Treatment Simulation, Planning and Delivery for Stereotactic Body Radiation Therapy

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2015 AAPM Therapy Educational Course

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Outline

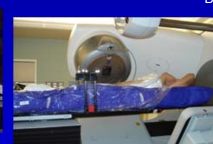
Immobilization and Simulation
Treatment Planning
Target Localization & Plan Delivery
Summary

Immobilization

- ➢Accurately re-position patient
- ➢Reduce/Minimize patient voluntary and involuntary motion
- ➢Reduce/Minimize organ/target motion
  - ---*Abdominal compression*
- ➢Comfortable for long treatment
- ➢Compatible with IGRT
- ➢Not interfere with treatment beam
- ➢Consider machine safety zones

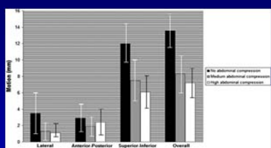

Body Pro-Lok ™ frame


Thermoplastic Long mask

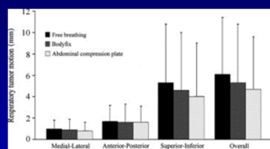

Body Fix


Abdominal Compression

Target Motion Reduction



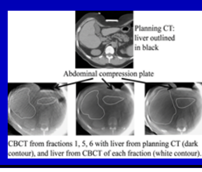
Lung tumor motion under varying levels of abdominal compression (pressure plate)
Heinzerling et al, IJROBP 2008



Comparison of free breathing, BodyFix and abdominal compression in 24 patients
Han et al, RadOnc 2010

Limitations

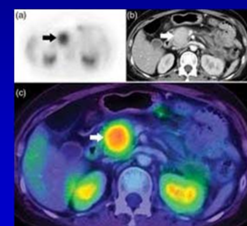
- *Patient discomfort*
- *Variable daily distortion in abdominal anatomy*



Changes in abdomen geometry with abdominal compression
Eccles et al, IJROBP 2011

Imaging

- Multimodality of high resolution(*1~2mm slice thickness*) images (CT/MRI, PET/CT)
- 4DCT/PET to evaluate internal motion



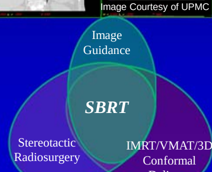
Challenges for SBRT

How to accurately define target? ---*4D imaging*

How to accurately localize target? *---IGRT*

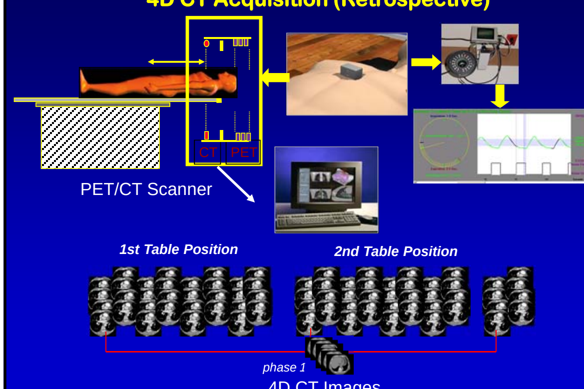
How to obtain conformal dose and steep dose gradients? *---3DCRT, Inverse Planning, IMRT, VMAT…*

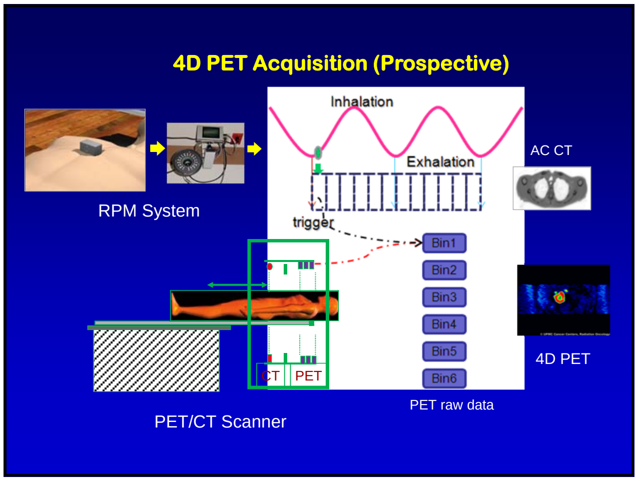
How to minimize dose to surrounding critical organs? *--- Gating, Tracking…*

