR Linac: Keypoints

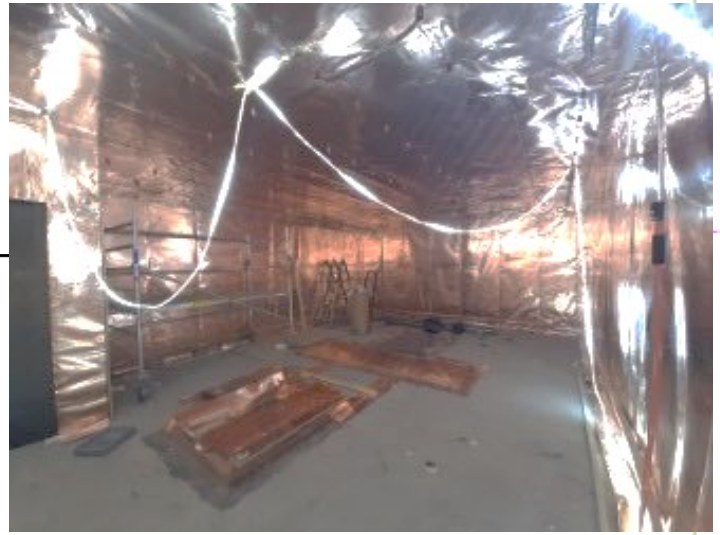
- On table adaptive radiation therapy
- Continuous MR imaging
- Real time tracking of targets & organ at risks

MR Linac: bunker considerations

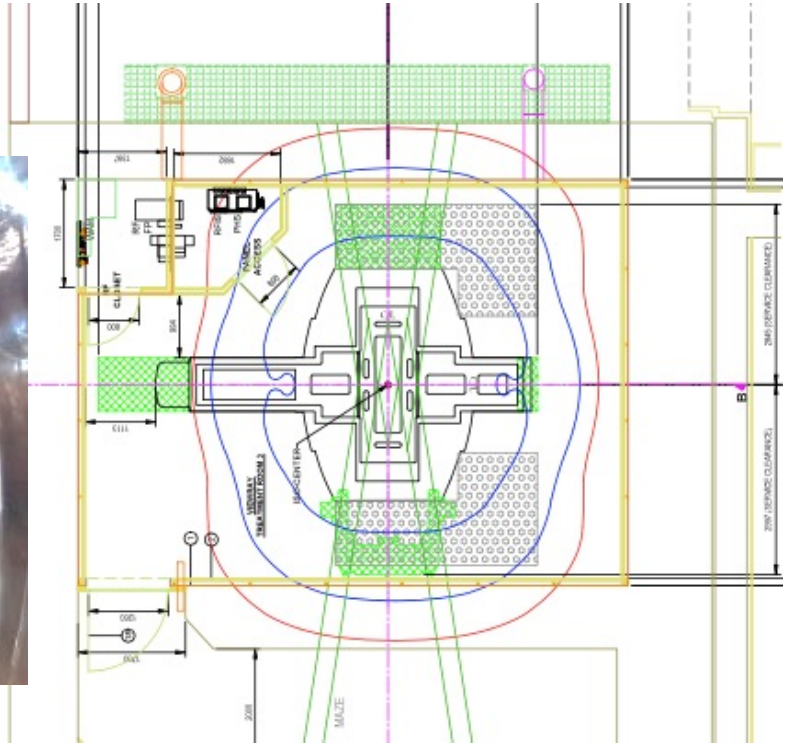


Quench vent needed

RF Shielding



Fringe fields: gauss lines



MR Linac concept

- **Markerless**
- Real time gating / tracking
- Margin reduction
- Adaptive treatment

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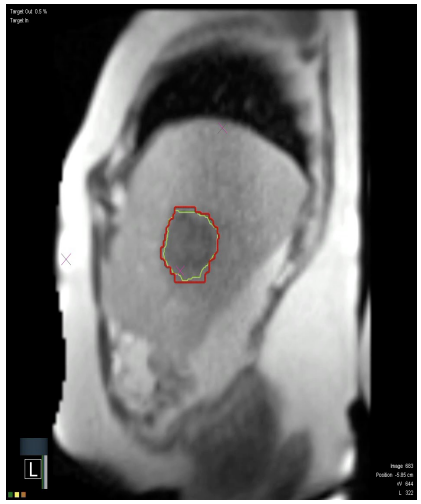
Markerless environment

