Educational Course, Therapy Track
Wednesday, August 7, 8:00 - 9:55 am

Quality Control of Lung SBRT: from 4D Simulation to 4D Verification

Learning Objectives:

1. Provide an evidence-based systematic review of uncertainties during lung SBRT
2. Discuss the root causes of the uncertainties and corresponding quality control strategies
3. Present data-driven practical and effective solutions to minimize the uncertainties

DukeMedicine

Speaker List and Topics

Topic	Speaker (Institution)
Uncertainty and QA for simulation and planning	Fang-Fang Yin, PhD Duke University
Uncertainty and QA for target delineation	Jeffrey Bradley, MD Washington University
Uncertainty and QA for delivery techniques	Stanley Benedict, PhD UC Davis Health System
Uncertainty and QA in localization and tacking in the treatment room	Krishni Wijesooriya, PhD University of Virginia
Uncertainty and QA for machine and patient specific QA	Jing Cai, PhD Duke University

DukeMedicine

Uncertainty and QA for Simulation and Planning

Fang-Fang Yin, PhD
Duke University Medical Center

DukeMedicine

Disclosure

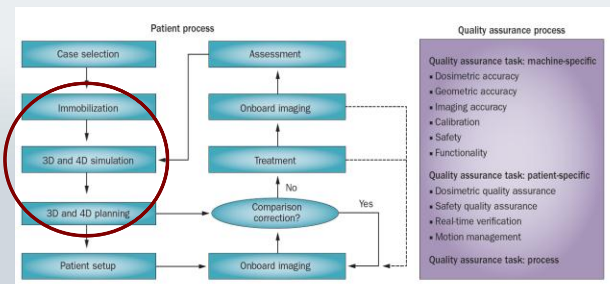
Some of research works are partially supported by grants from NIH and Varian Medical Systems.

Acknowledgements

Team faculty and staff in radiation oncology department, Duke University, especially to:
Dr. Jing Cai, Dr. Christopher R. Kelsey

DukeMedicine

Workflow for Lung SBRT



DukeMedicine

Salama, Kirkpatrick, and Yin
Nature Reviews|Clinical Oncology 2012

Uncertainties in Simulation and Planning

- Patient and motion constraints
  - Immobilization consideration
  - Surrogates (if applicable)
- Motion management
  - 3D-FB, 3D-BH, 4D-10 phase
  - MAX-IP (MIP), AVE-IP (AIP), MIN-IP (MinIP)
- Image fusion/interpolation
- Tumor ITV delineation based on 4DCT
- Interplay effect
  - tumor motion and MLC leaf motion
- Dose calculation

DukeMedicine

Approaches to Minimize Uncertainties

- Minimize motion
  - Patient motion: immobilization
  - Organ motion: motion management, organ "immobilization"
- Minimize target volume delineation
  - Better imaging:
- Improve dose calculation
  - Better algorithm
  - Better images
  - Interplay
- Ensuring the accuracy – phantom based process QA

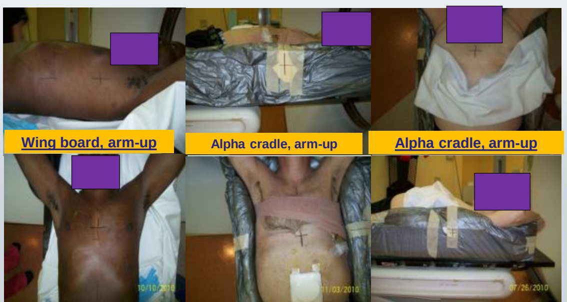
DukeMedicine

Patient Motion: Immobilization

Body Immobilization
- BodyFix
- Body frame
- Styrofoam
……



Patient Motion: Immobilization



DukeMedicine

Active Breathing Control

The residual errors of GTV
ML: 0.3±1.8 mm
AP: 1.2±2.3 mm
SI: 1.1±3.5 mm

Cheung, et al, Red J 2003

- Remains some inter–breath hold variability in peripheral lung
- Limited reduction of PTV margin

DukeMedicine

Abdominal Compression

Mean motion reduction:
3.5 mm for lower lobe tumors
0.8 mm for upper/middle lobe

Sometime, compression increased tumor motion

Mean ITV reduction:
3.6 cc for lower lobe lesions
0.2 cc for upper/middle lobe lesions

