On-board Imaging System of Varian Trilogy & TrueBeam Systems

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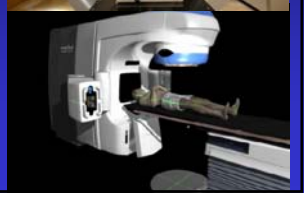
Clinical Evaluation of CBCT: Radiation dose, scatter, motion artifacts

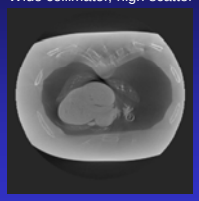
Linear accelerator with onboard cone-beam



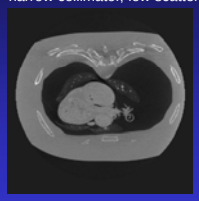
Scatter Artifacts

- Large Scatter-to-Primary Ratios (SPR) in CBCT cause severe cupping/shading artifacts.

Wide collimator, high scatter



narrow collimator, low scatter



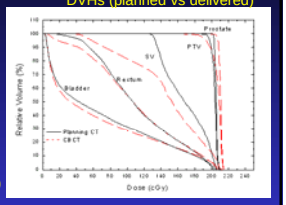
Display window: [min max]; no anti-scatter grid, no scatter correction.

Zhu L, Wang J, Xing L, Scatter correction for cone beam CT in radiation therapy, *Medical Physics* 36(6):, 2258-68, 2009.

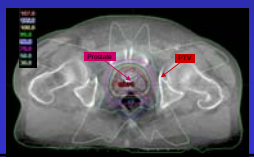
Use CBCT for Dose Verification

Planned (IMRT)

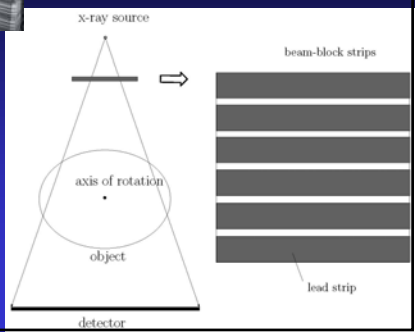
DVHs (planned vs delivered)



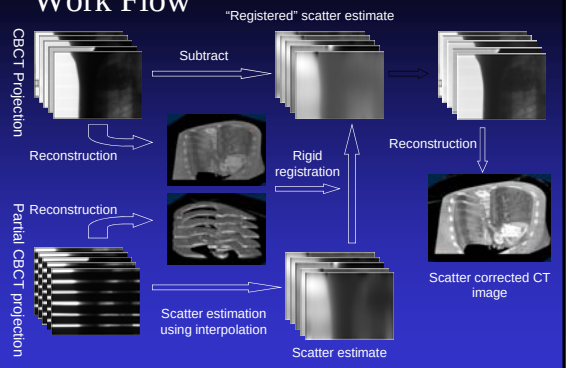
To be delivered (reconstructed dose on CBCT)



Yang Y, Schreibmann E, Li T, Wang C, **Xing L**: Evaluation of on-board kV cone beam CT (CBCT) based dose calculation. *Physics in Medical Biology*, 52: 685-705, 2007.



Work Flow



L. Zhu, J. Wang and L. Xing, Med. Phys. 2008

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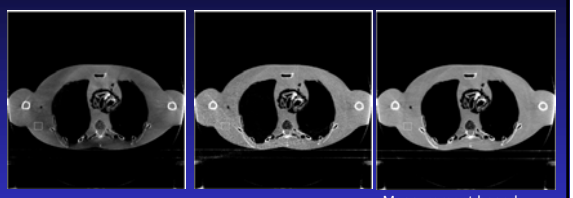
Scatter noise in post-processing methods



No scatter correction, no noise suppression,

Noise in the ROI: 1.01e-6

Measurement-based scatter correction, no noise suppression,

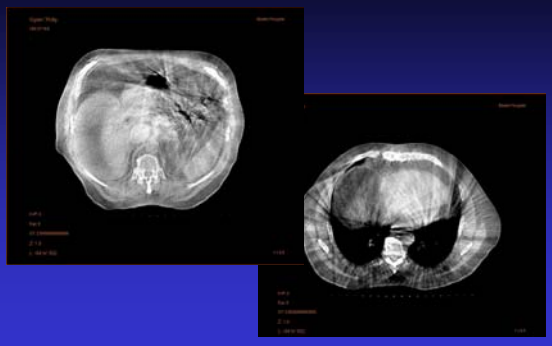
Noise in the ROI: 1.01e-5

Measurement-based scatter correction, PWLS noise suppression, (Wang et al., 2006)

