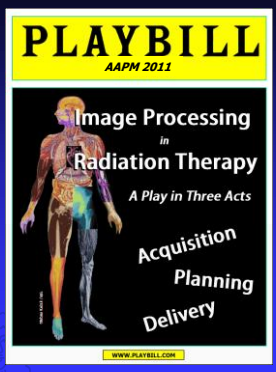
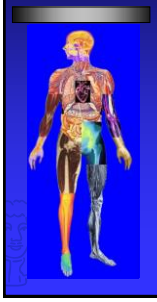


Disclosure

- Our department has research contracts with:
  - Elekta Oncology Systems
  - Philips Radiation Oncology Systems
  - Siemens Medical Solutions
- Our department licenses software to:
  - Elekta Oncology Systems

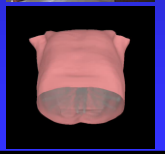
Radiotherapy Procedure

Act I:
Tattoo, align and scan patient

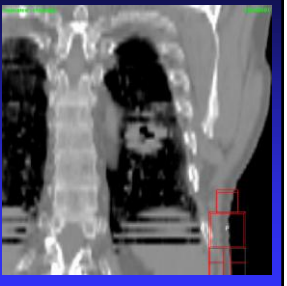


Act II:
Define the target and design a treatment plan

Act III:
Align patient on machine on tattoos and treat (many days)



Setup Errors

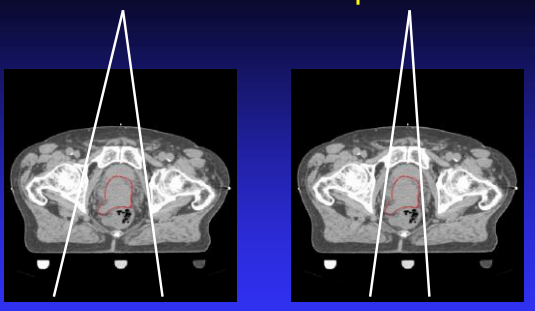


The patient moves from day to day

Organ Motion

Organs move from day to day

How can we solve this problem ?



1. Use large margins, irradiating too much healthy tissues

2. Use small margins, and risk missing the target

3. Or: use image guided radiotherapy

Image Guided Radiotherapy

- Image the tumor + organs-at-risk or their surrogates just prior or during treatment
- Assess changes in patient position relative to treatment plan
- Adapt treatment plan (couch shift) to account for changes, increasing treatment precision

Safety Margins

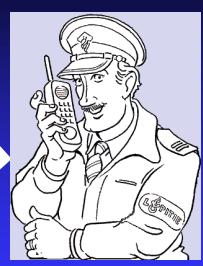
Verellen et al. Nature Reviews Cancer 2007

Many In-room Imaging Systems

Visualization

Visualization: Image Fusion

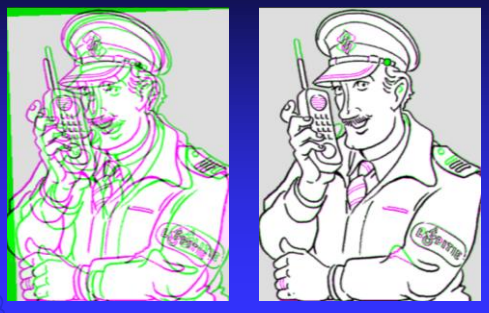
Reference Image



Localization Image

Visualization: Sliding Window

Visualization: Overlay

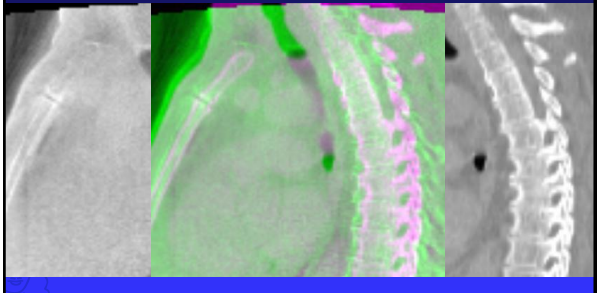


Complementary color overlay clearly shows gross differences and local differences provided adequate contrast

