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Working with an MRgRT program:
online ART, motion management with CINE MRI and special QAs


Viewray MRIDIAN

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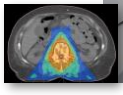
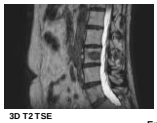
University Medical Center Utrecht

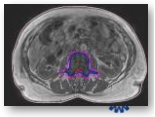
Why MRgRT program is a good idea:
MRI guidance from treatment table for high precision irradiation

- Very first patients on pre-Unity
- Spinal bone metastases
- 1x8 Gy
- Goal: Demonstrate technical accuracy and safety in the clinical setting
- Geometrical **accuracy of 0.3mm**, shown by EPID-DRR comparison




Theraview comparison EPID and pseudoCT DRR


3D T2 TSE



From Raaymakers et al. PMB (2017)

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Online Adaptive radiotherapy

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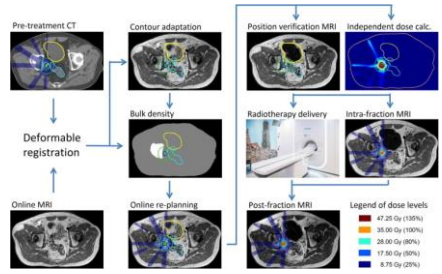
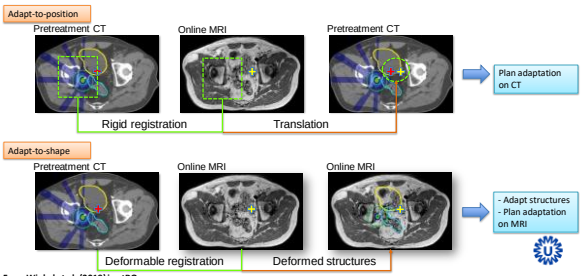
Workflow for first lymph node treatments at Unity



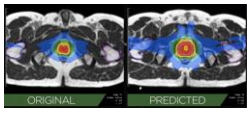
Werensteijn-Honingh el et al., Rad. Oncol. (2019)

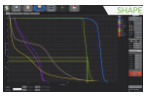
Plan adaptation via 'Adapt-to-Position' or 'Adapt-to-Shape'

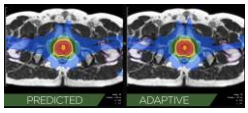


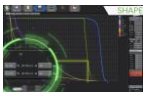
From Winkel et al. (2019) in ctRO

Viewray's ROAR: Real-time, On-table, Adaptive, Radiotherapy









- On-line MRI
- Contour propagation/editting
- Dose prediction on current anatomy
- Full re-planning if desired
- Delivery with gating
- Clinical at ~15 sites

Stills from Viewray movie
https://vimeo.com/300812322

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Motion management and cine MRI

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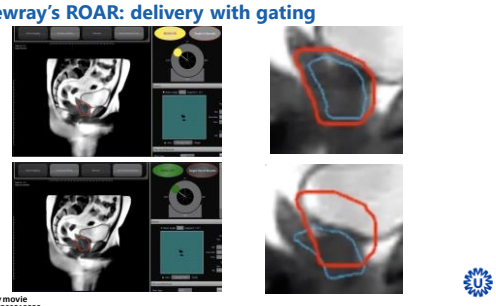
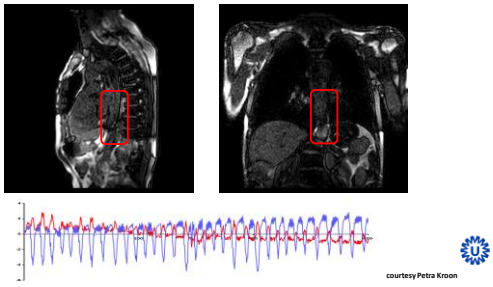
Viewray's ROAR: delivery with gating



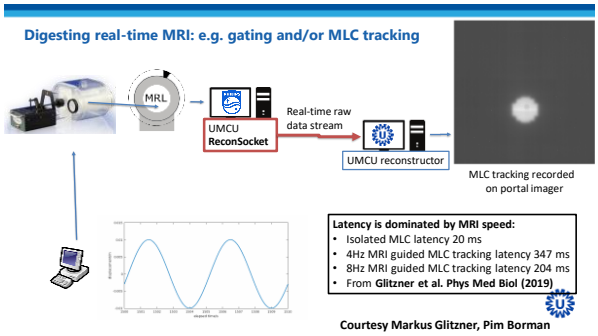
Stills from Viewray movie
https://vimeo.com/300812322