Noise in the ROI: 9.75e-7

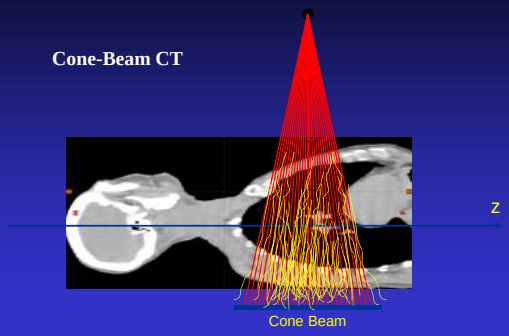
L. Zhu, J. Wang and L. Xing, Med. Phys. 2008

Motion artifacts in fan beam CT and CBCT

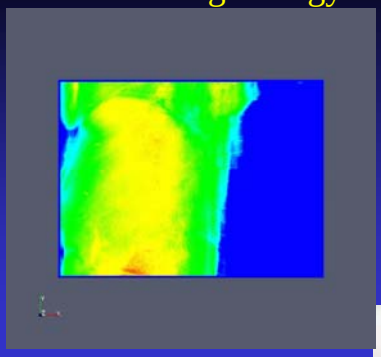


Scatter

Cone-Beam CT



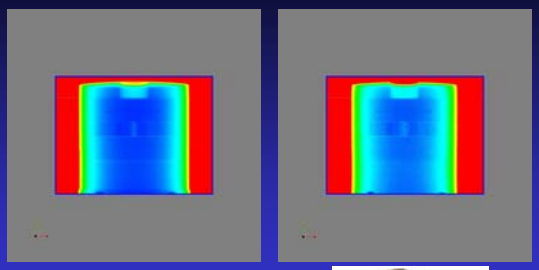
CBCT using Trilogy

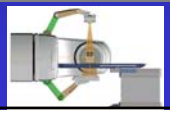


Tianfang Li et al, Li T, Xing L: IJROBP, 67: 1211-1219, 2007

Stanford Research

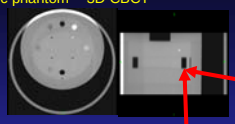
CBCT projections before and after phase sorting



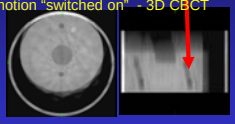


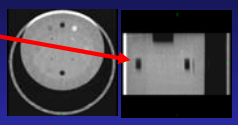
CBCT phantom images

Static phantom - 3D CBCT



motion "switched on" - 3D CBCT





motion "switched on" - 4D CBCT

Li, Koong, Loo, Xing, Med. Phys., 2006

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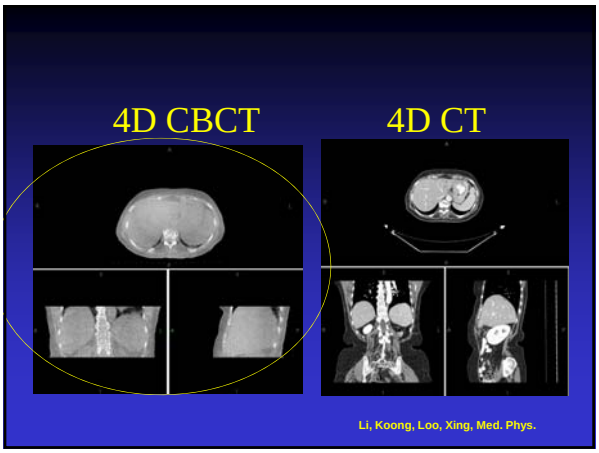
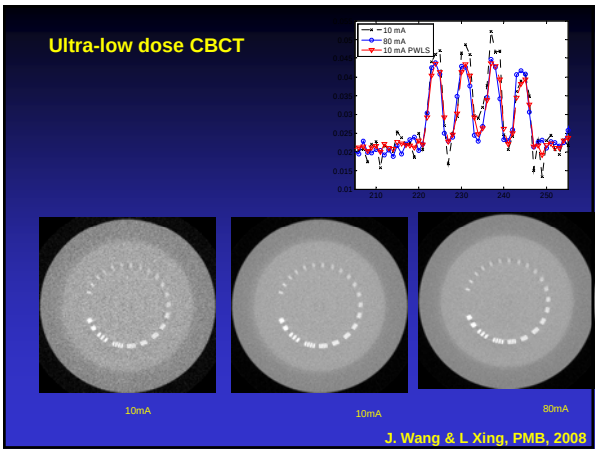




