DUKE UNIVERSITY MEDICAL CENTER

SBRT I: Overview of Simulation, Planning, and Delivery

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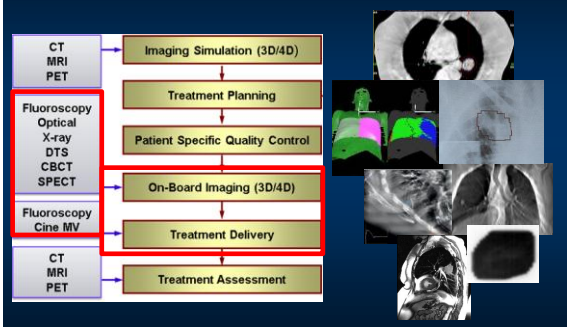
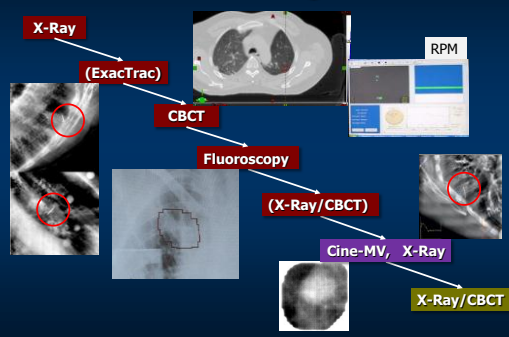
Disclosure

I have received research funding from NIH, the Golfers Against Cancer (GAC) foundation, and Philips Health System.

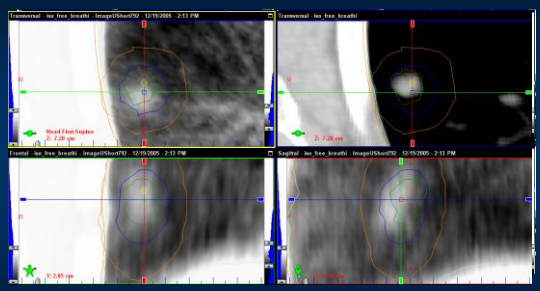
Imaging in Lung SBRT



The Process: Image Guidance



Free-breath 3D CBCT Match

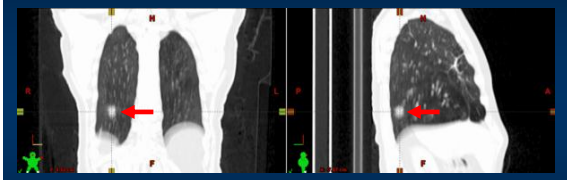


Wang et al Ref J 2007

Uncertainties in lung SBRT IGRT

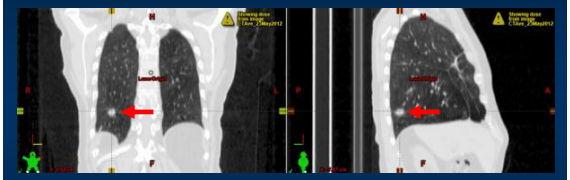
- Tumor volume in CBCT
- Soft-tissue contrast
- Inter-observer variations
- Reproducibility of tumor location at breath-hold
- Internal-external motion correlation
- Changes of tumor size and motion
- Changes of anatomy
- Shifts and rotations in matching
- …….

Which CT for CBCT Matching?



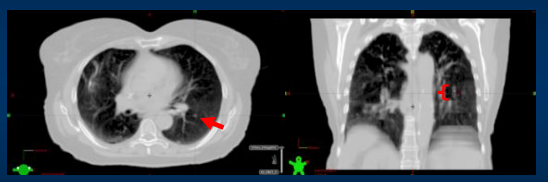
4DCT-AIP v.s. CBCT

Which CT for CBCT Matching?