2D Cine MRI during lymph node Unity treatment



courtesy Petra Kroon

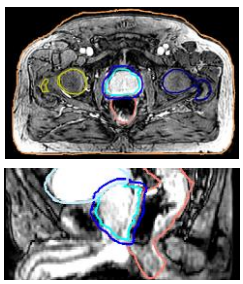
Digesting real-time MRI: e.g. gating and/or MLC tracking



Latency is dominated by MRI speed:
- Isolated MLC latency 20 ms
- 4Hz MRI guided MLC tracking latency 347 ms
- 8Hz MRI guided MLC tracking latency 204 ms
- From **Glitzner et al. Phys Med Biol (2019)**

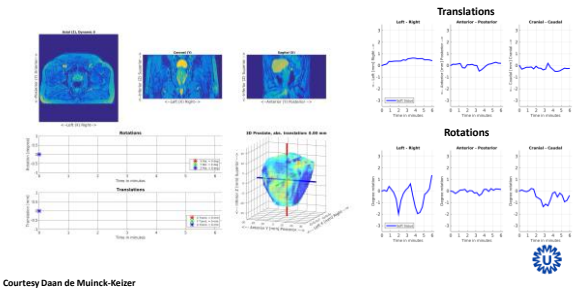
Courtesy Markus Glitzner, Pim Borman

Repeated 3D MRI (16 sec) during prostate treatment



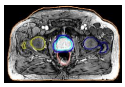
Slide courtesy Charis Kontaxis

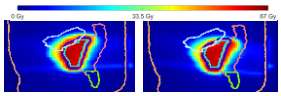
Intra-fraction prosate tracking using 0.05Hz intra-fraction 3D MRI

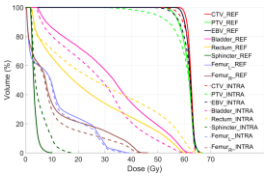


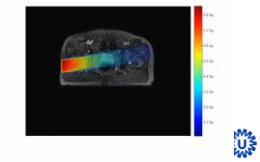
Courtesy Daan de Muinck-Keizer

Combining cine 3D MRI and log-files: time-resolved dose reconstruction







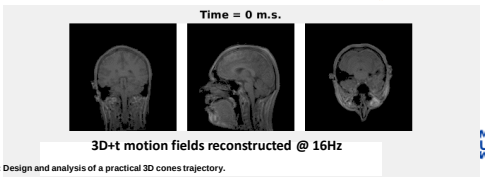


Slide courtesy Charis Kontaxis

Volumetric MRI at 16HZ by sampling motion fields

- Six cones of **3D cone trajectory**[2] , TR = 10ms each
- Snapshot acquisition @ **16Hz**
- 1.5T Philips Ingenia
- **480x acceleration** w.r.t. fully-sampled
- "8"-shaped head motion
- Affine spatial model, temporal cubic B-spline model

Work by Alessandro Sbrizzi and Niek Huttinga



[2]: Gurney et al: Design and analysis of a practical 3D cones trajectory.

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(Special) Quality Assurance (QA)

MRI Quality Control and Quality Assurance approach

System config	
System & connectivity	test#
DICOM functionality	1.1
coordinate system test	1.1
table	1.1
patient communication	1.1
camera's	1.1

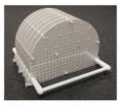
Quality assurance (QA) tests			
General Image Quality	test#	Sequence specific tests	test#
PIQT	6.1	geometric fidelity	3.2
ACR	6.2	low contrast detectability	6.2
FBIRN	6.3	signal-to-noise	6.2
absolute SNR	6.3	robustness	2.3 / 3.2 / 6.2