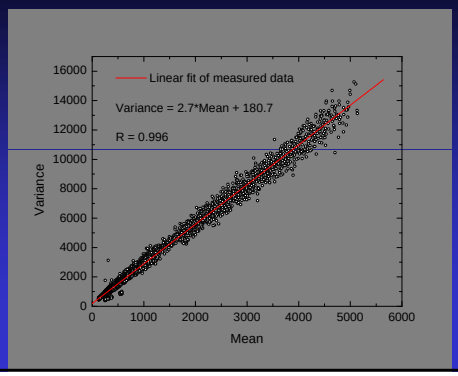
PWLS (Penalized Weighted Least-Squares method):

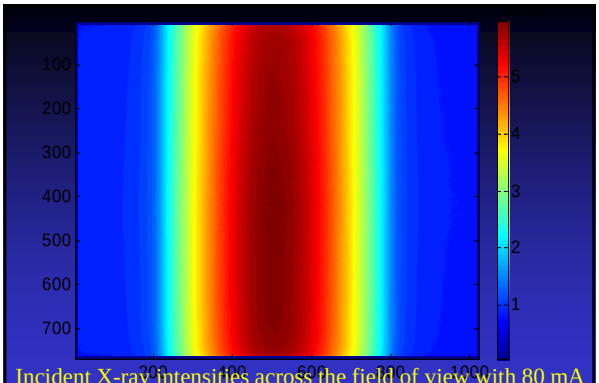
$$\Phi(p) = (\hat{y} - \hat{p})^T \Sigma^{-1} (\hat{y} - \hat{p}) + \beta R(p)$$

$$R(p) = \sum_n w_{in} (p_i - p_n)^2$$

$$w_{in} = \exp[-(\frac{p_i - p_n}{\delta})^2]$$

Noise property of projection images





Incident X-ray intensities across the field of view with 80 mA tube current and 10 ms pulse time. Relative intensity is mainly caused by the bow-tie filter.

iterative Gauss-Seidel updating strategy

$$R(p) = \sum_n w_{in} (p_i - p_n)^2$$

$$p_i^{(k+1)} = \frac{y_i + \beta\sigma_i^2 (\sum_{n \in N_i^1} w_{in} p_n^{(k+1)} + \sum_{n \in N_i^2} w_{in} p_n^{(k)})}{1 + \beta\sigma_i^2 \sum_{n \in N_i} w_{in}}$$