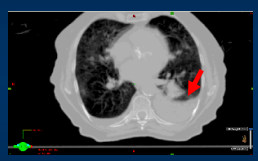
3D FB-CT v.s. CBCT

CBCT Matching: Tiny Tumor



Tumor Size ~ 5 mm; Tumor Motion ~ 20 mm

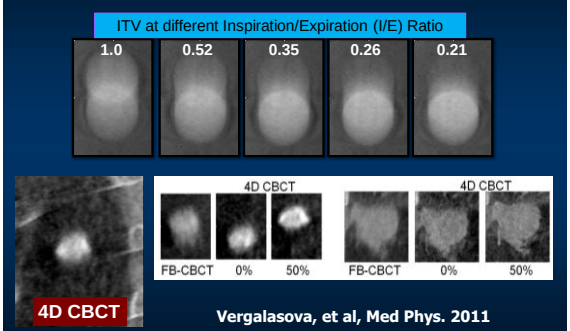
CBCT Matching: Large Anatomical Change



Pleural effusion at Sim
Largely disappeared at 1 fx

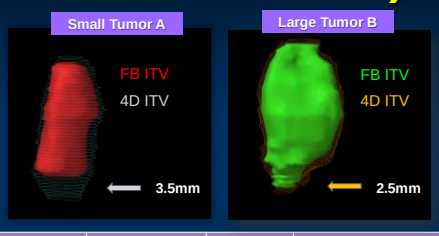
Re-simed, Re-planned

CBCT ITV Uncertainty



Vergalasova, et al, Med Phys. 2011

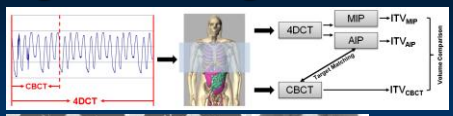
CBCT ITV Uncertainty



Tumor	Free-Breathing ITV (cm^3)	4D ITV (cm^3)	Volume Underestimation (%)
A	1.78	2.97	40.1
B	35.62	46.98	24.2

Vergalasova et al, Med Phys 2011

Target Matching Uncertainty

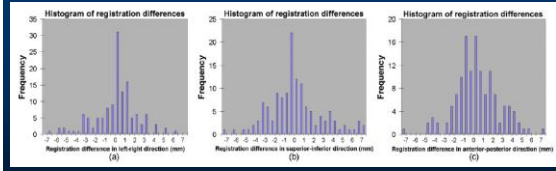


Turner et al 2013 AAPM

Image Registration Uncertainty: Inter-observer Variation

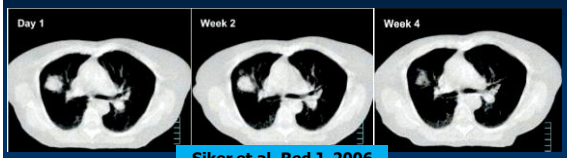
Table 2 Registration differences between institutions and reviewers (for different protocols)

Protocol no. (disease site)	No. of datasets	Absolute value of difference of shifts (mm), mean ± SD (range) Left-right	Superior-inferior	Anterior-posterior
0915 (lung)	71	1.8 ± 1.2 (0.0-6.4)	2.0 ± 1.1 (0.0-6.9)	2.0 ± 0.9 (0.0-5.0)
0813 (lung)	21	1.7 ± 0.8 (0.1-5.1)	2.2 ± 1.0 (0.3-5.0)	2.0 ± 1.1 (0.1-4.8)



Cui et al, Red J , 2011; 81:305-312.

MVCT for Lung SBRT IGRT



Siker et al, Red J, 2006

Table 3 Registration differences between institutions and reviewers (for different imaging modalities)

Imaging modality	No. of datasets	Absolute value of difference of shifts (mm), mean ± SD (range) Left-right	Superior-inferior	Anterior-posterior
kV CBCT	96	1.7 ± 1.1 (0.0-6.7)	1.6 ± 0.9 (0.0-6.9)	1.7 ± 1.1 (0.0-5.0)
MVCT	37	1.5 ± 1.0 (0.1-5.1)	3.7 ± 1.7 (0.1-8.2)	1.9 ± 0.9 (0.0-7.3)
Overall	133	1.7 ± 1.0 (0.0-6.7)	2.2 ± 1.5 (0.0-8.2)	1.8 ± 1.0 (0.0-7.3)

Cui et al, Red J , 2011; 81:305-312.

Question: Which one of the following answers represents the best estimate of the inter-observer variation in image registration in lung SBRT?

20% 1. 1 mm
20% 2. 2 mm
20% 3. 3 mm
20% 4. 5 mm
20% 5. >5 mm

10

Discussion

Correct Answer:

2. 2 mm

Reference:

Cui Y, Galvin JM, Straube WL, Bosch WR, Purdy JA, Li XA, Xiao Y, Multi-system verification of registrations for image-guided radiotherapy in clinical trials. Int J Radiat Oncol Biol Phys, 2011; 81:305-312.