- MR imaging
  - T2/T1- weighted contrast
  - highlighting fat and fluids
- Cine- MR with 8 frames/sec
- Improved contrast used to highlight the tumor and allow daily tracking
- Unique to be able to see and track actual tumor (not a surrogate) in realtime



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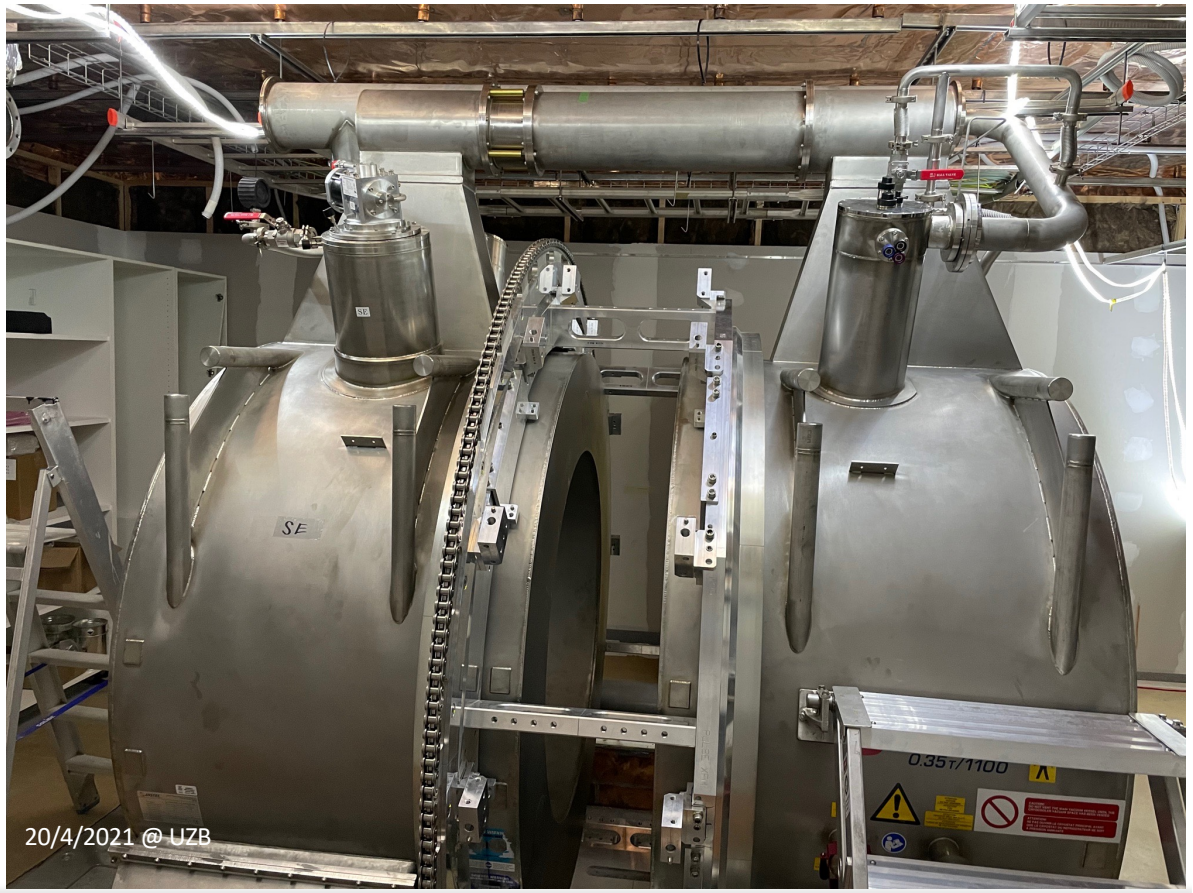