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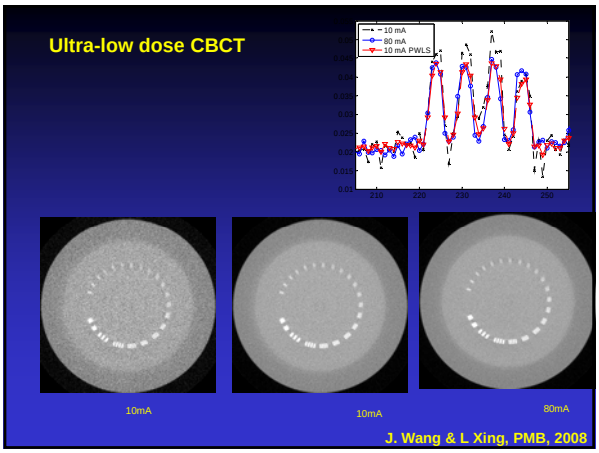
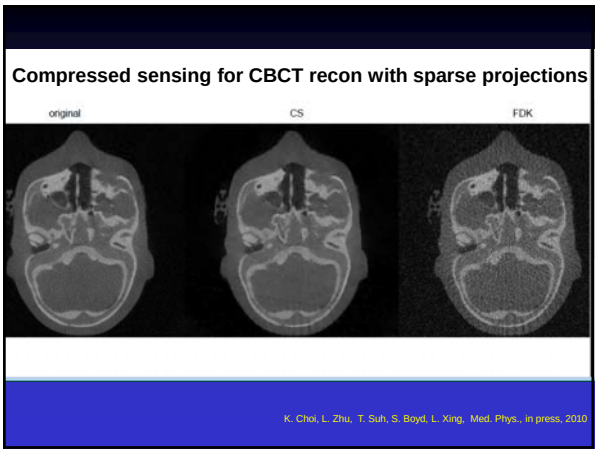
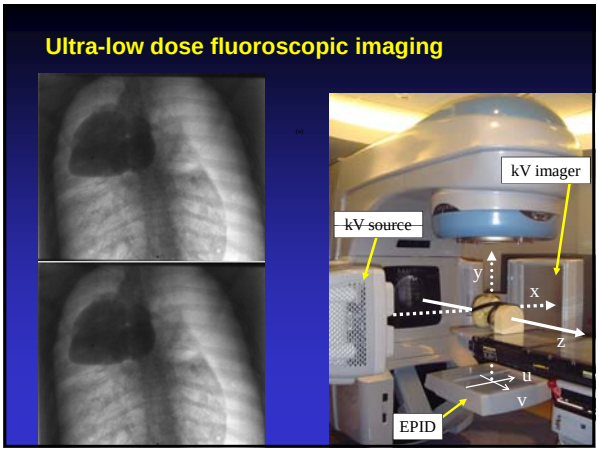
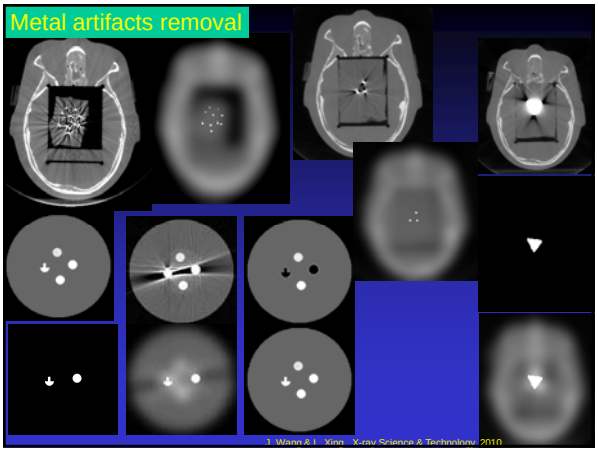
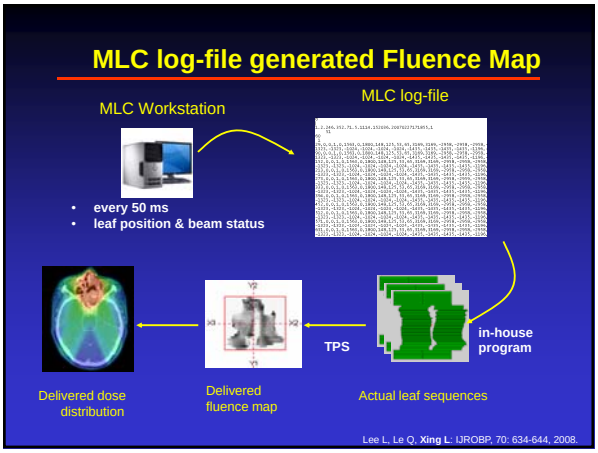








Dose Reconstruction: Closing the Loop of IMRT/RapidArc/Gated RapidArc treatment



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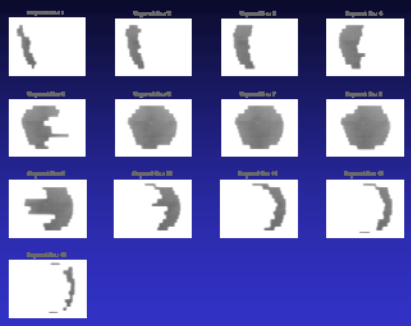
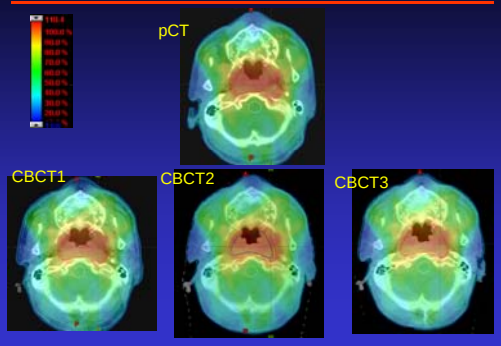


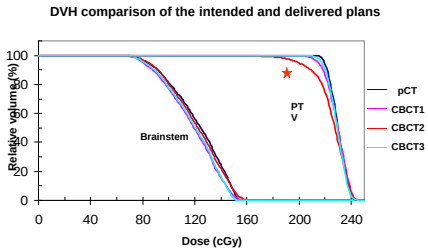
Figure 2.10 (a)