Table 2 Registration differences between institutions and reviewers (for different protocols)

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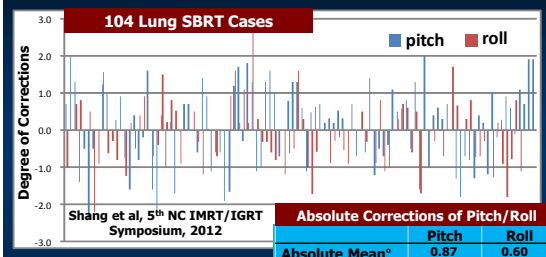
Rotational Shifts in Lung SBRT



Shang et al, 5th NC IMRT/IGRT Symposium, 2012

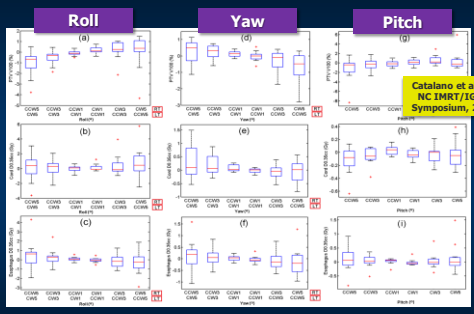
Net Average of Pitch & Roll

	Pitch	Roll
Average °	0.10	-0.10
SD °	1.07	0.65

Absolute Corrections of Pitch/Roll

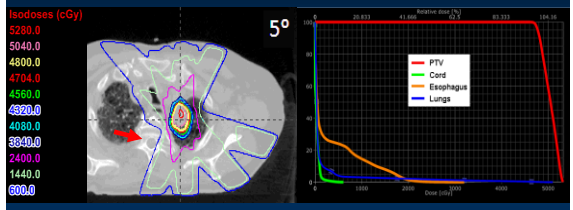
	Pitch	Roll
Absolute Mean°	0.87	0.60
Variance°	0.33	0.30
Cases >0.5°	69.2%	50.0%
Pitch or Roll >0.5°	89.4%	
Pitch or Roll >1.0°	51.0%	

Dosimetric Effects of Rotations



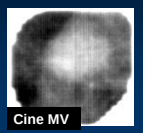
- 95.6% of all differences were <1% or <1Gy.
- Overall small dosimetric effects of uncorrected rotations.

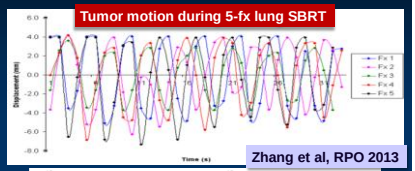
Dosimetric Effects of Rotations



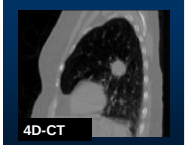
- Large inter-subject variations at large rotation angles.
- Up to 4% reduction in PTV coverage, 6 Gy increase in cord D0.35cc, and 4 Gy in Esophagus D0.35cc observed.

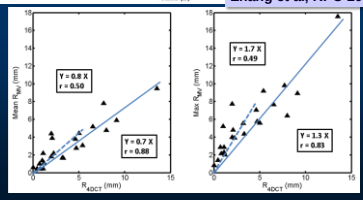
Cine MV: tumor motion during TX



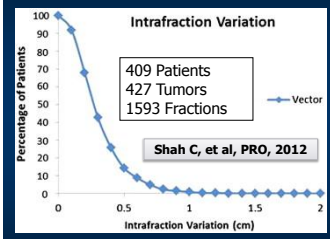


Zhang et al, RPO 2013





Intra-fractional Mean Tumor Position Shift

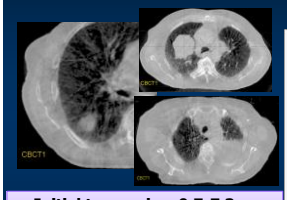


Shah C, et al, PRO, 2012

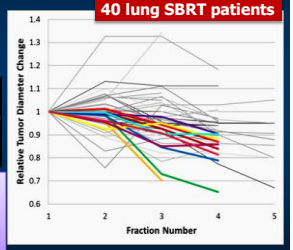
- Intra-fractional variation:
  - AP: 0.0 ± 1.7 mm
  - ML: 0.6 ± 2.2 mm
  - SI: −1.0 ± 2.0 mm
  - 3D: 3.1 ± 2.0 mm
- 3D vector variation:
  - > 2mm in 67.8%
  - > 5mm in 14.3%