Dosimetric gain for lung sparing was not clinically relevant

DukeMedicine

Bouilhol et al, 2012, Phys Med

Organ "Constraints" in SBRT

Total intravenous anesthesia (TIVA)

High-frequency jet ventilation (HFJV)

Animal study:
Motion range: < 3 mm

Yin et al 2001 Red J:
"Extracranial radiosurgery: Immobilizing liver motion using high-frequency jet ventilation and total intravenous anesthesia"

DukeMedicine

Organ Motion: Surrogates/Imaging

- Anatomical surrogates
  - Diaphragm
  - Bony structures
  - Tumor
- Implanted surrogates
  - Gold seeds
  - Coils
  - Devices

X-Mark Diameter and Length Per Implant Site

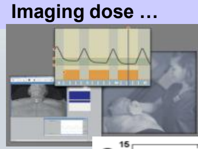
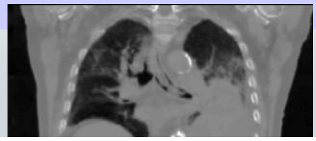
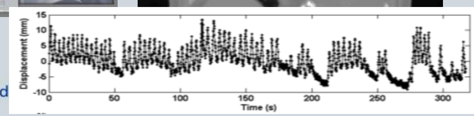
Diameter	Needle Gauge	Prostate	Breast	Lung	Cervix	Liver
0.45 mm	21 g	1 cm 2 cm	1 cm 2 cm	1 cm 2 cm 3 cm	1 cm	
0.85 mm	18 g	1 cm 2 cm	1 cm	1 cm 2 cm 3 cm	1 cm 2 cm	1 cm
1.15 mm	17 g	1 cm 2 cm	1 cm		1 cm 2 cm	

Imaging Modality

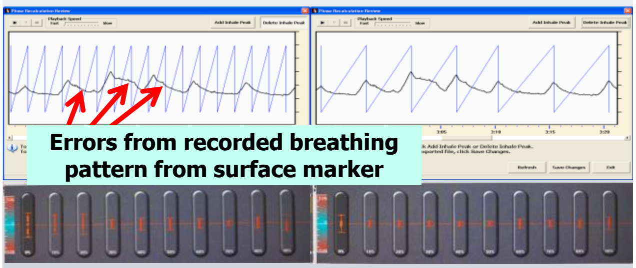
Diameter	CT-kV	Fluoro-TRUS-MRI	EPID-Portal-MV
0.45 mm	Y	Y	
0.85 mm	Y	Y	Y
1.15mm		Y	Y

Organ Motion: 4DCT Imaging

Challenges:
- Poor soft-tissue contrast
- Only produce one breathing cycle
- Correlation between internal target and external surrogates
- Imaging dose …