Case 1: Dose Distribution

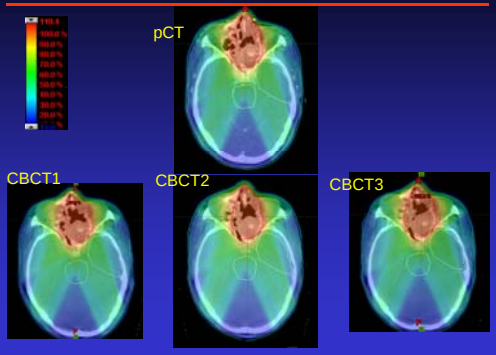


Lee L, Le Q, **Xing L**: IJROBP, 70: 634-644, 2008.

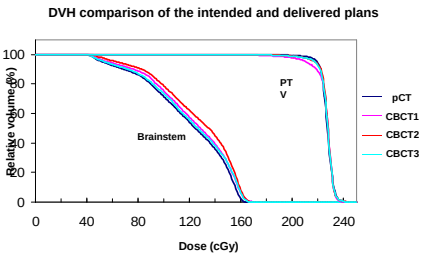
Case 1: DVHs



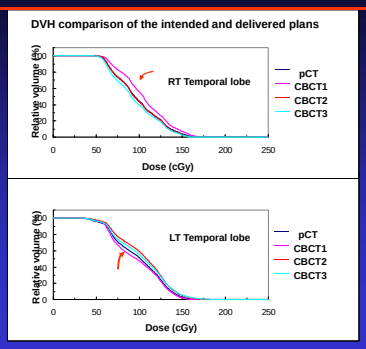
Case 2: Dose Distribution



Case 2: DVHs



Case 2: DVHs



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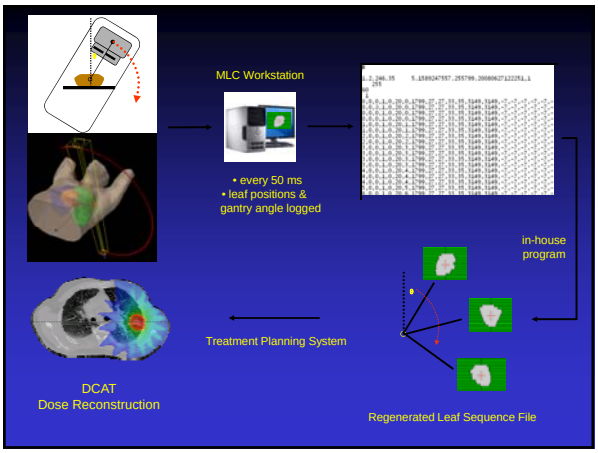
Case 2: Dosimetric comparison

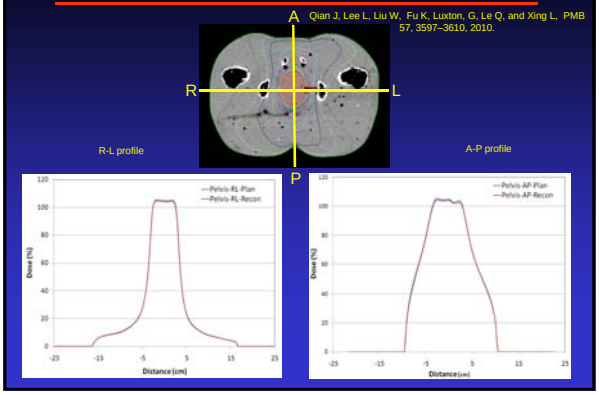
Dosimetric end point	pCT	CBCT1	CBCT2	CBCT3
PTV, D_{95} (cGy)	219.4	211.3	217.5	218.2
PTV, V_{93} (%)	99.2	97.0	98.8	98.5
Brainstem, D_{max} (cGy)	164.9	171.0	169.1	167.8
RT Temporal lobe, D_{max} (cGy)	174.8	188.5	170.8	169.8
LT Temporal lobe, D_{max} (cGy)	174.9	167.4	191.3	199.1