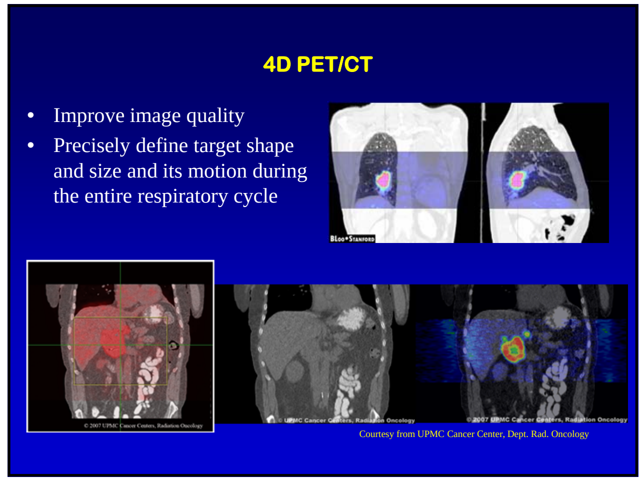


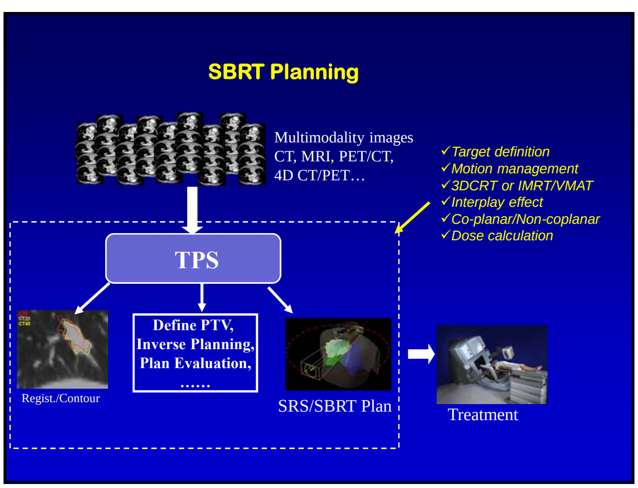
Courtesy of Stanley H. Benedict, PhD

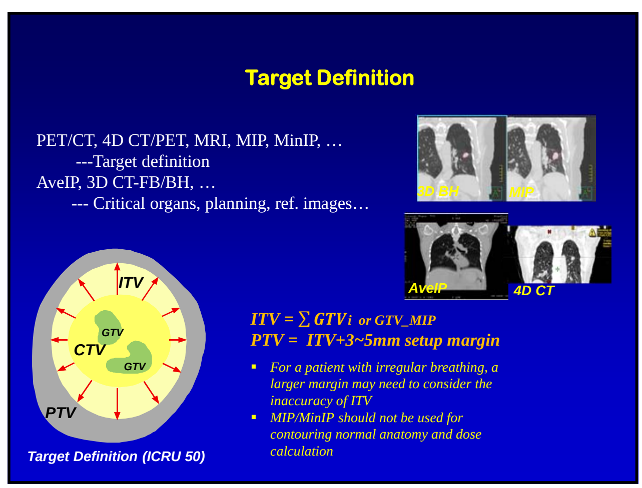
4D CT Acquisition (Retrospective)




4D PET Acquisition (Prospective)
RPM System
Inhalation
Exhalation
AC CT
trigger
Bin1
Bin2
Bin3
Bin4
Bin5
Bin6
CT
PET
4D PET
PET raw data
PET/CT Scanner


4D PET/CT
• Improve image quality
• Precisely define target shape and size and its motion during the entire respiratory cycle
Courtesy from UPMC Cancer Center, Dept. Rad. Oncology

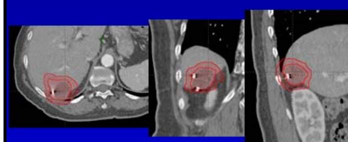

SBRT Planning
Multimodality images
CT, MRI, PET/CT,
4D CT/PET…
✓Target definition
✓Motion management
✓3DCRT or IMRT/VMAT
✓Interplay effect
✓Co-planar/Non-coplanar
✓Dose calculation
TPS
Regist./Contour
Define PTV,
Inverse Planning,
Plan Evaluation,
……
SRS/SBRT Plan
Treatment


