ICR The Institute of Cancer Research

CANCER RESEARCH UK

in partnership with The ROYAL MARSDEN NHS Foundation Trust

Using a research real-time control interface to go beyond dynamic MLC tracking

Dr. Simeon Nill

Joint Department of Physics at The Institute of Cancer Research and the Royal Marsden NHS Foundation Trust
London

08/04/2016

Disclaimer

2

- ICR/RMH has a research agreement with Elekta on MLC tracking
- ICR/RMH is a member of the Elekta Atlantic Research Consortium

3

Overview

- Introduction to Elekta linacs
  - Brief overview of the control system
  - Options to deliver non-clinical research plans
- Introduction to MLC tracking
  - Real time tracking interface
  - Evaluation of system latency
  - Multi-institutional tracking comparison
- Online dose reconstruction
  - Framework for online dose reconstruction
  - First results for simulated prostate and lung tracking
- Summary / Outlook

4

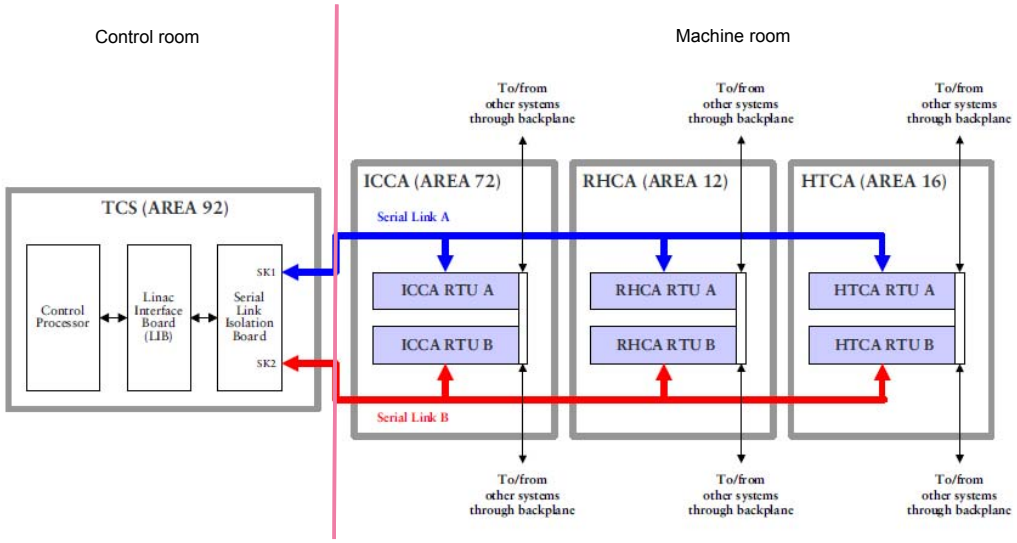
Elekta Digital Linac

- Fully digital control system
- 160 leaf Agility MLC
- 5 photon energies (3xFF/ 2xFFF)
- 5 electron energies
- Hexapod (6D couch)

Possibility to dynamically change the MLC, Diaphragm, Gantry and Collimator movement during irradiation