220 cGy at 100%

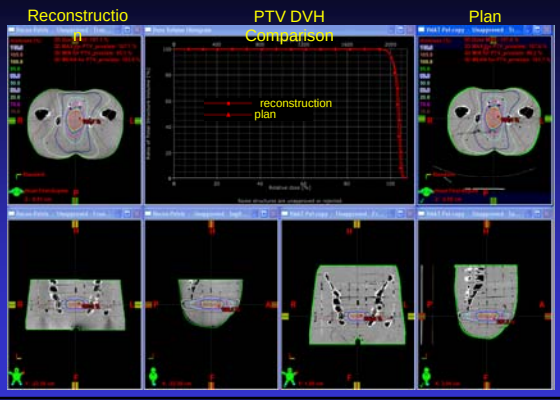


Planned and Reconstructed Dose Profile Comparison

Qian J, Lee L, Liu W, Fu K, Luxton, G, Le Q, and Xing L, PMB 57, 3597–3610, 2010.

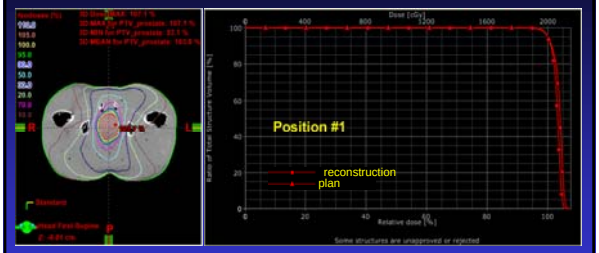


Dose Distribution Comparison



Positioning Errors and Dose Delivered to PTV

Positioning errors intentionally introduced

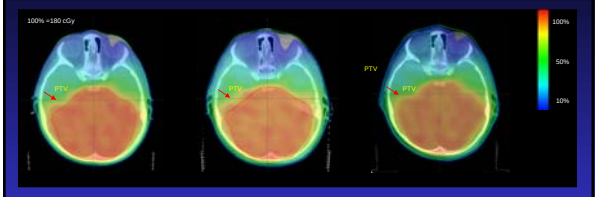


Position #1: same as the plan

Position #2: L R: 0 mm; A P: -2 mm; S I: 2 mm

Position #3: L R: 3 mm; A P: 5mm; S I: 5 mm

Patient Study



pCT CBCT1 CBCT2

- CBCT1 / CBCT2: monitored the anatomic change, if any
- CBCTs' dose distribution very close to pCT's

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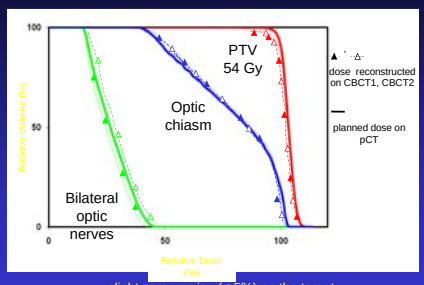
DVH Results



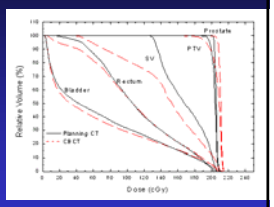
- slight compromise (< 5%) on the target coverage
- dose deposited to the critical organs:

in general <10% change; worst ~20%

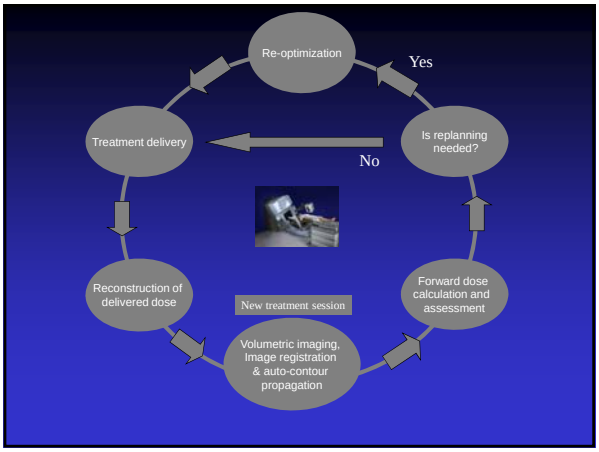
Use CBCT for Dose Verification

Planned (IMRT)

DVHs (planned vs delivered)



Delivered (reconstructed dose on CBCT)