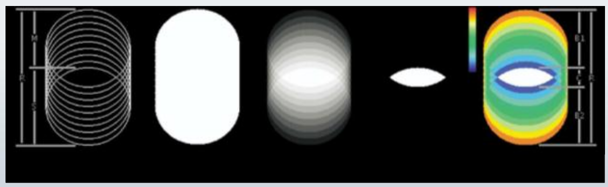
Organ Motion: 4DCT Imaging



Errors from recorded breathing pattern from surface marker

Deviated　　Corrected

Organ Motion: 4DCT Imaging



- FB/BH CT
- 10-phase FB 4DCT { MIP, AIP, MinIP
- Fluoroscopy

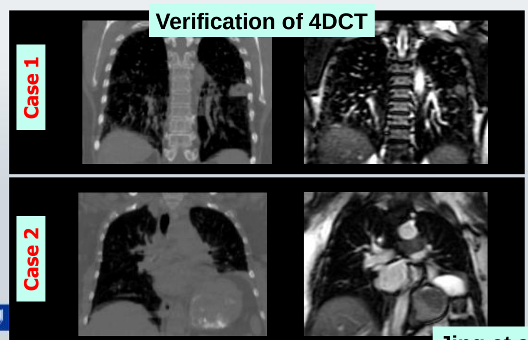
→ Treatment Planning System

Cover, et al, Red J, 2006

Sample Images in Lung SBRT

3D-FB　　4DCT-AIP　　4DCT-MIP

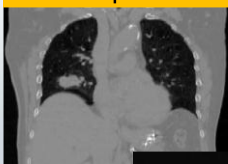
Organ Motion: 4DCT Imaging



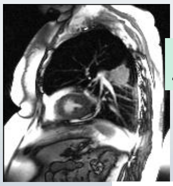
Jing et al

4DCT Imaging – Treatment Validation

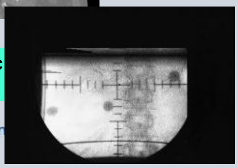
Is 4-D CT enough for motion pattern?



Cine 4D MRI



Fluoroscopic imaging



Portal image

DukeMedicine

4DCT Validation: XCAT Phantom

Fig. 2. Anterior views of the male (left) and female (right) anatomies of the 4D XCAT phantom.

- Segars et al. Realistic CT simulation using the 4D XCAT phantom *Med. Phys.* 35(8). 2008
- Segars et al. 4D XCAT phantom for multimodality imaging research *Med. Phys.* 37(9). 2010

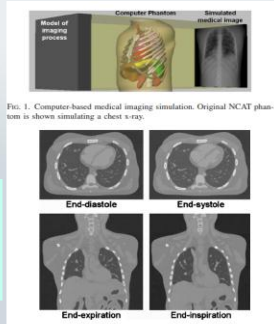
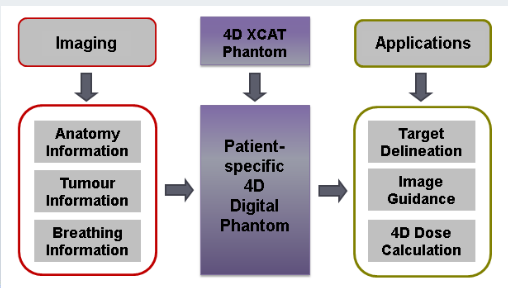


Fig. 1. Computer-based medical imaging simulation. Original NCAT phantom is shown simulating a chest x-ray.

Fig. 14. Cardiac-gated (top) and respiratory-gated (bottom) CT images generated using the 4D female XCAT.

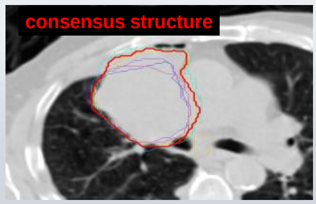
DukeMedicine

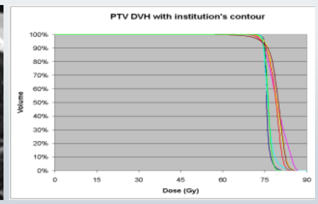
4DCT Validation: XCAT Phantom



DukeMedicine

Contouring Variation in NSCLC



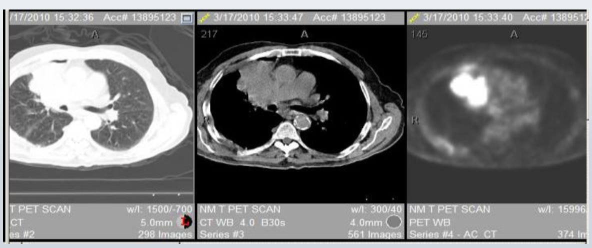


Data from multi-institutional pre-clinical trial planning study of RTOG 1106

DukeMedicine

Cui, *et al. Med Phys* 2012

Target Delineation: Multimodality Imaging



DukeMedicine

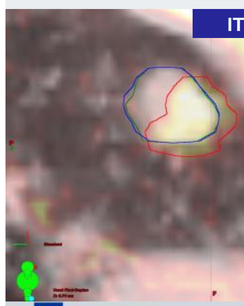
Courtesy from Dr. Kong, U. Michigan

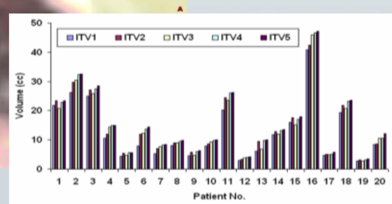
Which CT for ITV Delineation?