5

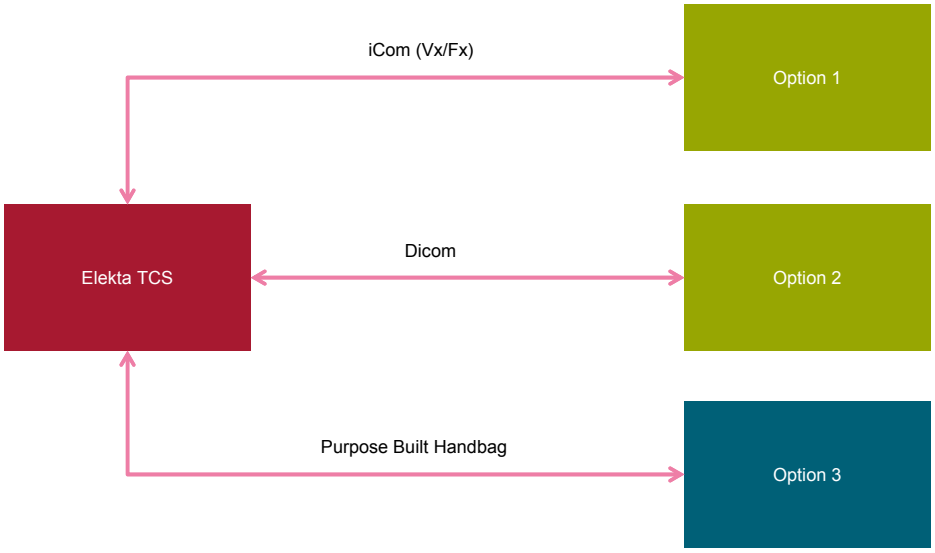
Elekta Digital Control System



From: Elekta corrective maintenance manual

6

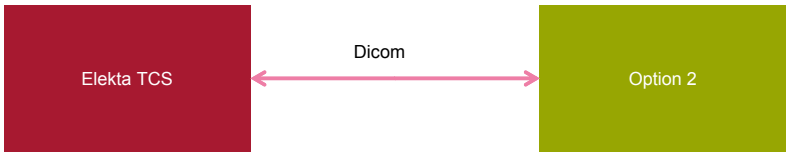
Elekta Linac Interfaces



Integrity Dicom conformance statement: https://www.elekta.com/software-solutions/dicom-conformance-statements.html

Elekta Linac Dicom Interface

7

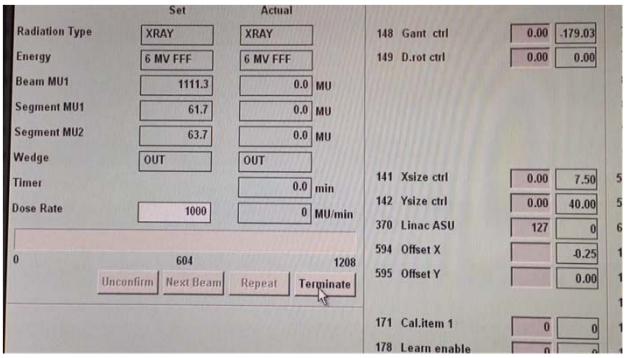


- Generate Dicom plan using your research software
- Ensure conformance to Elekta Dicom statement
- Send to linac
- Deliver as stored beams within service mode
- Not limited by R&V restrictions

Integrity Dicom conformance statement: https://www.elekta.com/software-solutions/dicom-conformance-statements.html

Dicom Example

8

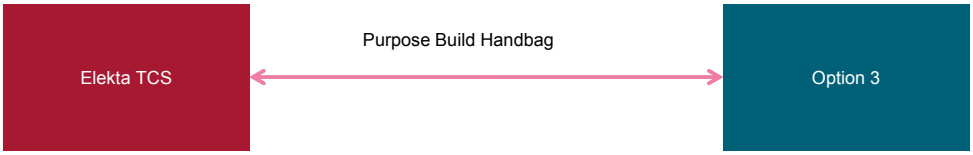


VMAT FFF plan

- Dynamic change of collimator angle (0->5->0)
- Change of energy during arc delivery (6->10->6)

9

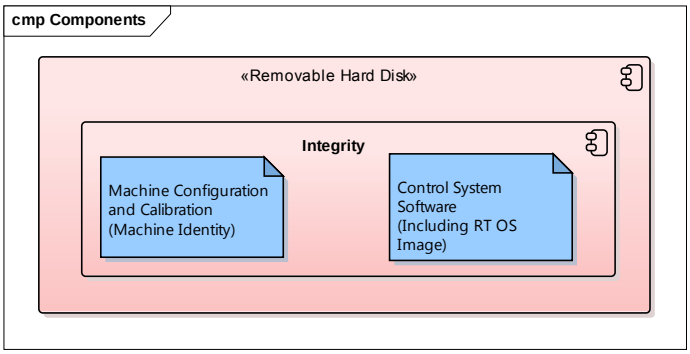
Elekta Linac Research Interfaces



- Research agreement with Elekta required
- Provides a tailored customised handbag
- No need for a dedicated research linac