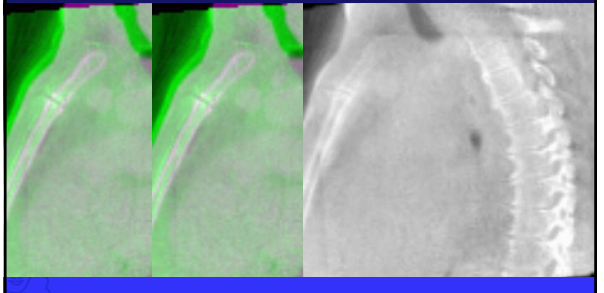
Visualization: Animation

Animation clearly shows local changes

Bone Registration



Bone Registration



Pop Quiz

What is the purpose of IGRT

19% 1. Make pretty images
20% 2. Minimize setup errors
20% 3. Quantify organ motion
21% 4. Reduce PTV margins
20% 5. Sell more expensive treatment machines

Pop Quiz

What is the purpose of IGRT

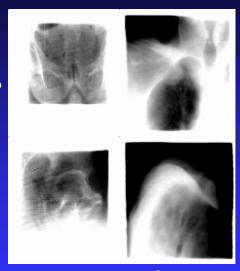
a) Make pretty images
b) Minimize setup errors
c) Quantify organ motion
d) Reduce PTV margins
e) Sell more expensive treatment machines

Correct Answer: d)
Seminars in Radiation Oncology Volume 17, Issue 4

2D Image Guidance

Electronic Portal Imaging

Portal Image Quality



A-P

Lat.

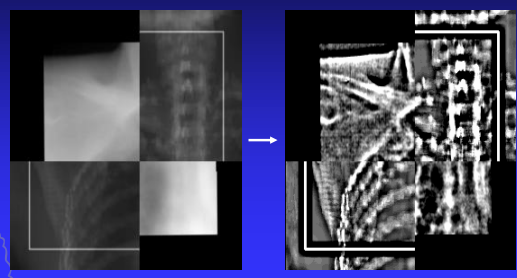
Prostate Lung

Image quality is limited by:

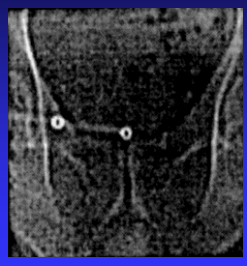
- *Projective nature of 2D images*
- *Low DQE of EPIDs in MV range*
- *Limited dose used for imaging (ALARA)*
- *Limited contrast differences of tissue in the MV range*