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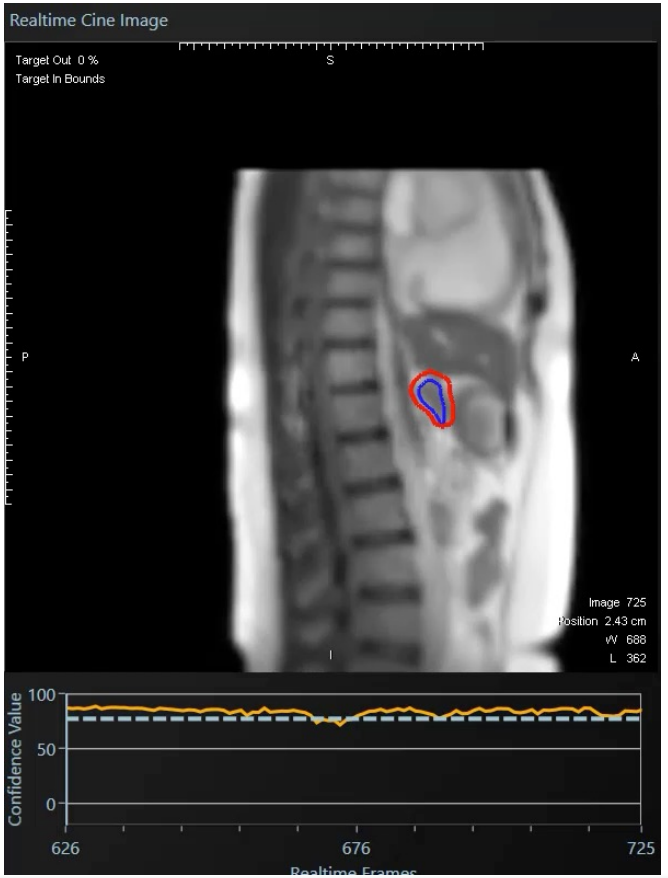
Real time gating / tracking

- Soft tissue tracking during beam delivery
- Beam control
  - Automatically control the beam based on the location of the target
- Confidence that the target is being treated and not surrounding OAR when movement occurs
- At 8 frames/sec, every 125 msec beam hold decision



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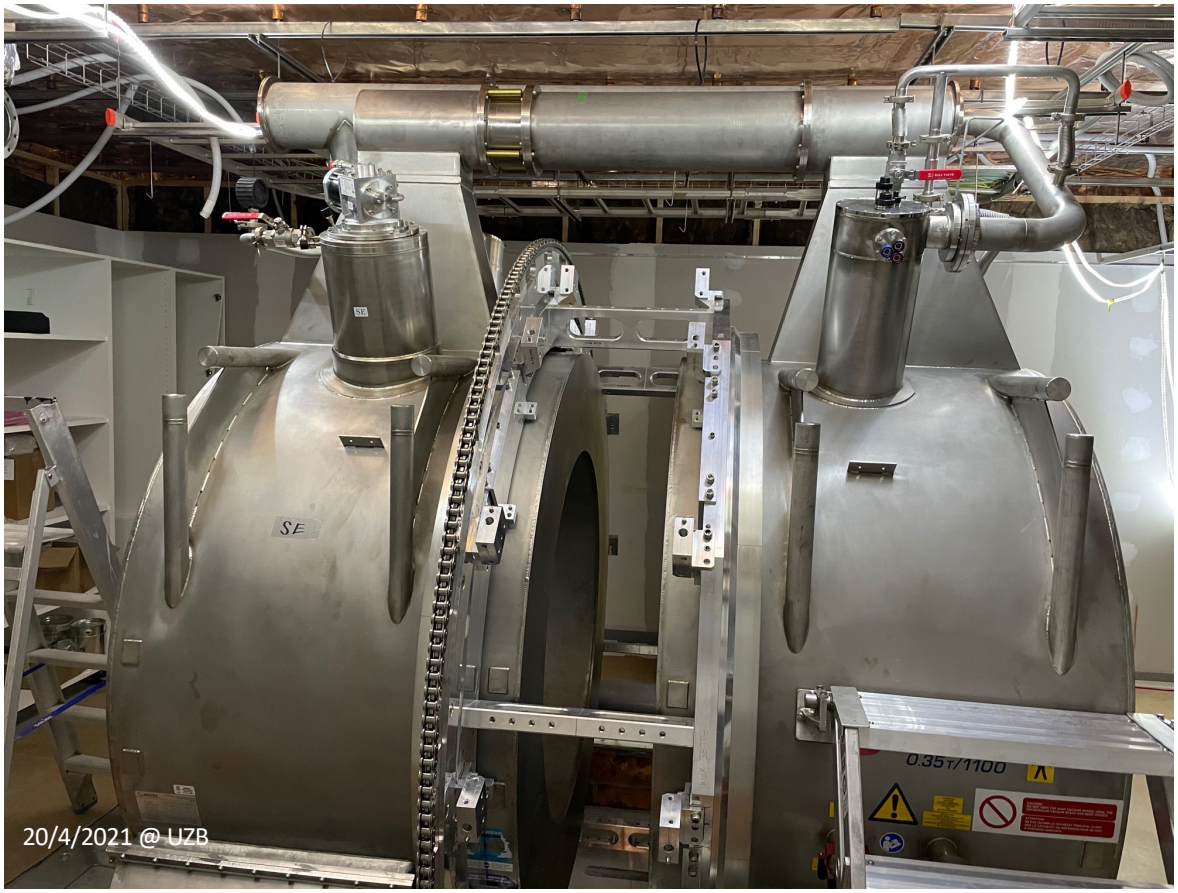