Target Definition
PET/CT, 4D CT/PET, MRI, MIP, MinIP, …
---Target definition
AveIP, 3D CT-FB/BH, …
--- Critical organs, planning, ref. images…
3D BH
MIP
AveIP
4D CT
ITV
GTV
CTV
GTV
PTV
Target Definition (ICRU 50)
ITV = ∑ GTVi or GTV_MIP
PTV = ITV+3~5mm setup margin
▪ For a patient with irregular breathing, a larger margin may need to consider the inaccuracy of ITV
▪ MIP/MinIP should not be used for contouring normal anatomy and dose calculation

Motion Analysis

- Analyze target motion in different phase
- Consistence of motion of fiducial markers with target
- Analyze target size and shape change
- Determine residual error and target margin for gating treatment

PTV : ITV +3~5mm margin



Liver example

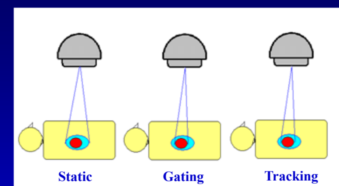
Pancreas example

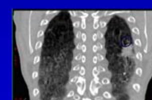
Goodman et al, IJROBP, Vol. 78, 2010

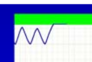
Loo et al, IJROBP, 63, 2005

Motion Management (Delivery)

- Large Margin
- Gating Technique
- Breath-holding Technique
- Tracking Technique







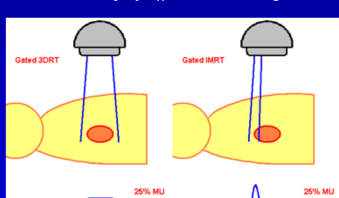
Breath-holding technique

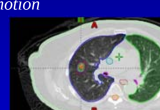
Non-Gating *(motion<=5mm)*
Respiratory Gating *(motion>5mm)*

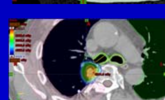
Tracking technique

3DCRT or IMRT/VMAT?

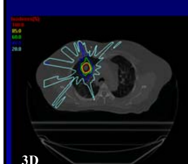
- Advantages:
  - *Better dose conformality*
  - *Easy to control/constrain dose to OARs*
  - *Inverse planning*
- Disadvantages:
  - *Higher MU, longer treatment time*
  - *Interplay effect between target and MLC motion*

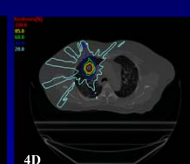


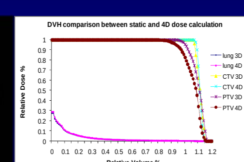




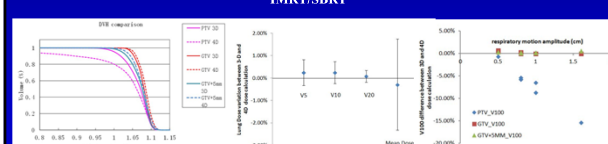
Interplay Effect







IMRT/SBRT

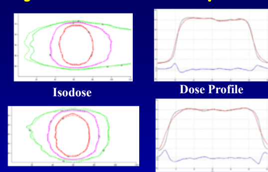


VMAT/SBRT

Li, Yang et al, JACMP, 2013

Interplay Effect: Gated RapidArc

3cm 1D motion, 4.0s period



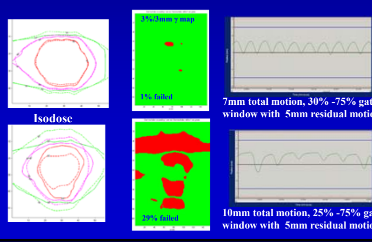
Isodose

Dose Profile

5mm residual motion

10mm residual motion

Quasar phantom with real patient data



Isodose

Case 1

7mm total motion, 30% -75% gating window with 5mm residual motion

Case 2

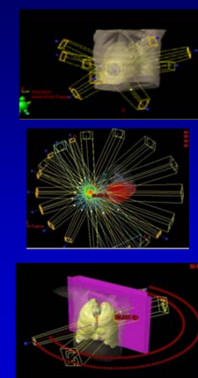
10mm total motion, 25% -75% gating window with 5mm residual motion

Riley, Yang et al, Med. Phys. 2014

Coplanar or Non-Coplanar Beams?

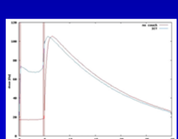
- Advantages:
  - *Better dose gradients in axial planes*
- Disadvantages:
  - *Complicated treatment*
  - *Longer treatment time*
  - *Potential collision*

8-12 non-overlapped beams (1-2 partial arcs) on the disease side can generate acceptable dose performances for most lung SBRT cases.