Mostly limited to bony anatomy alignment minimizing setup errors

Preprocessing: unsharp masking



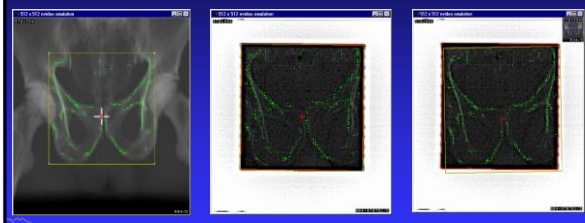
Top-hat transform



Original image

Binary top-hat enhanced image

Portal image analysis - 2D



Reference image Match field-edge Match anatomy

→ *Setup Error = Anatomy Match – Field-Edge Match*

3D EPID Dose reconstruction prostate VMAT plan

EPID movie *Dose per frame* *Accumulated dose*

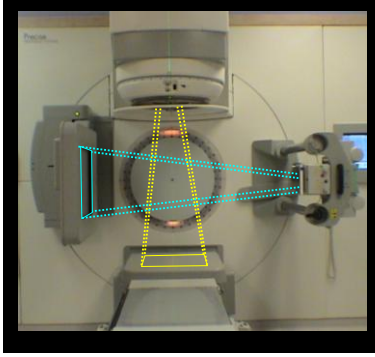
axial slice through isocentre

- *Energy: 10 MV*
- *243 frames*
- *delivery time: 96 s*

3D Image Guidance

Jean-Pierre Bissonnette: PMH

MV/kV Coincidence

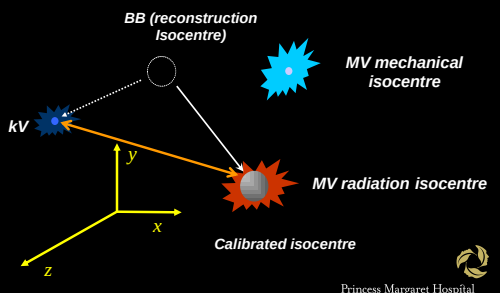


- Treatment and imaging beams are <u>orthogonal</u>

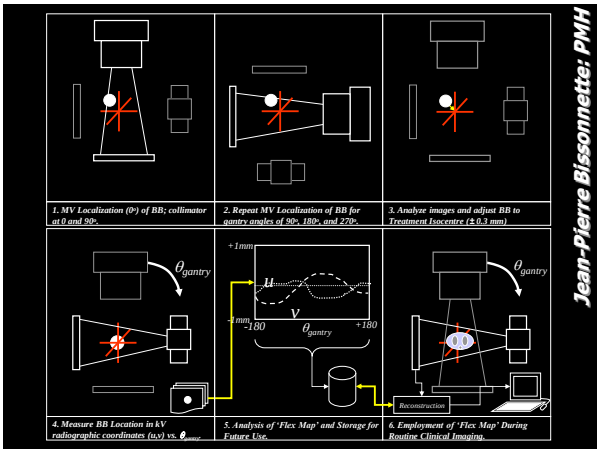
Princess Margaret Hospital

Jean-Pierre Bissonnette: PMH

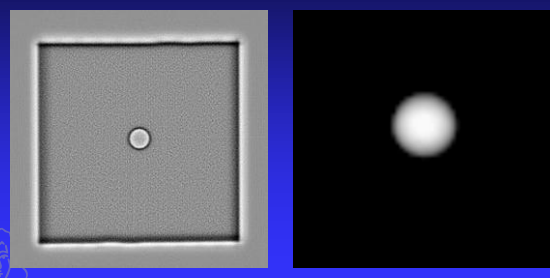
kV/MV Calibration Concept



Princess Margaret Hospital

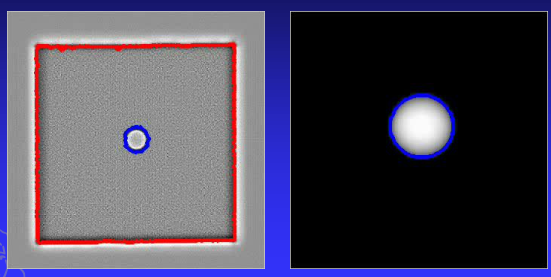


Geometry: Flex calibration

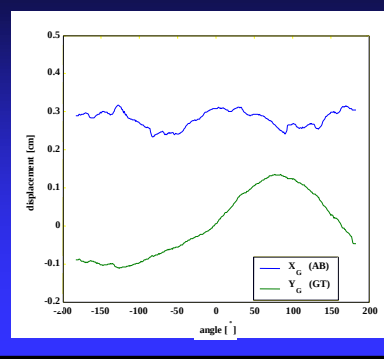


MV Flex kV Flex

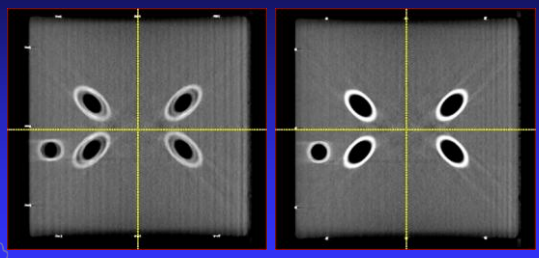
Geometry: Flex calibration



MV Flex kV Flex



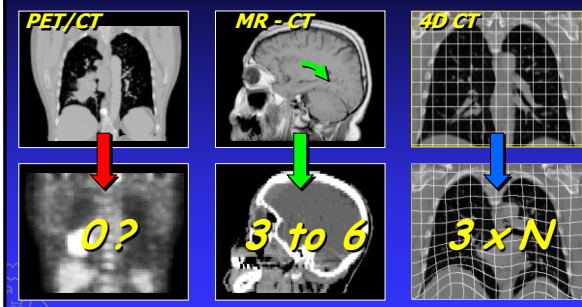
Geometric non-idealities (Flex)



2 mm panel shift *Correctly Calibrated*

Marc Kessler / UM

How many Degrees of Freedom?