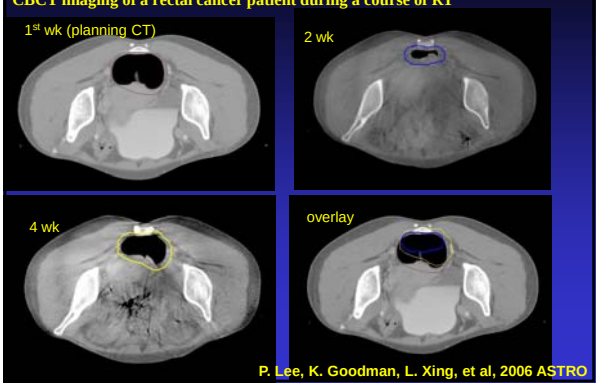


Adaptive Radiation Therapy

- What are needed to bring ART into clinic?
  - CBCT.
  - Deformable model.
  - Automated contour mapping from pCT to CBCT.
  - Retrospective dose reconstruction.
  - Deformable registration for cumulative dose calculation
  - Inverse planning for ART
  - Dose shaping tool.

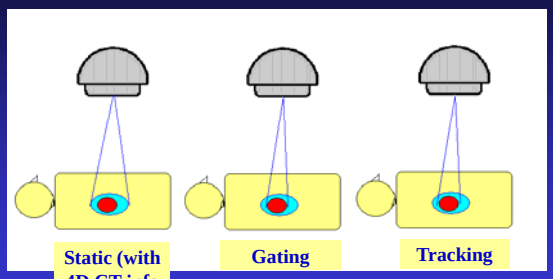
IMMOBILIZATION DOES NOT ALWAYS WORK!

CBCT imaging of a rectal cancer patient during a course of RT



P. Lee, K. Goodman, L. Xing, et al, 2006 ASTRO

4D Treatment Planning



Adapted from Y. Yang, UPMC

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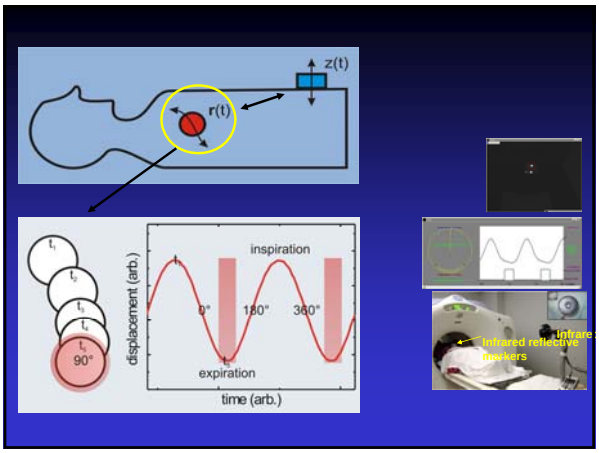