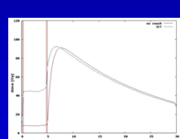


Dose Calculation

- **Inhomogeneity correction algorithms**
  - *PBC is not appropriate for lung SBRT*
  - *AcurosXB, convolution/superposition, MC should be used*
- **Dose calculation grid <= 2mm**
- **Couch top should be inserted**



photon beam (6 MV)

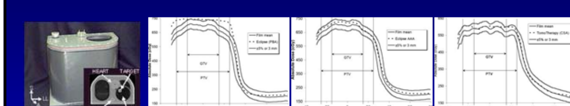


photon beam (15 MV)

Irradiating through the Couch Top (from straight below) is equivalent to 12 mm of water.

Data for Brainlab Exactrac 6D couch top

Inhomogeneity Correction



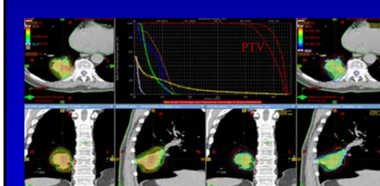
RPC Thorax Phantom

Eclipse PBC

Eclipse AAA

TomoTherapy CSA

S. E. Davidson et al, Med. Phys., 2008.



PBC

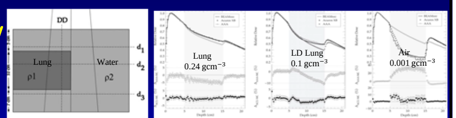
Acuros XB

Dose difference for targets from PBC and AcurosXB could be more than 10%

PBC should not be used for lung SBRT

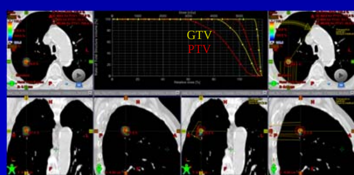
Inhomogeneity Correction

For a small isolated target, even AAA is not accurate enough!

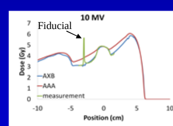


6 MV 4.0 cm x 4.0 cm photon beam

*Bush et al, Med Phys **38**, 2011*



AAA Acuros XB



Courtesy of Amy Yu, Ph.D.

Target Localization & Plan Delivery

Patient Simulation (*CT/MRI/4DCT/PET*)

Treatment Planning

Pre-Tx Setup (*kV/MV, CBCT*)

Fluoroscopic Verification

Plan Delivery & Beam-Level Imaging (*kV, Fluoro, Cine MV, kV/MV CBCT*)

Post-Tx Image & Data Analysis

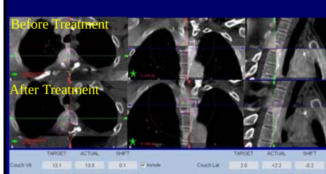
TrueBeam - Varian

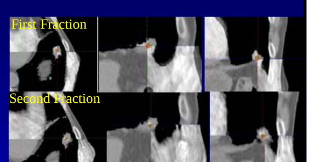
Versa - Elekta

Cyberknife - Accuray

Novalis - Brainlab

Image-guided Target Localization





Accuracy

Spine *1~3 mm*

Lung *<5mm*

Abdomen *<5mm*

Lung Ref CT: *Ave-IP, 50% CT, EBH-CT,…*

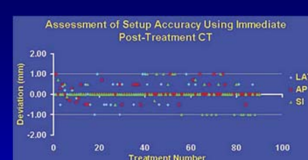
Live/Pancreas/Prostate: Fiducials

AAPM Task Group N0. 101

TABLE IV. Achievable accuracies reported in the literature categorized by body site and immobilization/repositioning device.