10

Clinical to Research to Clinical

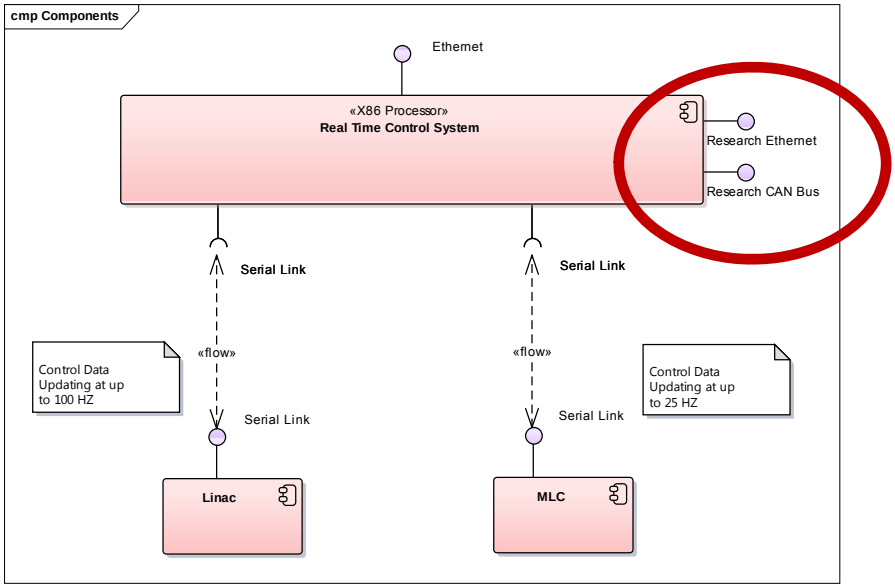


- Research supported linacs may switch between configurations and software builds and back again with minimal effort
- **Entire** machine configuration, calibration and identity is contained on a removable hard disk