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IGRT

Margins based on skin marks

Lat	Ant	Post	Cran	Caud
15	16	14	10	10

Margins based on imaging

Lat	Ant	Post	Cran	Caud
8	11	7	10	10

Average of 20-25% LESS healthy tissue irradiated

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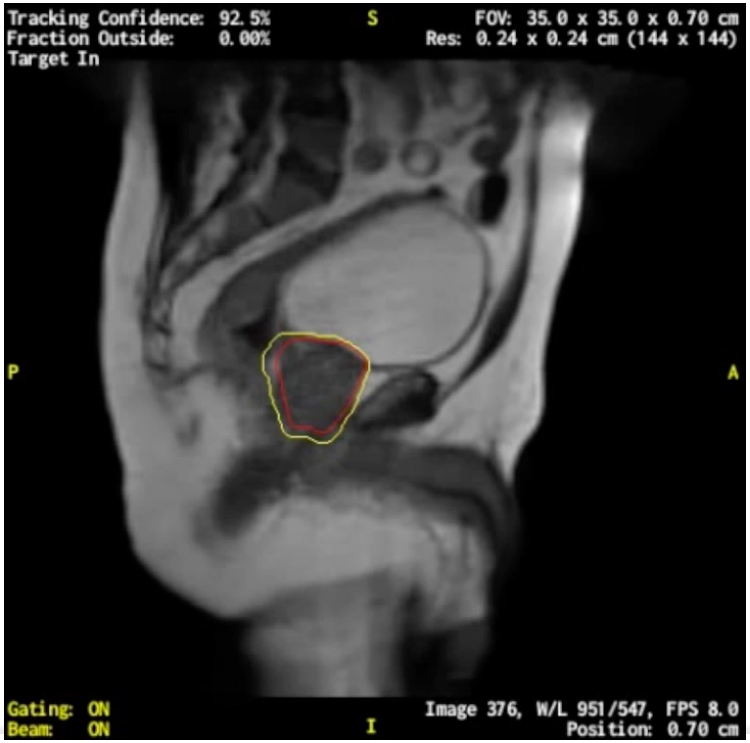
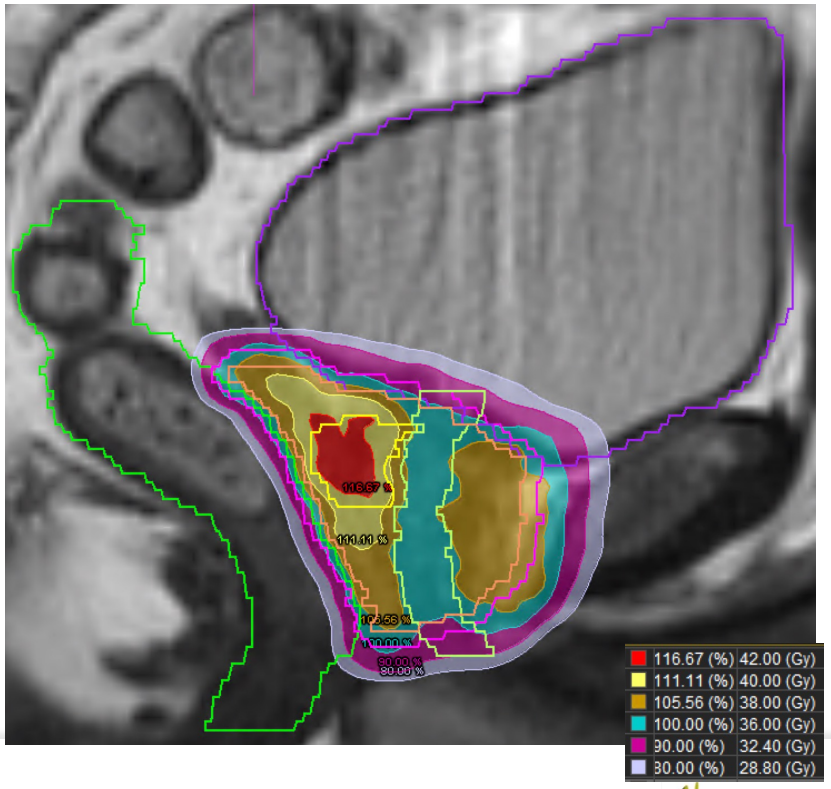
Ultrahypofractionated Stereotactic Ablative Radiotherapy (SABR)