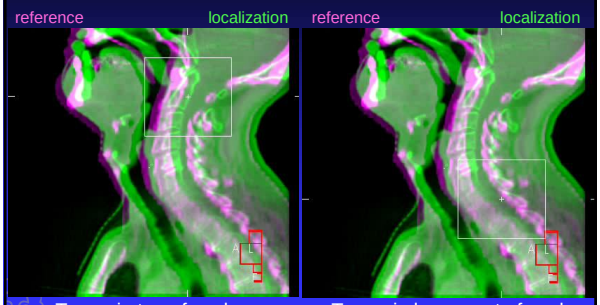
None ? ***Few*** ***Many***

Requirements for IGRT registration

- Fast and robust image registration
- Easy visual validation
- Registration result drives a couch shift

→ Rigid registration with 6 degrees of freedom is a likely candidate

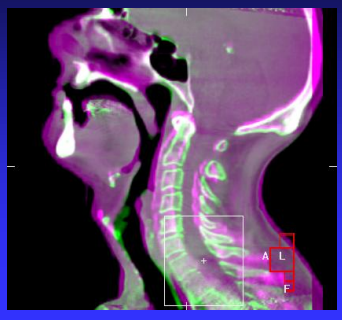
Automatic matching on region of interest built-in in Synergy system



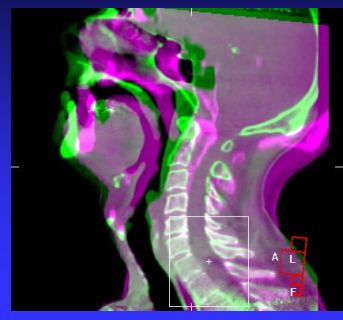
Tumor in top of neck
Required table shift:
(-3.2, -1.5, -0.6) mm

Tumor in lower part of neck
Required table shift:
(+1.5, -3.2, -6.1) mm

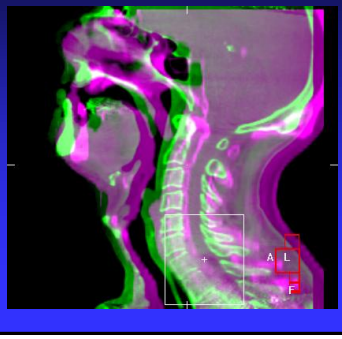
Rotations



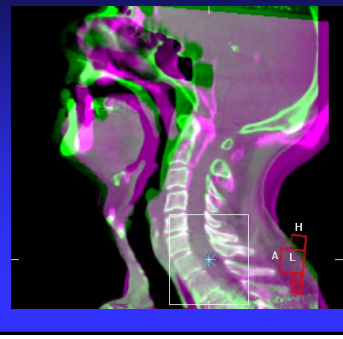
Rotations



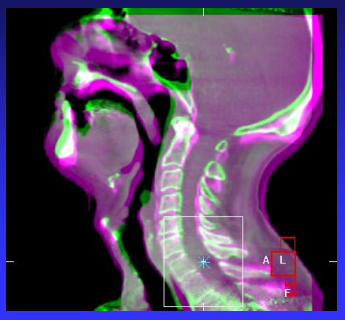
Correction by Couch Shift



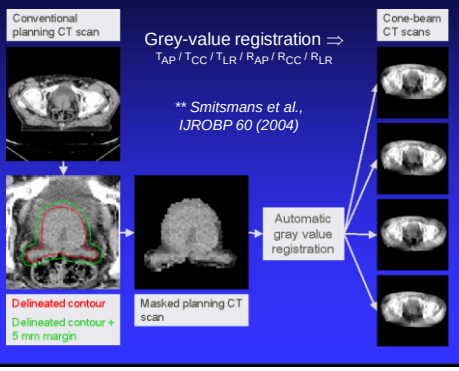
Modify Rotation Point



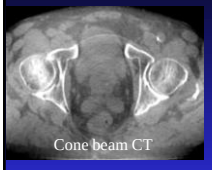
Correction by Couch Shift



Soft Tissue Guidance

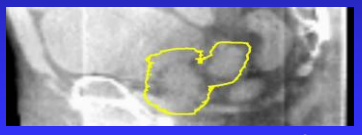


Automatic prostate localization in CBCT (30 s)


Cone beam CT


10 CBCT scans: automatic bone match


Planning CT contours placed automatically


10 CBCT scans: automatic prostate match
help line (GTV+3.6 mm)

Smitsmans *et al.*, IJROBP 2004, 2005

Pop Quiz

How many degrees of freedom are typically used for IGRT image registration

Pop Quiz

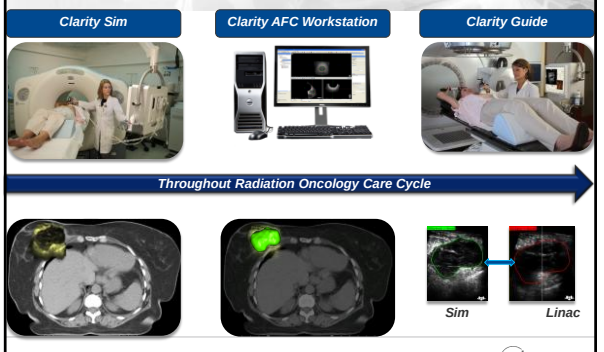
How many degrees of freedom are typically used for IGRT image registration