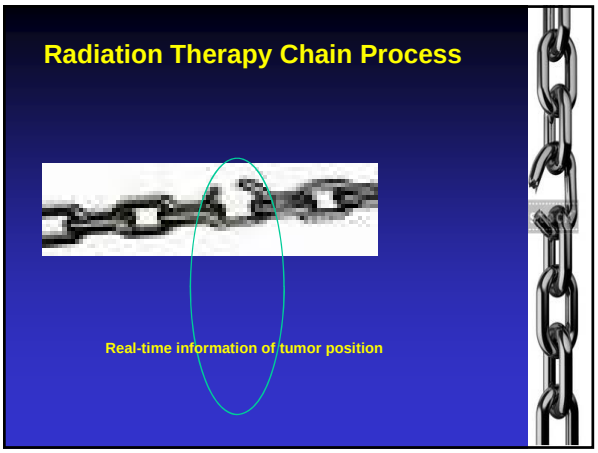

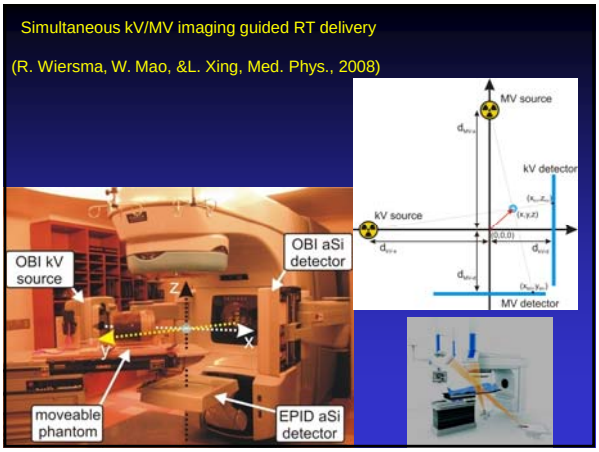

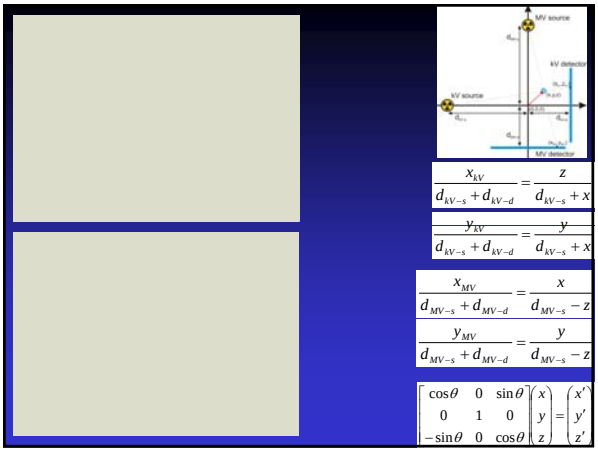

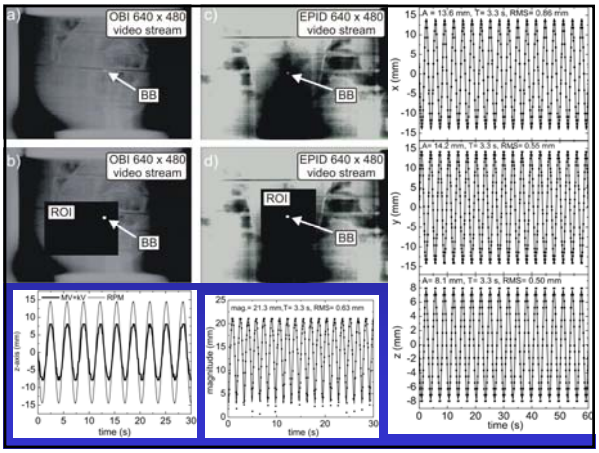

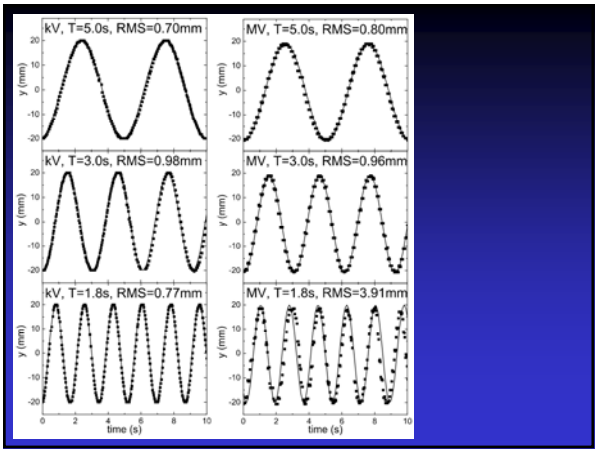

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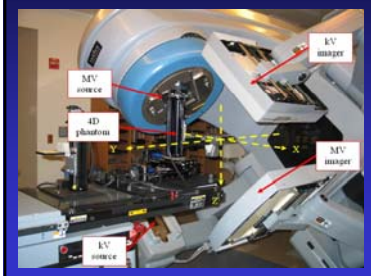
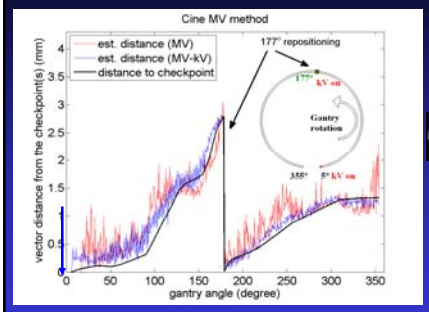
Results – example 1

Real-time Image Guidance for Prostate VMAT/IMRT



Example 1



- The sudden drop represents repositioning.

ACKNOWLEDGEMENT

L. Zhu, T. Li, J. Qian, R. Wiersma, W. Liu, J. Wang, K. Choi, L. Lee, B. Meng, X. Zhang, Y. Yang, A. de la Zerda, B. Armbrush,…

Clinical faculty –
A. Koong, Q. Le, B. Loo, G Luxton, C. King, S. Hancock, P. Maxim, E. Mok, L. Wang …

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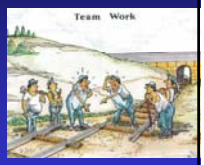
National Science Foundation
Varian Medical Systems



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