Courtesy of Elekta

11

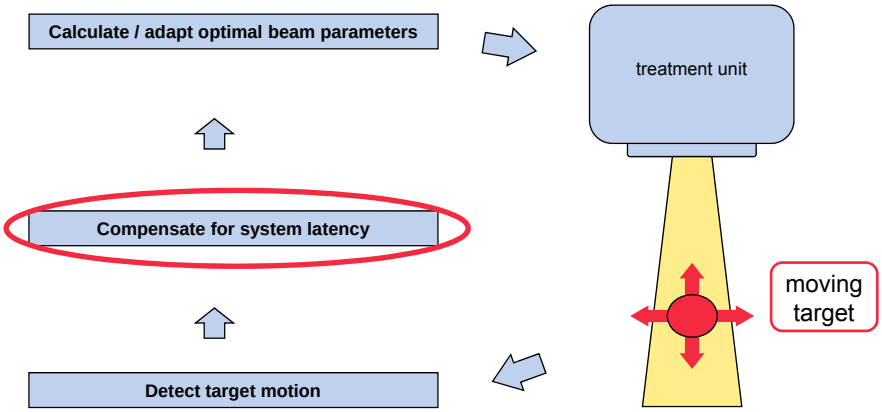
MLC Tracking Handbag



Courtesy of Elekta

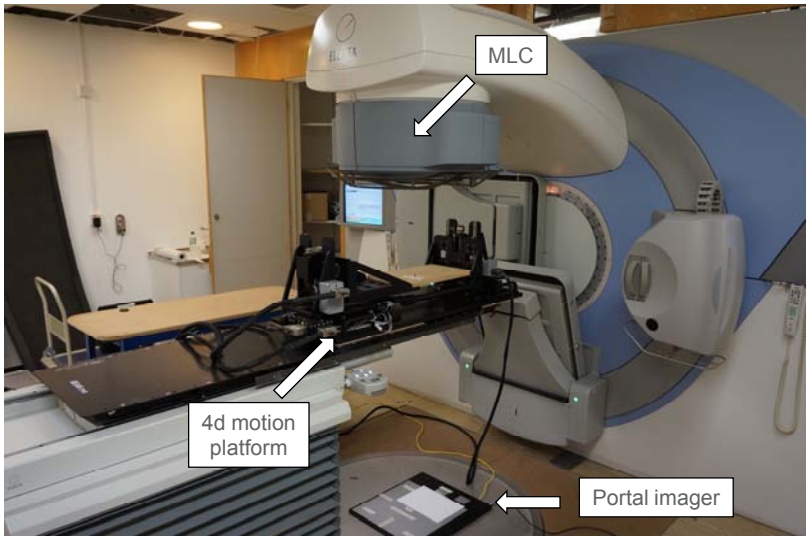
12

MLC Tracking: Overview



13

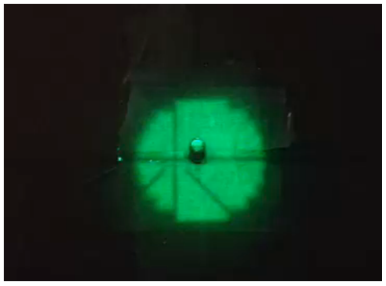
Experimental set-up: Maple



14

Results: Summary

Type	Motion*	Effective latency [ms]**	RMSE [mm]**
Leaf-only	LR	56-61	0.6-1.6
Jaw+leaf	SI	71-76	0.7-1.5
DLG+leaf	LR	57-73	1.9-3.3



Fast et al (2014), Medical Physics 41, 111719.

*assuming gantry & collimator angles at 0°

**depending on target update frequency and maximum target speed

15

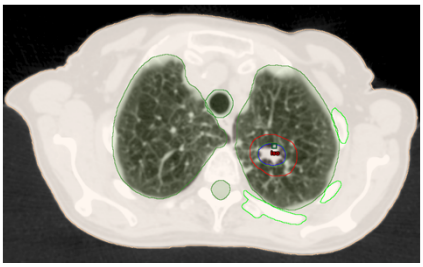
Cross-platform real-time adaptive radiotherapy performance characterization