Quality Control (QC)							
B0-field	test#	Imaging gradients	test#	RF excitation and reception	test#	Hybrid tests	test#
B0-direction	2.1	image orientation	3.1	flip angle accuracy	4.1	MR-MV alignment	5.1
absolute field strength	2.2	gradient non-linearities	3.2	RF cage seal	4.2	radiation influence	5.2
magnetic field homogeneity	2.2	ghosting	3.3	receiver coil performance	6.1	gantry angle dependent B0	5.3
f0 stability	2.3	gradient delays	N/A	coil covariance	6.3	spurious noise w/ linac operation	4.2
cryogen	2.3	eddy currents	N/A				

Bulk of the tests are Quality Control tests (on sub-systems)
Quality Assurance tests serve as null-measurement

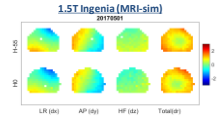
Slide courtesy Rob Tijssen

QC Results: geometric fidelity

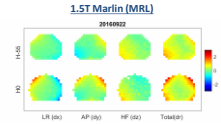


3D FFE sequence
Geometric correction turned ON
Right column shows total distortion
vector sum of x y and z distortions

3D Geometric QA for research use



DSV (mm)	Maximum displacement vector (dr)
150	0.57 mm (0.02 mm)
250	1.06 mm (0.05 mm)
350	**1.98 mm** (0.08 mm)
400	2.42 mm (0.05 mm)



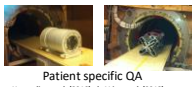
Tijssen et al. Rad. And Oncol. 2019

Working up dosimetry and protocols for QA

Absolute dosimetry
De Prez et al. (2016, 2019a)

Machine QA, acceptance and commisioning
Smit et al. (2014a, 2014b), Woodings et al. (2018), Woodings et al. (in preparation)

Reference dosimetry
Van Asselen et al. (2018), de Prez et al. (2019b)



Patient specific QA
Houweling et al. (2016), de Vries et al. (2018)

More details:
WE-G-SAN4-211.35
Commissioning/ verification of MRI-linacs…
By Jochem Wolthaus

Periodic machine QA procedures, e.g. star-shot for isocenter calibration
Van Zijp et al. (2016)

Linac QA scheme

Test	Frequency
Daily constancy	
EPID-imaging	Daily
Dosimetry	
Absolute Dosimetry	Weekly
Dose Linearity	Weekly
Energy Measurement	Weekly
Starcheck Profile Measurement	Weekly
Film measurements	
Opposing Fields	Weekly
Focal Spot Alignment	Weekly
Spokefilm	Monthly
Stripe Test	Monthly
Watertank Measurements	
Profiles and PDD's	3-Monthly
Outputfactors	3-Monthly
Field Edges	3-Monthly
Diagonals	3-Monthly
Other Measurements	
Radiation Leakage	Annual
Cryostat and Couch transmission	Annual

Philips SPT	Weekly
Monitoring the helium level	Weekly
Gradient non-linearities	Monthly (alternating 2-weekly with B0)
Absolute Field-strength and B0 homogeneity	Monthly transverse (alternating 2 weekly with gradient) Monthly all orientations
Gradient non-linearities, third party phantom	Monthly
ACR measurements	Monthly
Flip angle accuracy (B1 mapping)	3 Monthly
Gantry dependent B0	3 Monthly
Radiation influence	3-Monthly
MR-MV alignment	3-Monthly
Log Parsing	Annually
Ghosting	Annually
RF cage seal & spurious noise	Annually
Stability during dynamics (and ghosting)	Annually
Image Orientation (and Dicom connectivity)	Annually

Slide courtesy Jochem Wolthaus

Portal imaging on the MRLinac

An EPID as verification tool

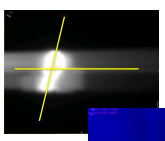
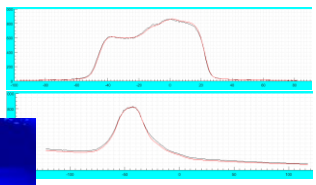
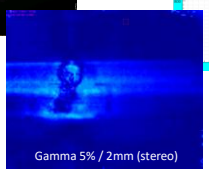
- The geometrical alignment and QA tool
  - Beam alignment
  - MLC calibration
  - Watertank alignment
  - Measurement equipment alignment (IC, 2D/3D detector)
- EPID panel rigidity and alignment <0.1 mm