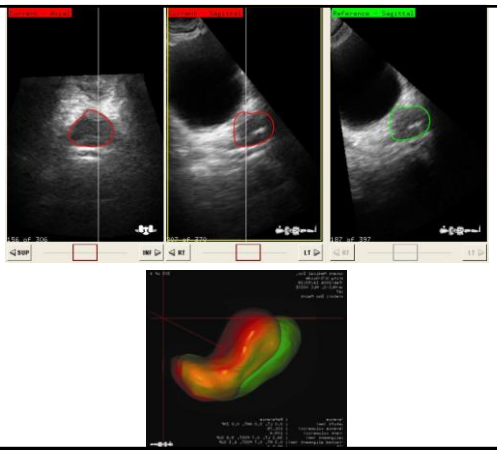
a) 0
b) 3
c) 6
d) 42
e) Not enough

Correct Answer: c)
Van Herk et al. Seminars in Radiation Oncology, 2007

Martin LaChaine: Elekta

Ultrasound Guided RT (Clarity™)

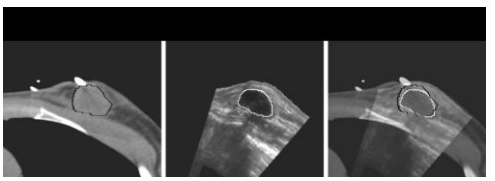




Frank Verhaegen: Maastro

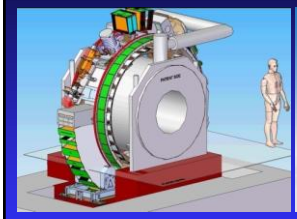
Frank Verhaegen: Maastro

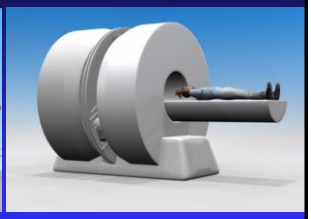
3DUS vs CT for breast seroma cavity



Planning CT *Daily US* *Fusion*

Radiotherapy systems with integrated MRI





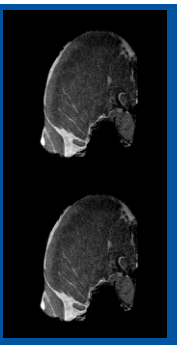
MRI-Linac Utrecht
Courtesy of Bas Raaijmaakers

MRI-Co60 ViewRay
Courtesy of Jim Dempsey

1.5 T MRI accelerator for MRI guided RT at UMC Utrecht

Bas Raaymakers: UMC

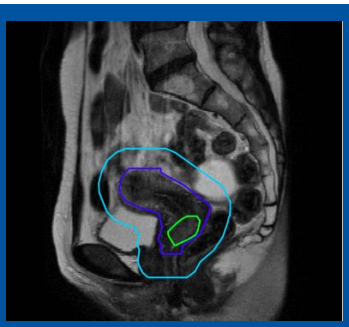
Prototype MRI accelerator



No impact of beam on MRI

Bas Raaymakers: UMC

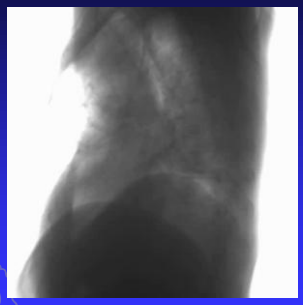
Inter- and intra- fracation motion of cervix