$ITV_{10phase}$ (blue line)

ITV_{MIP} (green line)

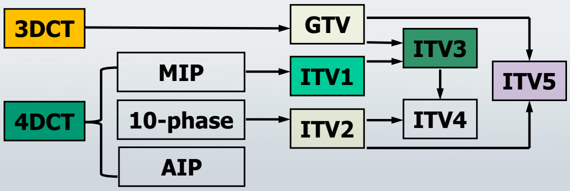
GTV_{3D} (red line)





Ge et al, Red J 2012

Tumor ITV Individualization

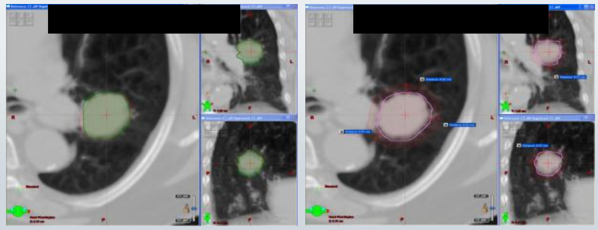


With irregular breathing patterns, ITV is always an approximation

- Tumor Motion
- Tumor Size
- Tumor Location
- Breathing Irregularity

DukeMedicine

Case: ITV, PTV Determination



- ITV = GTV_FB + GTV_MIP
- PTV = ITV + Setup Margin (3-5mm)

DukeMedicine

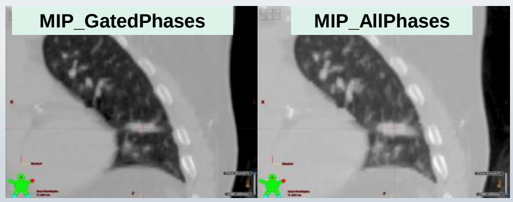
Caution: Proper Margin Design

- Motion
  - Immobilization
  - Motion management
- Motion management technique
  - Breath hold
  - Gated treatment
  - Free breathing
- Delivery technique
  - Dose rate
  - 3D CRT
  - IMRT/VMAT

- Margin should be estimated by imaging.
- Margin should be added for each uncertainty.
- If all have been considered, 5 mm margin is still recommended.

DukeMedicine

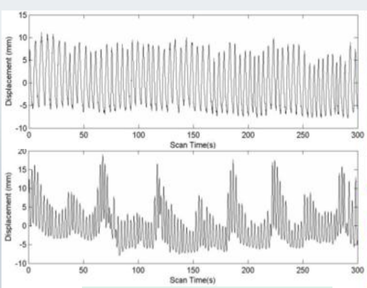
Respiratory Gating Planning

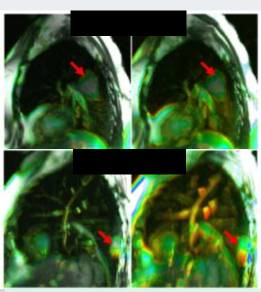


4DCT	MIP_AllPhases (0%-90%)		
	MIP_GatedPhases (30%-70%)	→	ITV, PTV
	AIP_AllPhase (0%-90%)	→	CBCT online match
	AIP_GatedPhases (30%-70%)	→	Dose calculation

Duke

How Accurate is 4DCT AIP?



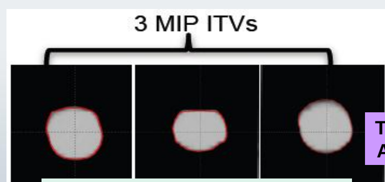


Cai, et al, Med. Phys. 2008

'4DCT' Truth

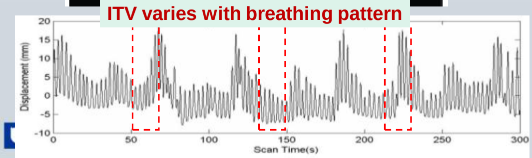
DukeMedicine

Organ Motion: ITV Variation from MIP



Turner, et al AAPM 2012

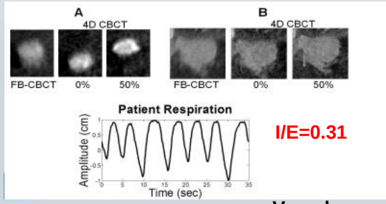
ITV varies with breathing pattern

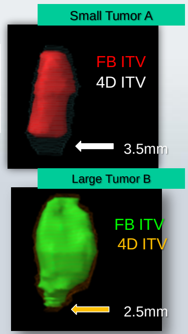


Organ Motion: ITV Underestimation

ITV from irregular breathing patient

Tumor	Free-Breathing ITV (cm³)	4D ITV (cm³)	Volume Underestimation (%)
A	1.78	2.97	40.1
B	35.62	46.98	24.2