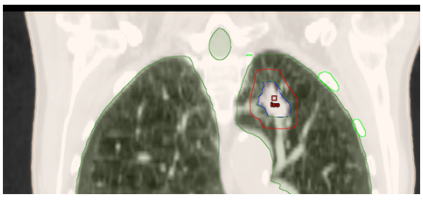
10 institutions
25 researchers

Slide courtesy of Emma Colvill

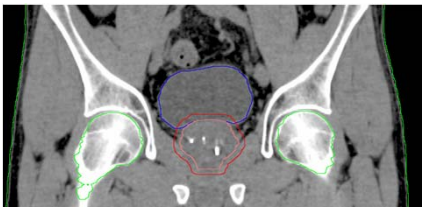
16

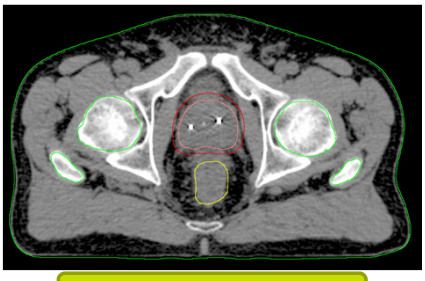
Lung and Prostate Cases





Median volume Hansen Acta Onc 2014





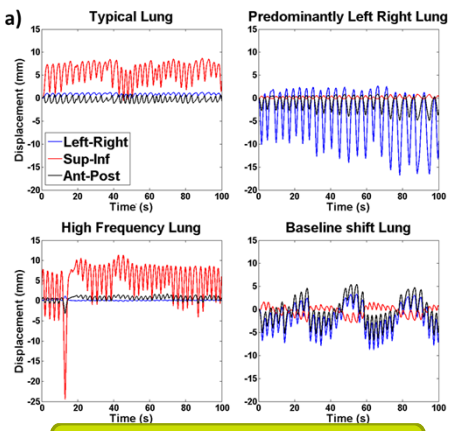
Median volume Ng IJROBP 2012

Slide courtesy of Emma Colvill

17

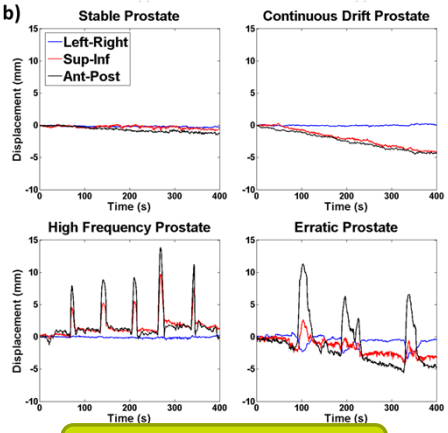
Patient-Measured Motion Files

Lung



Cyberknife-measured lung tumor motion
Suh PMB 2008

Prostate

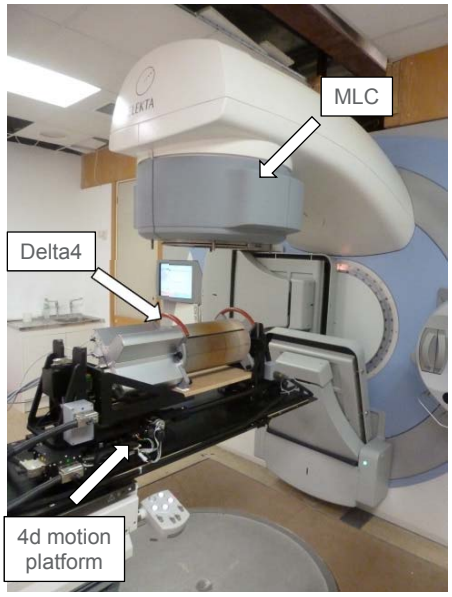


Calypso-measured prostate motion
Langen IJROBP 2008

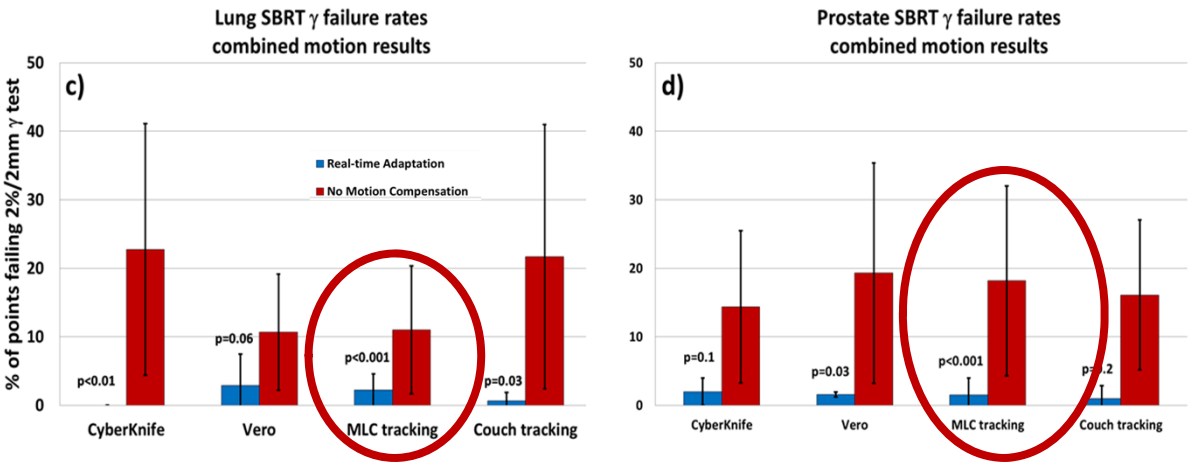
Slide courtesy of Emma Colvill

18

Experimental set-up: Agility MLC



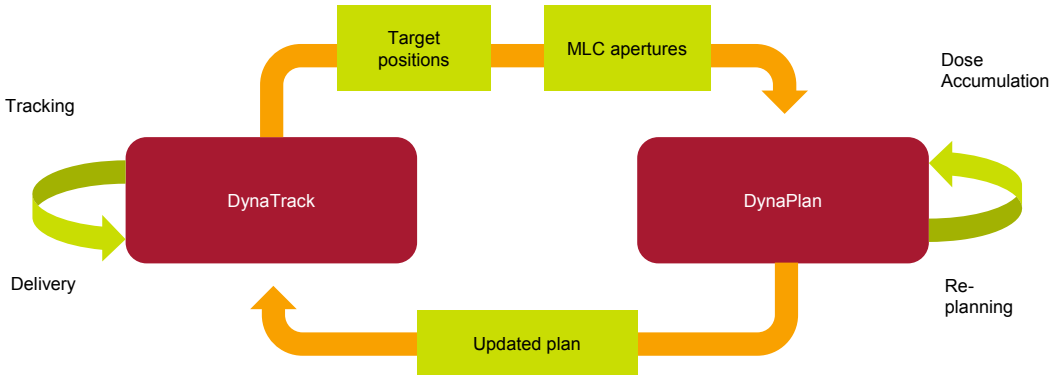
Adaptation systems 2%/2mm



Radiother Oncol. 2016 Apr;119(1):159-65. doi: 10.1016/j.radonc.2016.03.006. Slide courtesy of Emma Colvill