➔ **Margin of 3 mm**

MR Linac concept

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- **Adaptive treatment**

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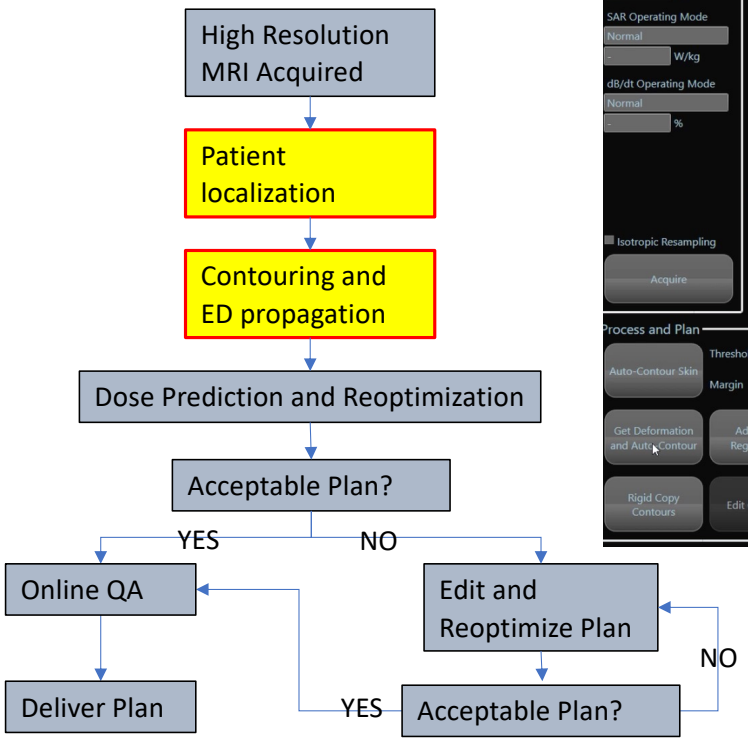
Treatment


High Resolution MRI Acquired
Patient localization
Contouring and ED propagation
Dose Prediction and Reoptimization
Acceptable Plan?
YES
NO
Online QA
Deliver Plan
Edit and Reoptimize Plan
NO
YES
Acceptable Plan?