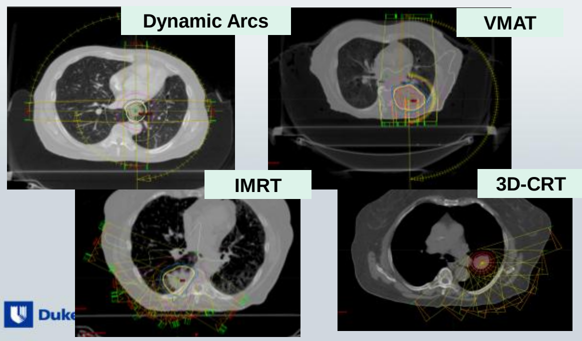
Vergalasova et al Med Phys 2011

Considerations for Planning

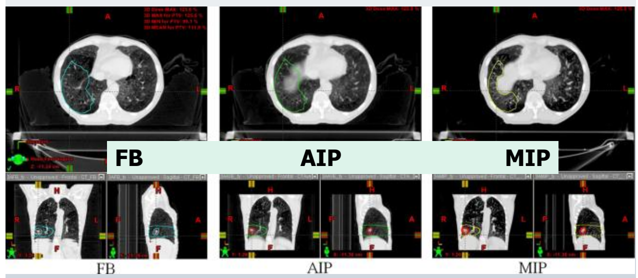
- Beam design/Clearance
- Delivery technique
- Dose calculation
- Image guidance strategy
- Motion management strategy
- Verification method
- Treatment adaptation

DukeMedicine

Beam Design and Planning Techniques



Which CT for Dose Calculation?



DukeMedicine Tian, et al, Med Phys 2012

QA: Which CT for Dose Calculation?

- AIP vs. FB
  - Dosimetric similarity
  - Target volume better for AIP
- AIP vs. MIP
  - MIP has slightly better target coverage
  - MIP datasets are prone to under- or over-estimate both OAR and target volumes
- AIP dataset is more suitable for planning

DukeMedicine Tian, et al, Med Phys 2012

Caution: Inhomogeneity Correction

With heterogeneity corrections applied:

- Volume of PTV receiving 60 Gy or more (V60) decreased on average 10.1% (SE=2.7%) from 95% (p=0.001)
- Maximum dose to any point 2 cm or greater away from the PTV increased from 35.2 Gy (SE =1.7 Gy) to 38.5 (SE=2.2 Gy)

Dosimetric Evaluation of Heterogeneity Corrections for RTOG 0236: Stereotactic Body Radiation Therapy of Inoperable Stage I/II Non-Small Cell Lung Cancer

Ying Xiao, Ph.D,[1*] Lech Papiez, Ph.D.,[2] Rebecca Paulus, B.S.,[3] Robert Timmerman, M.D.,[2] William L. Straube, M.S.,[4] Walter R... Jeff Michalski, M.D.,[4] and James M. Galvin, D.Sc.[1]

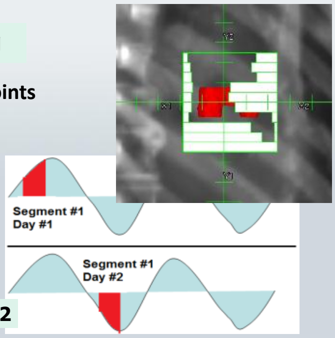
Red J 2008

Cauiton: MLC Interplay Effect

Beam-on timing

Beam-on @ different points in breathing period

Differences in delivered dose



S Benedict AAPM 2012

Interplay Between Tumor Motion and MLC Leaf Motion

International Journal of Radiation Oncology*Biology*Physics

Available online 24 February 2012

In Press, Corrected Proof — Note to users

Dosimetric Impact of Breathing Motion in Lung Stereotactic Body Radiotherapy Treatment Using Image-Modulated Radiotherapy and Volumetric Modulated Arc Therapy