20

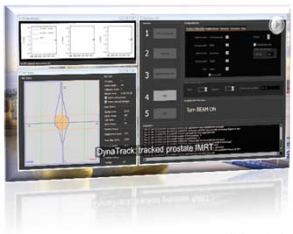
Beyond dynamic MLC tracking: Online dose reconstruction



- Applications not limited to MLC tracking
- Designed with MRI-Linac in mind

Research RT software platform at ICR

21



Simulated Patient Case

22

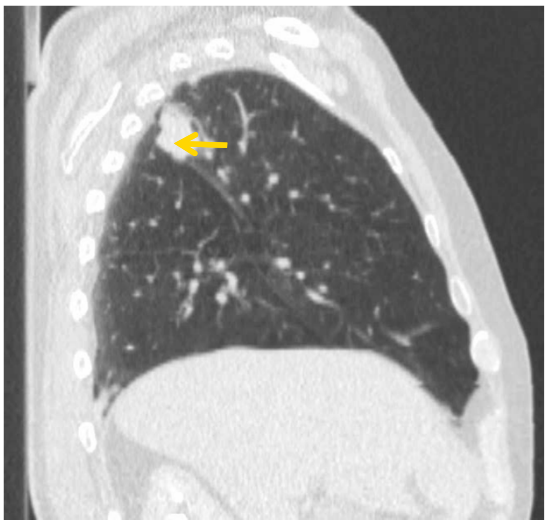
Planning CT

- Phase-binned 4DCT
- 10 phases

Planning strategies

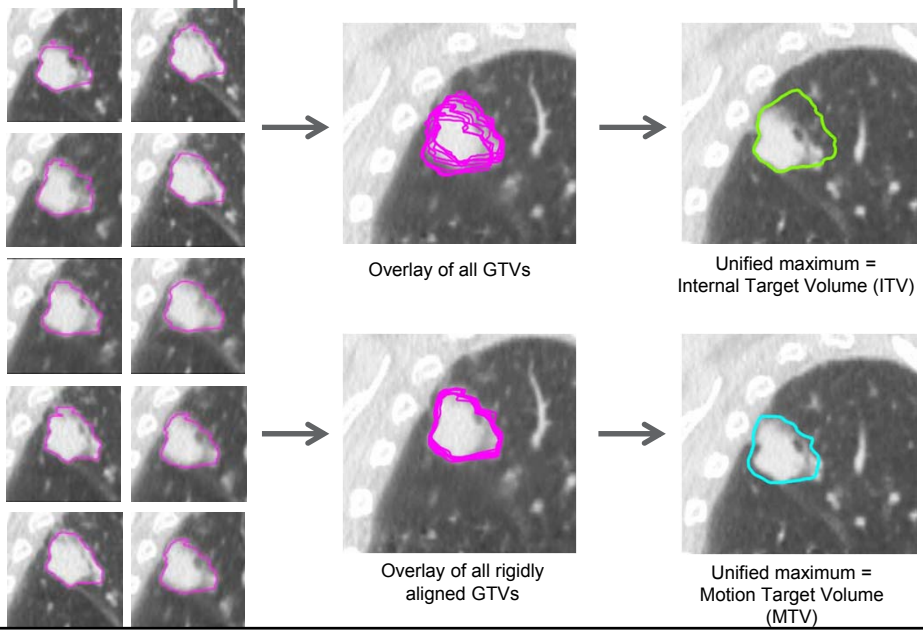
- Conventional ITV + 5mm
- Motion Target Volume (MTV) + 5mm