Patient & Plan
Positioning
RealTarget
RealTx
Done
Linac
On
Off
Image Volumes
Imaging Setup
FOV (LRxAPxHF) cm
Resolution
Imaging Time
SAR Operating Mode
dB/dt Operating Mode
Isotropic Resampling
Acquire
Plan Image
Current Image
Process and Plan
Auto-Contour Skin
Threshold
Margin
Get Deformation and Auto-Contour
Advanced Registration
Rigid Copy Contours
Edit Contours
Get Couch Shift
Manual
Automatic
Rigid
Deformable
Set Isocenter Manually
Find Shift From Fusion
Mark 3-Point Setup
Set to center of
Find
Couch Location
Original
Actual
Shift
Reset
Lateral
Vertical
Axial
Acquire Couch Position
Send Shift to Couch
Display
Show MPR Lines
Colormap Overlay
Fused(Plan)
Primary(Current)
Moving Window Overlay
Window Size
Structures
Points of Interest
System Status
Treatment Not Enabled
MRI
RTCS
Couch
Linac
Services
QATool
TDCU
Doors Fully Closed
RTCS Interlock
Beam On Button
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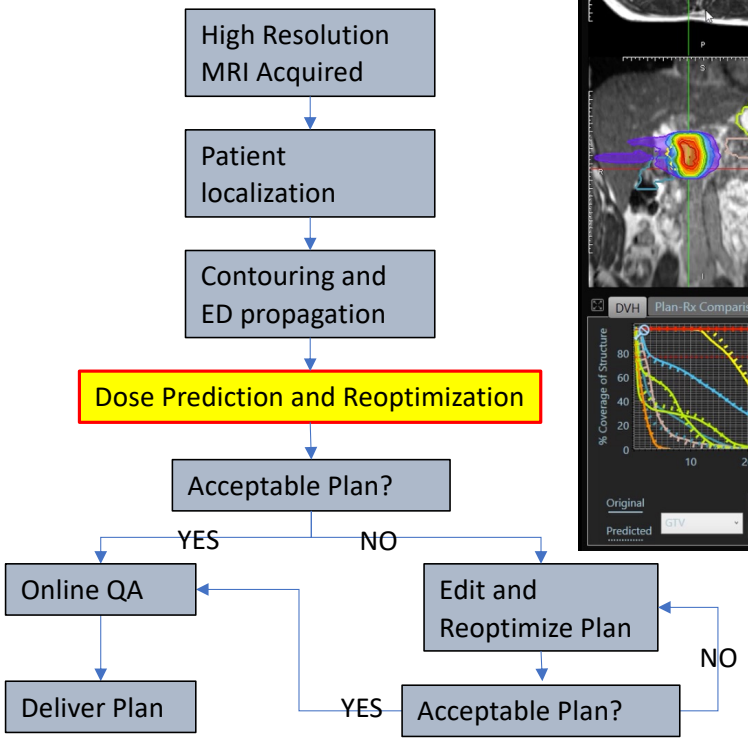
Treatment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RealTx
Done
Original
Predicted
Reoptimized
Display
Left Image View - Planning
Right Image View - Daily
Structures
Skin
PTV
Duodenum
LargeBowel
SmallBowel
Stomach
Kidneys
Kidney_L
Kidney_R
Pancreas
Liver
Spinal Cord
GTV
PTV+3cm
PTV_OPT_High
ALL_OAR
All_OAR+0.2cm
PTV_OPT_Low
CTV_OPT
PTV+6cm
PTVring
Linac
On
Off
Abdomen, Demo
AAPM
MRN
DOB
Jan 1 1990
Diagnosis
Pancreas
Fraction
1 of 5
Site
Pancreas
SBRT
Rx
Plan
Reference Plan IMRT
Machine
20999
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RTCS Interlock
Beam On Button
DVH
Plan-Rx Comparison
Statistics
Cost Functions
% Coverage of Structure
Dose(Gy)
Original
Predicted
Dose
Predicted
Optimization
Predict Original Plan Dose on Current Images
Weight Optimization
Finalize Treatment Plan
Treat with Original Plan
Treat with New Plan
Perform Online QA
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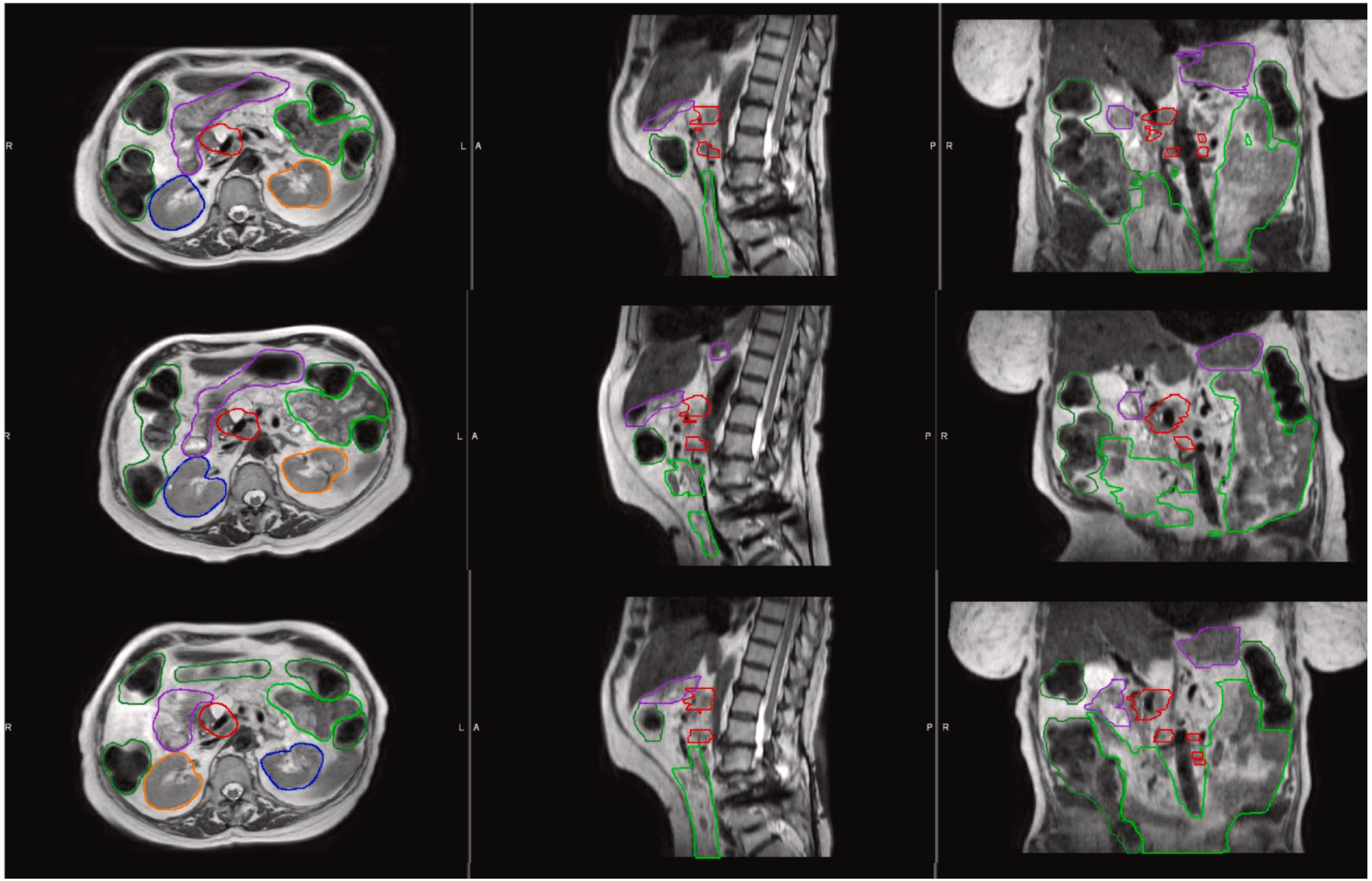
Fraction 1