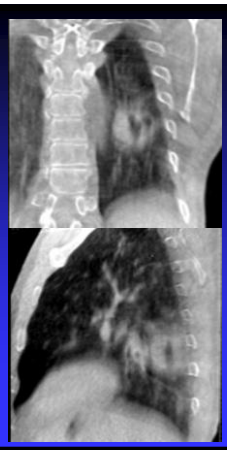


Day to day variation

4D Image Guidance

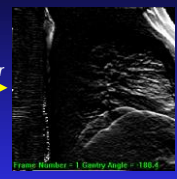
Breathing





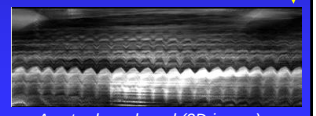
Respiratory signal extraction

Vertical derivative filter



Horizontal projection

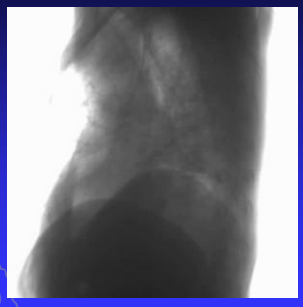
Temporal concatenation

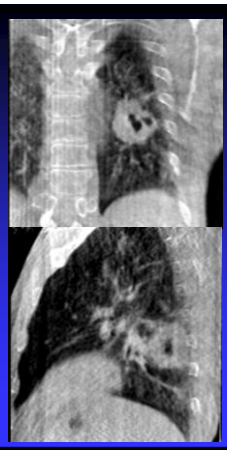


Amsterdam shroud (2D image)

[Zijp, ICCR, 2004]
[van Herk, ICCR, 2007]

RCCBCT

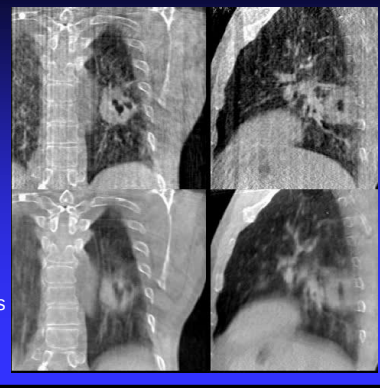




3D versus 4D CBCT

- 4D Data set
- 8 x 84 projections

- 3D Data set
- 670 projections

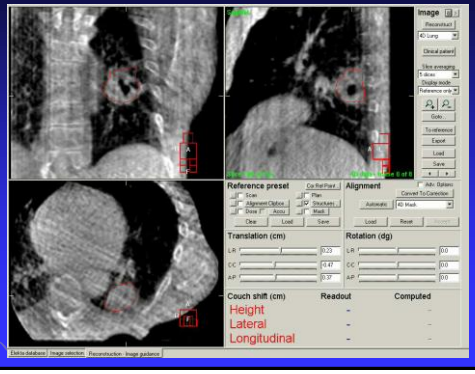


ROI by GTV Expansion

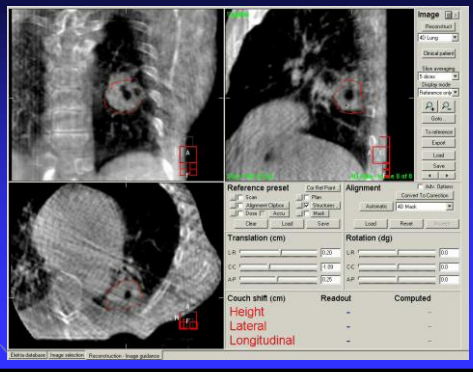
4D CBCT + GTV Contour

Local Rigid Body Registration

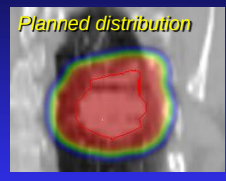
Visual Validation

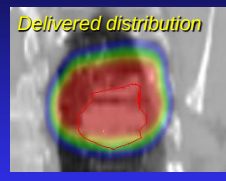


Apply Correction



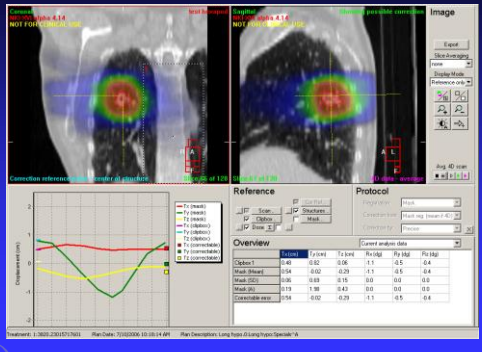
Impact of Respiratory Motion on Dose Distribution



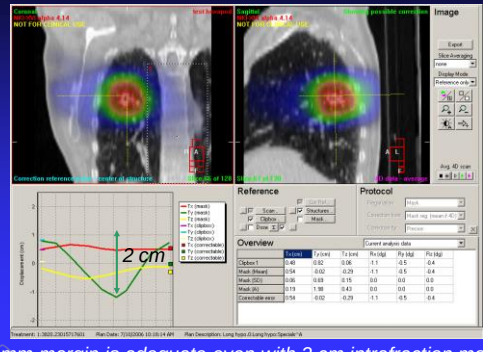


- *Shift of the dose distribution due to displacement of the mean tumor position*
- *Blurring of the dose distribution due to breathing around the mean position*