Author, year	Site	Immobilization/repositioning	Reported accuracy
Lax, 1994[a]	Abdomen	Wood frame/stereotactic coordinates on box to skin marks	3.7 mm Lat, 5.7 mm Long
Hamilton, 1995[b]	Spine	Screw fixation of spinous processes to box	2 mm
Murphy, 1997[c]	Spine	Frameless/implanted fiducial markers with real-time imaging and tracking	1.6 mm radial
Lohr, 1999[d]	Spine	Body cast with stereotactic coordinates	≤3.6 mm mean vector
Yenice, 2003[e]	Spine	Custom stereotactic frame and in-room CT guidance	1.5 mm system accuracy, 2–3 mm positioning accuracy
Chang, 2004[f]	Spine	MI™ BodyFix with stereotactic frame/linac/CT on rails with 6D robotic couch	1 mm system accuracy
Tokuuye, 1997	Liver	Prone position jaw and arm straps	5 mm
Nakagawa, 2000[g]	Thoracic	MVCT on linac	Not reported
Wulf, 2000[h]	Lung, liver	Elekta™ body frame	3.3mm lat,4.4 mm long
Fuss, 2004[i]	Lung, liver	MI™ BodyFix	Bony anatomy translation 0.4, 0.1, 1.6 mm (mean *X,Y,Z*); tumor translation before image guidance 2.9, 2.5, 3.2 mm (mean *X,Y,Z*)
Herfarth, 2001[j]	Liver	Leibinger body frame	1.8–4.4 mm
Nagata, 2002[k]	Lung	Elekta™ body frame	2 mm
Fukumoto, 2002[l]	Lung	Elekta™ body frame	Not reported
Hara, 2002[m]	Lung	Custom bed transferred to treatment unit after confirmatory scan	2 mm
Hof, 2003[n]	Lung	Leibinger body frame	1.8–4 mm
Timmerman, 2003[o]	Lung	Elekta™ body frame	Approx. 5 mm
Wang, 2006[p]	Lung	Medical Intelligence body frame stereotactic coordinates/CT on rails	0.3 ± 1.8 mm AP, -1.8 ± 3.2 mm Lat, 1.5 ± 3.7 mm SI

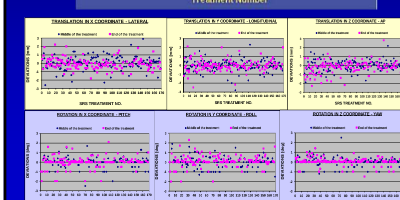
Target Positioning: *Spine*



Positional setup accuracy with CT–guided correction assessed by an immediate post-treatment CT

15 cases with 90 isocenter setup

E. L. Chang et al, IJROBP, 59, 2004.



166 cases

	Middle(*mm*):	End (*mm*)
X	0.5±0.5	0.5±0.5
Y	0.5±0.5	0.5±0.5
Z	0.5±0.5	0.5±0.5
3D	1.0±0.6	1.1±0.7

	Middle()	End ()
Yaw	0.2±0.4	0.2±0.3
Roll	0.4±0.5	0.4±0.5
Pitch	0.3±0.5	0.4±0.5

Gerszten et al, J Neurosurg , V113, 2010

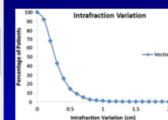
Target Positioning: *Lung*

Table 4

Intrafraction, interfraction, correction residuals, and target margins by immobilization device

Type	Interfraction variation vector (mm)	Correction residuals vector (mm)	IFV-vector (mm)	IFV > 2 mm	IFV > 5 mm	Final position variation vector (mm)	2-parameter margins (mm)			4-parameter margins (mm)		
							ML	AP	CC	ML	AP	CC
α-cradle	8.3 ± 5.0	2.2 ± 1.3	3.0 ± 1.7	71.6%	10.0%	2.9 ± 1.6	4.2	5.7	5.0	3.7	5.8	4.6
Body frame	6.9 ± 5.2	2.3 ± 1.6	2.3 ± 1.4	49.0%	3.9%	2.2 ± 1.2	2.9	4.1	4.1	2.3	4.0	3.7
BodyFIX	10.7 ± 8.7	2.4 ± 2.4	3.0 ± 2.5	60.3%	15.1%	3.2 ± 2.6	5.4	7.2	6.3	5.0	7.3	6.1
None	7.8 ± 4.1	2.6 ± 1.7	3.3 ± 2.2	66.7%	19.2%	3.3 ± 2.2	4.4	6.5	6.9	3.9	6.7	6.5
Hybrid	12.6 ± 10.2	1.8 ± 0.9	2.7 ± 1.6	64.5%	8.4%	2.7 ± 1.5	3.6	5.1	5.1	3.1	4.6	4.2
Wing board	7.4 ± 4.1	2.5 ± 1.2	3.3 ± 1.7	72.7%	15.9%	3.2 ± 1.6	4.5	5.7	6.2	4.2	5.1	5.8

AP, anteroposterior; CC, craniocaudal; IFV, intrafraction variation; ML, mediolateral.