Fraction 2

Fraction 3



Dosimetric benefit of MR-guided online adaptive radiotherapy in different tumor entities: liver, lung, abdominal lymph nodes, pancreas and prostate

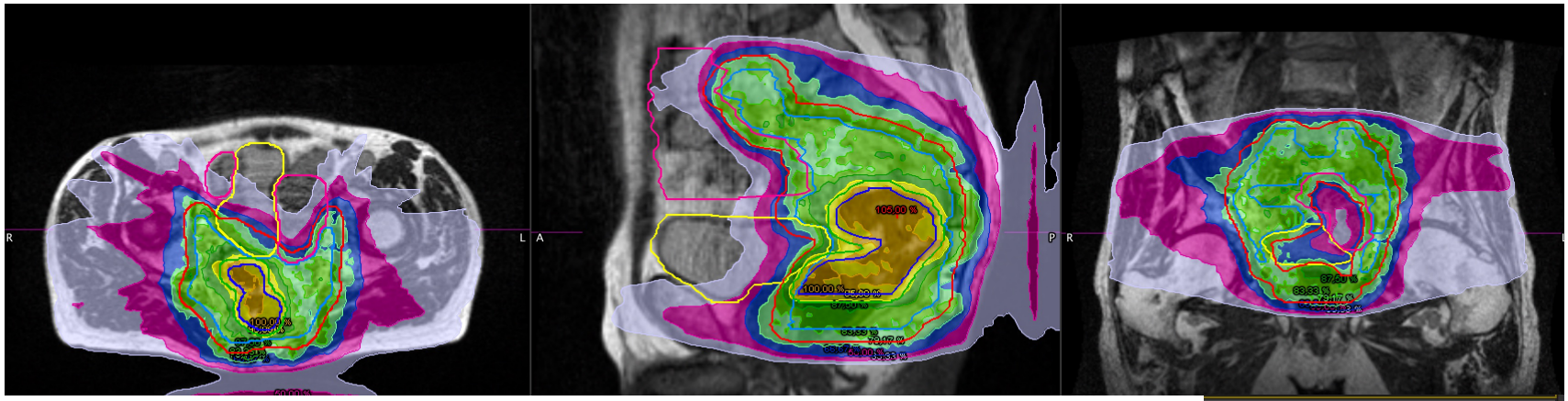
Lukas Nierer[1*], Chukwuka Eze[1], Vanessa da Silva Mendes[1], Juliane Braun[1], Patrick Thum[1], Rieke von Bestenbostel[1], Christopher Kurz[1], Guillaume Landry[1], Michael Reiner[1], Maximilian Niyazi[1], Claus Belka[1,2] and Stefanie Corradini[1]