- RTOG 1021 (3-Fx, 9-beam)
- 18 Gy to 95% of PTV per fraction



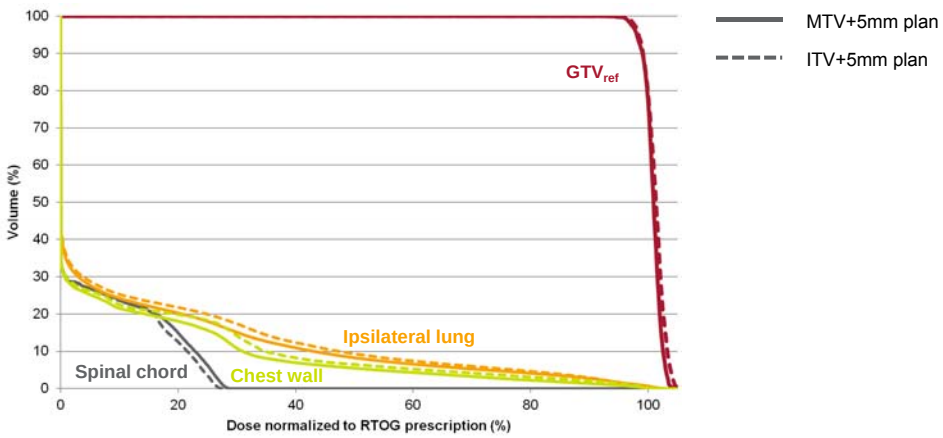
23

ITV vs MTV concept



24

Results

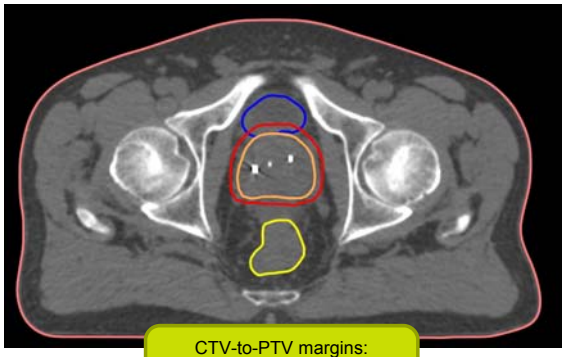


Computation time

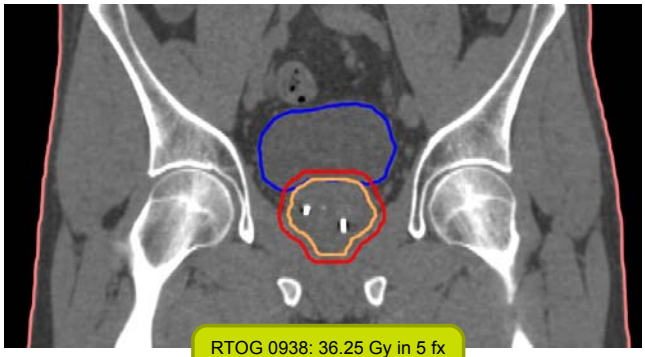
- Dose calculation time: ≤ 10 ms (voxel size: 2x2x2 mm^3)
- EMT dose accumulation: ≤ 30 ms
- Memory throughput: ≤ 90 GB/sec on single workstation computer
- Pre-calculated dose influence data with 5x5 mm^2 beamlet resolution for each individual 4DCT phase (Monte Carlo algorithm)
- Dose deformation through Energy-Mass Transfer
- Single workstation with 2x Intel Xeon CPU E5-2697 v3