Planned dose distribution: hypofractionated lung treatment 3x18 Gy



Realized dose distribution with daily IGRT on tumor (no gating)



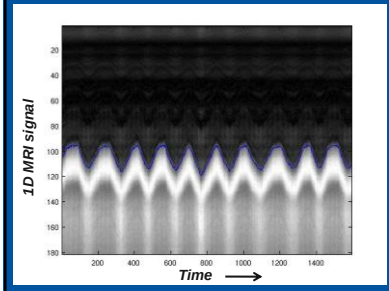
9 mm margin is adequate even with 2 cm intrafraction motion

Jim Dempsey / ViewRay

4D Liver MRI

Bas Raaymakers: UMC

1D MRI, Navigator echos (NE) 15 ms per acquisition

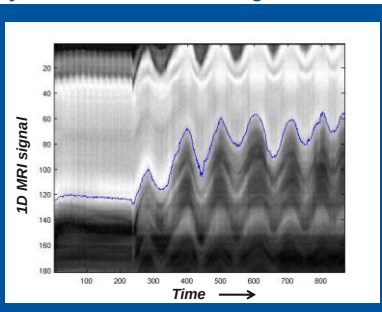


Monitoring breathing at superior side of liver

- *In diagnostics used to track/gate respiration*
- *Imaging stack is moved according to NE signal*
- *Diaphragm monitored*
- *Can be positioned anywhere in any orientation*

Bas Raaymakers: UMC

1D MRI navigators, monitoring breath hold stability and on-set of breathing

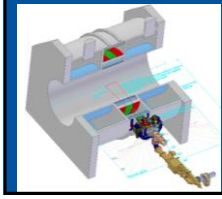


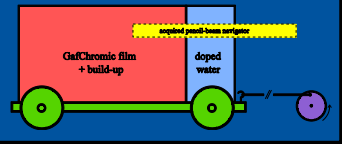
Monitoring breath hold at inferior side of liver

Bas Raaymakers: UMC

Gated radiation on moving cart

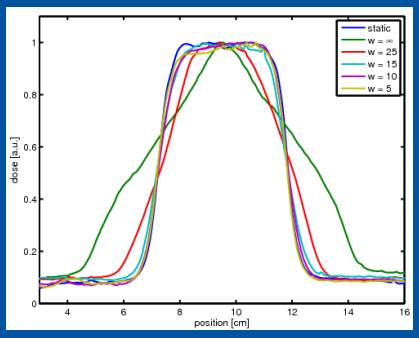
- Cart in scanner bore, moving along FH-direction
- Motion by electric motor/crankshaft mechanism
  - *Sinusoidal/respiratory-like motion*
- Radiation sensitive film to record dose
- Water phantom to track position
- 5x5 cm^2 radiation beam, dose ~2Gy, in static situation T = 2.5 min.





Bas Raaymakers: UMC

Gated radiation delivery



Pop Quiz

Which motion management strategy has the largest impact on the delivered dose:

18% 1. 4D Imaging
22% 2. 4D Planning
20% 3. 4D Delivery
20% 4. 4D Image Guidance
20% 5. The impact of respiration is over exaggerated

Pop Quiz

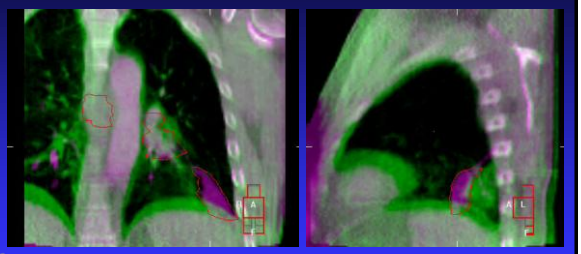
Which motion management strategy has the largest impact on the delivered dose:

a) 4D Imaging
b) 4D Planning
c) 4D Delivery
d) 4D Image Guidance
e) The impact of respiration is over exaggerated