Conclusions

All subgroups clearly benefited from online plan adaption in terms of improved PTV coverage. Moreover, for the liver, lung and abdominal lymph node cases, a systematic improvement in GTV coverage was found, resulting in excellent target coverage after re-optimization in most fractions. In combination with the breath-hold-based technique, these subgroups can fully exploit the potential of oMRgRT systems. In the pancreatic cancer subgroup, online plan adaption resulted in largely decreased OAR doses but the target coverage could not always be improved due to the limiting OAR constraints. While many fractions of the prostate subgroup could, in theory, also be effectively treated without plan adaption, most fractions still showed improved PTV coverage and few fractions even showed large CTV coverage improvements after online plan re-optimization.

Radiation Oncology 2022;17:53

Intensified Total Neoadjuvant Treatment on MRIdian



	1	105,00 (%)	31,50 (Gy)
	1	100,00 (%)	30,00 (Gy)
	1	95,00 (%)	28,50 (Gy)
	1	87,50 (%)	26,25 (Gy)
	1	83,33 (%)	25,00 (Gy)
	1	79,17 (%)	23,75 (Gy)
	1	66,67 (%)	20,00 (Gy)
	1	50,00 (%)	15,00 (Gy)
	1	33,33 (%)	10,00 (Gy)

- 5 x 5 Gy presecral space
- **5 x 6 Gy gross tumor volume**
- 24 weeks of FOLFOX or Capox
- cCR → Watchfull waiting approach

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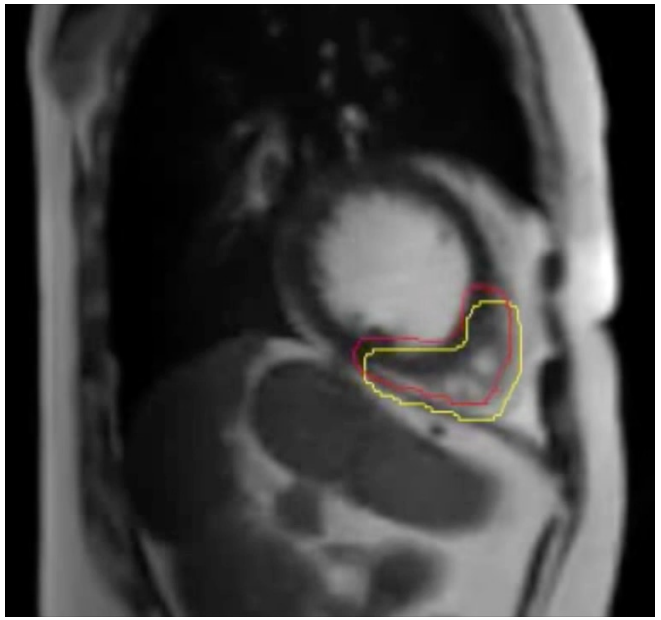
MR Linac

- Push boundaries in radiotherapy
- Reduction of PTV margins
- Deliver treatments in less fraction
- Real time confident visualization
- Automated beam off
- Online adaptive RT
- Perform markerless abdominal SBRT

Cardiac sarcoma



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Acknowledgement

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