- **Depending on immobilization (Range: 2.3 – 3.3 mm)**
- **Body Frame < Alpha Cradle < Body Fix < Wing Board**

Change of Tumor During Lung SBRT



40 lung SBRT patients



- **Initial tumor size: 0.7-7.3 cm**
- **Change of tumor diameter:**
  - **Range: -34.2% to 33.0%**
  - **Mean: -7.9 ± 11.45%**

Qin et al, Red J, 2013

ExacTrac

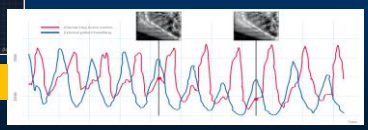
Chang et al, Radiother Oncol, 2010

ExacTrac 6D v.s. CBCT 6D	
ML: 1.06 mm	Pitch: 1.22°
AP: 1.43 mm	Row: 0.64°
SI: 1.43 mm	Yaw: 1.66°

- Small but maybe clinically significant discrepancies between ExacTrac X-ray 6D and CBCT 6D match

Cyberknife

- **Targeting error** 0.1 – 0.3 mm
- **Correlation error:** 0.3 – 2.5 mm
- **Prediction error:** 1.5 ± 0.8 mm
- **Total error** 0.7 – 5.0 mm



Synchrony Respiratory Tracking System (RTS)

Pepin et al, Med Phys. 2011

Question: Which one of the following answers represents the best estimate of the mean intra-fractional 3D tumor position shift in lung SBRT?

20%	1.	1 mm
20%	2.	2 mm
20%	3.	3 mm
20%	4.	5 mm
20%	5.	>5 mm

10

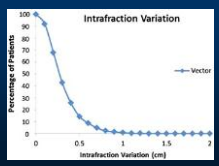
Discussion

Correct Answer:

3. 3 mm

Reference:

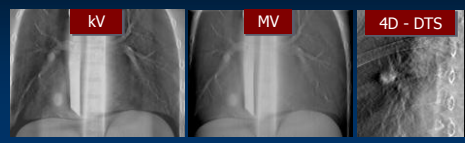
Shah C, Kestin LL, Hope AJ, Bissonnette JP, Guckenberger M, Xiao Y, Sonke JJ, Belderbos J, Yan D, Grills IS. Required target margins for image-guided lung SBRT: Assessment of target position intrafraction and correction residuals. Prac Radiat Onco. 3(1), 67-73.

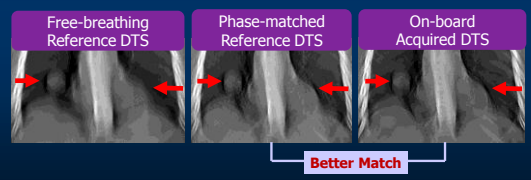


409 Patients
427 Tumors
1593 Fractions

3D: 3.1 ± 2.0 mm

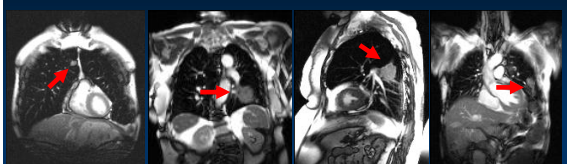
Onboard DTS Imaging

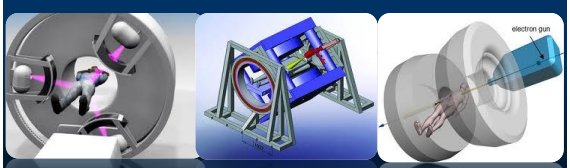




Courtesy from Dr. Ren of Duke University

MRI for Image Guidance

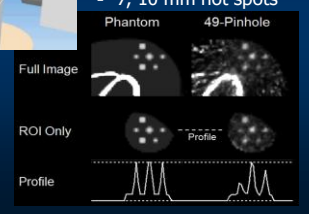




On-Board SPECT

Courtesy from Dr. Bowsher of Duke University

- 4-min scans
- 7, 10 mm hot spots



- SPECT on robotic arm
- Molecular targeting
- Multi-Pinhole collimation

Summary

- Uncertainties exist in each step of image guidance of lung SBRT
- Understanding root causes and characteristics of these uncertainties is important for successful implementation of lung SBRT
- Next generation of on board imaging techniques has the potential to minimize uncertainties of image guidance of lung SBRT

Acknowledgements

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