Correct Answer: d)
Guckenberger et al. Radiother. Oncol. 2009

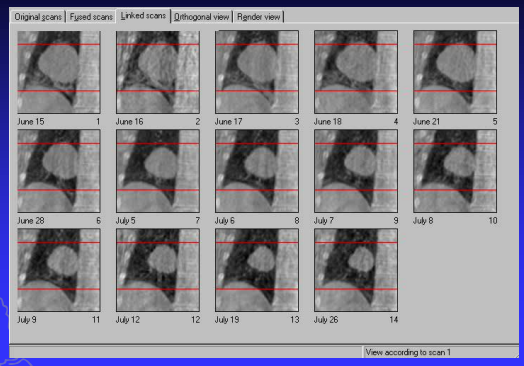
Adaptive Radiotherapy

Differential Variability



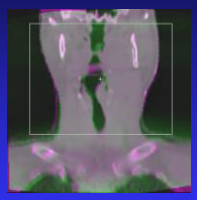
No couch correction can solve this problem

Repeat 4D cone beam CT

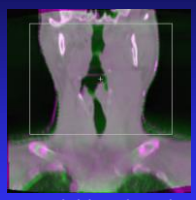


Shows respiration, tumor shrinkage and baseline position variation

Anatomical Changes

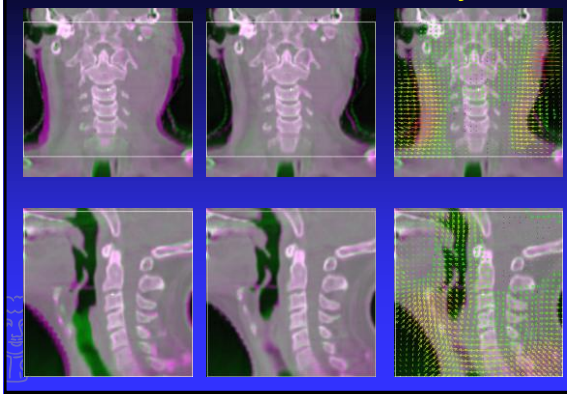


Bony anatomy registration

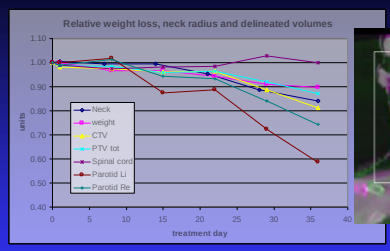


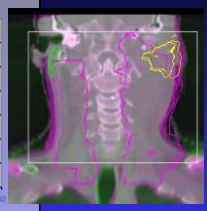
non-rigid registration

Fraction at day # 36



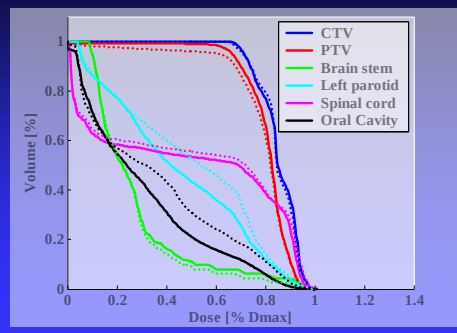
Results, volume change of target + OAR



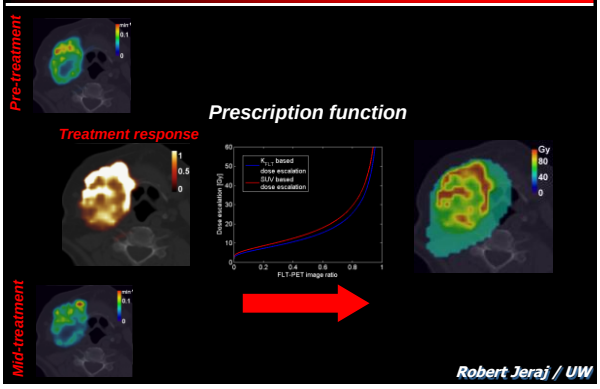


day	CTV	PTV	Spinal cord	Parotid Li	Parotid Re	t(s)
0	387	1051	20	31	21	-
1	381	1036	20	31	21	67
7	378	1035	20	32	21	120
14	373	1008	20	27	20	104
21	373	1012	20	28	19	55
28	344	969	21	23	17	141
36	315	916	20	18	15	155

Deformable Registration



Applications – dose painting



Summary

- Geometrical uncertainties limit the precision of radiotherapy
- 2D,3D&4D image registration and guidance increases the precision of RT allowing margin reduction and dose escalation
- Adaptive RT further individualized treatment delivery

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