25

Prostate case: Online dose accumulation



CTV-to-PTV margins:
- 1, 3 & 5 mm isotropic
- 3 mm posterior + 5 mm else

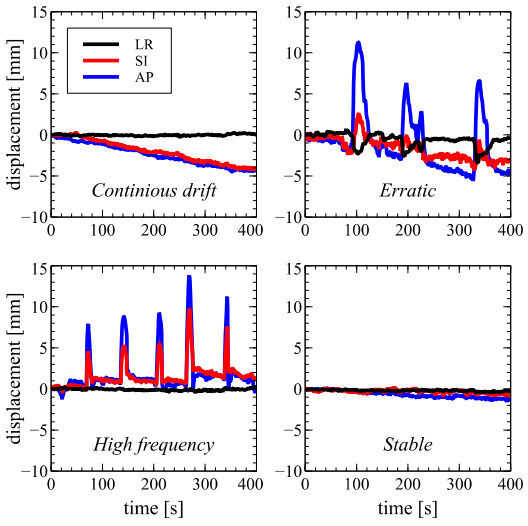


RTOG 0938: 36.25 Gy in 5 fx
7-beam IMRT
CTV: 55 cm^3

Fast et al (2016), Phys Med Biol. 2016 Feb 21;61(4):1546-62

26

Prostate motion patterns

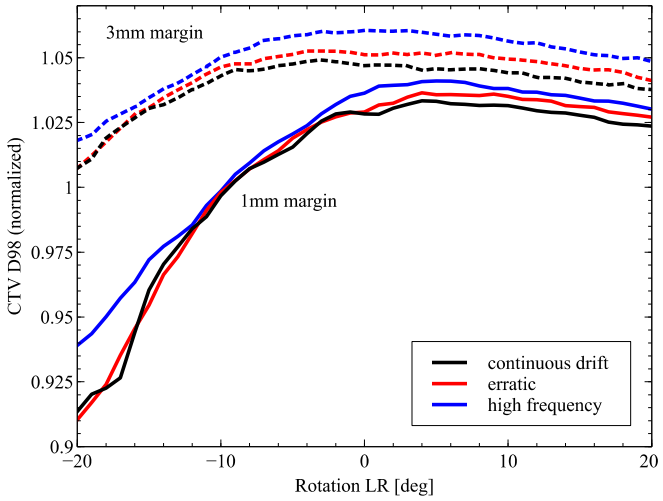


Calypso-measured prostate motion
Langen et al. (2008) IJROBP

Rotations about LR (centre of prostate)
-20° → 20°
(1° increments)

- Motion simulated as VOI shift

Results: translations (tracked) + rotations

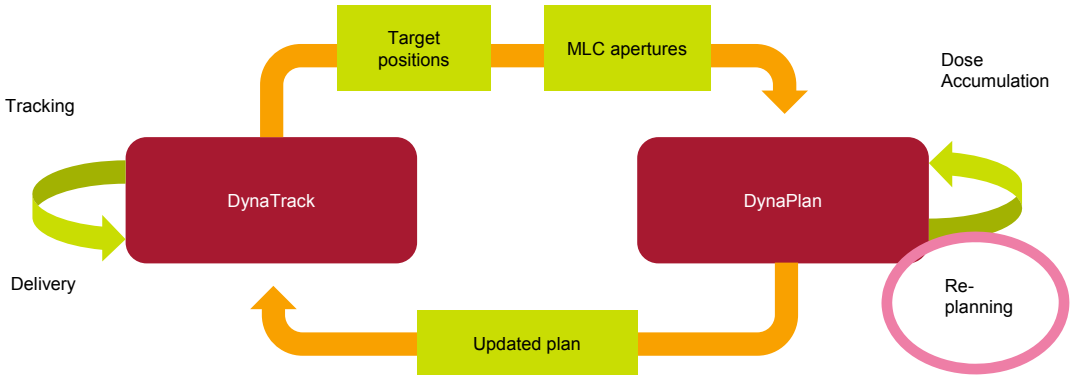


- Impact of rotations can be significant for smaller margins

Fast et al (2016), Phys Med Biol. 2016 Feb 21;61(4):1546-62

28

Next step: Online replanning



Online Inter-Beam Replanning Based On Real-Time Dose Reconstruction

Corijn Kamerling TH-CD-202-12
Today 11:50AM Room: 202

Summary:

Elekta linacs provide different options to develop dynamic delivery techniques

MLC Tracking with Agility MLC shows excellent results for motion compensation

Online dose reconstruction is a powerful tool for online plan QA and online plan adaption

ICR The Institute of Cancer Research

CANCER RESEARCH UK

in partnership with The ROYAL MARSDEN NHS Foundation Trust

NIHR Biomedical Research Centre for Cancer

Cancer Research UK Programme Grant C33589/A19727

Medical Research Council (MRC)

ICR/RMH is a member of the Elekta Atlantic Research Consortium

[Acknowledgements]

Uwe Oelfke
Martin Fast
Peter Ziegenhein
Corijn Kamerling
Martin Menten
Adrian Smith
Emma Colvill