Slide courtesy Jochem Wolthaus

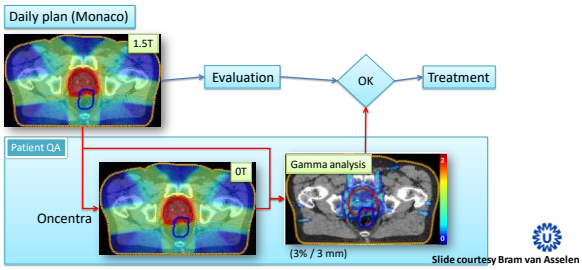
Film results comparing calculated and measured dose distribiution

More details:
WE-G-SAN4-211.35
Commissioning/ verification of MRI-linacs…
By Jochem Wolthaus

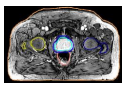
Slide courtesy Jochem Wolthaus

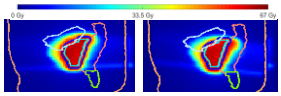
Secondary dose calculation as on-line QA



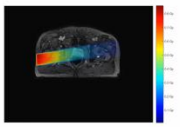
Slide courtesy Bram van Asselen

Combining cine 3D MRI and log-files: time-resolved dose reconstruction



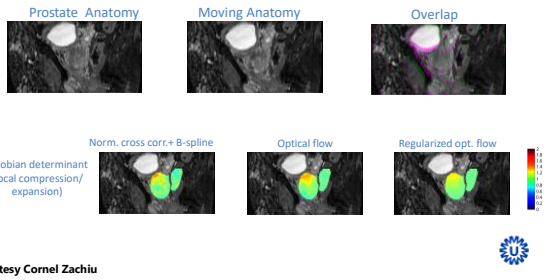


- Results rely on registration
- This example rigid registration to handle translations and rotations
- **Need for reliable deformation vector fields (DVF) from non-rigid registration**



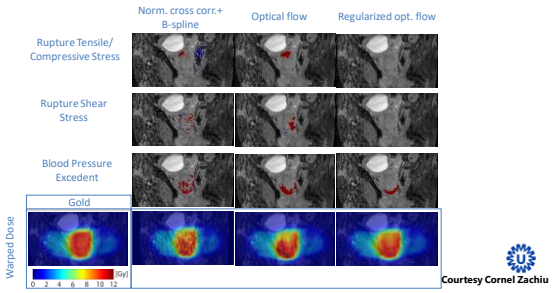
Slide courtesy Charis Kontaxis

How to assess physiologic plausibility of non-rigid image registration and define QA Criteria



Courtesy Cornel Zachiu

Biomechanical interpretation of the DVF as QA Criteria



Courtesy Cornel Zachiu

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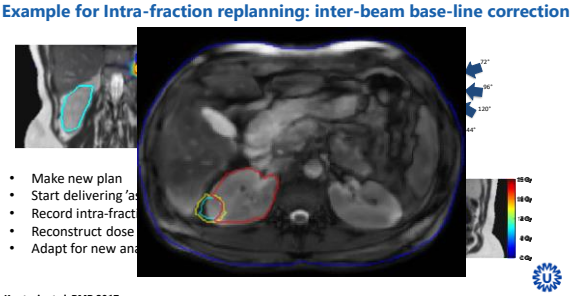
Combine:

soft-tissue guidance
fast 3D MRI
dose accumulation
fast treatment planning
proper QA

University Medical Center Utrecht

Example for Intra-fraction replanning: inter-beam base-line correction

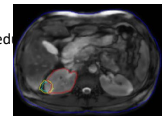


- Make new plan
- Start delivering 'a
- Record intra-fract
- Reconstruct dose
- Adapt for new ana

Kontaxis et al. PMB 2017

Summary

- MR linacs are in regular clinical use -> don't be scared
- Daily full re-planning is feasible
- Even without adaptation:
  - Repeated (inter- and intra-fraction) MRI for dose response assessment
- Higher precision -> dose escalation and/or hypo-fractionation
- Special QA, but can be implemented as regular clinical proced
- True 4D anatomical imaging: so time-resolved 3D
- Work towards: Real-time adaptive radiotherapy
- The best is yet to come!



In silico treatment of renal cancer. Continuously adapted treatment while accounting for accumulated dose

Thanks, acknowledgement and disclosure

- Acknowledge entire department for contributing
- Disclosure and thanks for external support:
- Thank you for bearing with me