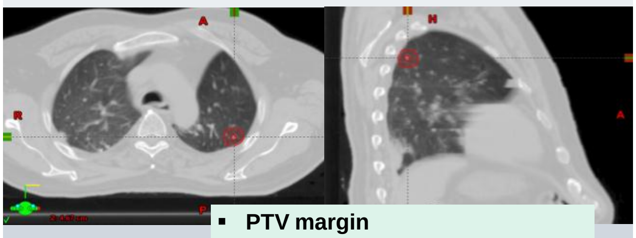
Min Rao, Ph.D., Jianzhou Wu, Ph.D., Daliang Cao, Ph.D., Tony Wong, Ph.D., Vivek Mehta, M.D., David Shepard, Ph.D., Jinsong Ye, M.S.

Patients: 10
GTV: 2.9 – 138.1 cm^3
Motion: 0.8 – 2.8 cm

CONCLUSIONS: Both VMAT and IMRT plans experienced negligible interplay effects between MLC sequence and tumor motion. For the most part, the 3D doses to the GTV and critical structures provided good approximations of the 4D dose calculations.

under some circumstances, the results of 4D calculations would indicate a substantial difference from those of 3D calculations in terms of target coverage. Due to the small number of patients, we were not able to correlate the magnitude of difference in dose distribution with either the GTV size or its extent of motion.

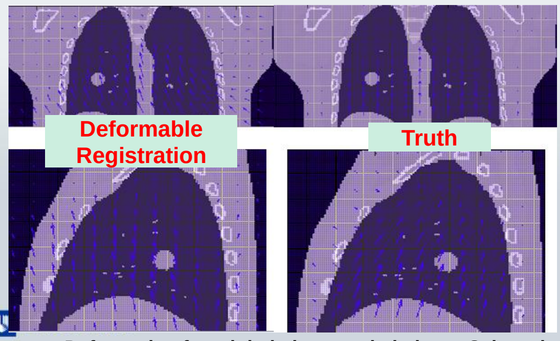
When Tumor Is Too Small



- PTV margin
- MLC leaf width
- Image guidance
- Small field dose calculation

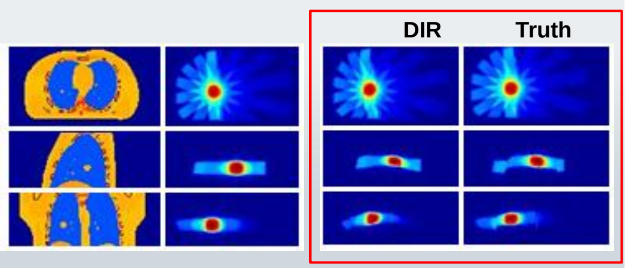
DukeMedicine

Lung Motion Displacement Vectors



Deformation from inhalation to exhalation Cai, et al

Caution: Dose Deformation

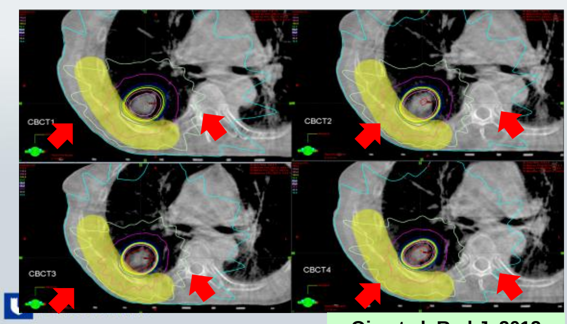


Inhalation → Exhalation

DukeMedicine

Cai, et al

Adaption: Is Replanning for Lung SBRT Needed?



Qin et al, Red J, 2012

Summary

- Treatment uncertainty could be reduced
  - Proper selection immobilization method
  - Patient specific motion management strategy
  - Comprehensive patient-specific plan design
- Each step needs to be carefully validated
- A phantom-based QA process could provide a tool to validate the treatment.

DukeMedicine

Thank you for your intention!

DukeMedicine