Intra-fraction variation (*mm*)

AP	**0.0±1.7**
ML	**0.6±2.2**
SI	**-1.0±2.0**
3D	**3.1±2.0**

A total of 409 patients with 427 tumors underwent 1593 fractions of lung SBRT

Shah C, et al, PRO, 2013

Fluoroscopy Verification

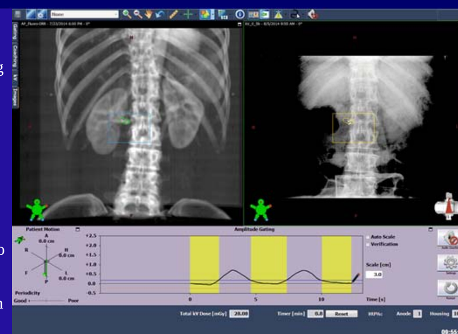
Tracking structures

Fluoroscopic imaging to verify gating window:

Yellow: in gating window, beam-on;

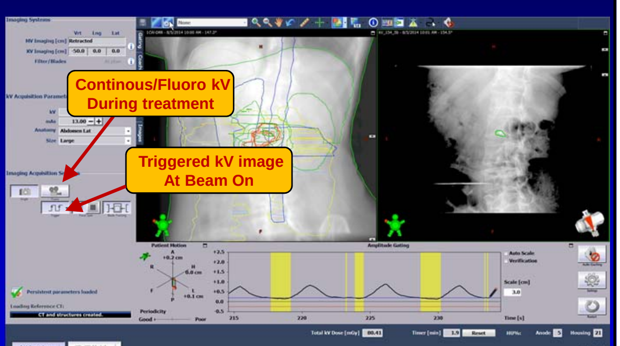
Green: out gating window, Beam-Off.

Gating window should be adjusted so that fiducials fall within tracking structures when beam is on.



Pre-Tx fluoro for a pancreas SBRT case

Beam-Level Imaging: kV Imaging



Beam-Level kV images for the same pancreatic SBRT case

Beam-Level Imaging: Cine MV Imaging

Advantage:

- *No dose, 'free' information*
- *Beam eye view*

Disadvantage:

- *MLC blocks image*
- *Image quality*

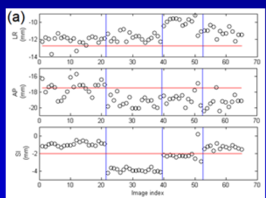
3D tracking if combined with kV imaging

Images courtesy of Azcona, Xing

Azcona, Li , Xing, et al, Med Phys 2013

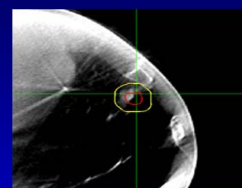
Beam-Level Imaging: Verification of Geometric Accuracy

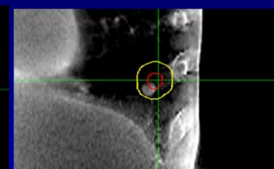
Intra-fraction Verification of SABR
- 20 SABR patients (lung/liver/pancreas)
- RPM-based gating treatment
- Geometric error: 0.8 mm on average; 2.1 mm at 95th percentile

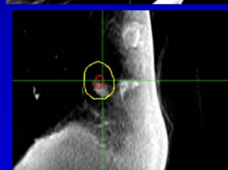


Li R , Xing L, et al. IJROBP, 2012

Beam-Level kV Volumetric Imaging



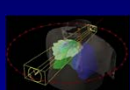


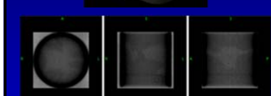


- Continuous fluoroscopy during dose delivery
- In-house program for CBCT reconstruction
- 20 lung SABR patients
- Treatment verification
- Routine clinical use

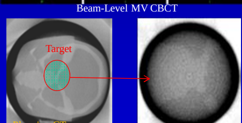
Li R, Xing L et al, IJROBP. 2013

Beam-Level MV Volumetric Imaging

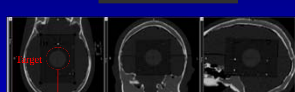




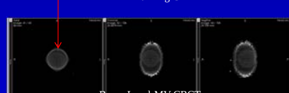
Beam-Level MV CBCT



Dynamic Arc



Planning CT



Beam-Level MV CBCT

RapidArc

Images courtesy of Tianfang Li, Ph.D., UPMC

Summary

- **4D imaging is required for accurate motion management**
- **New techniques (Inverse planning, IMRT/VMAT, Gating/Tracking,…) can improve target conformity and critical structure sparing**
- **Patients should be positioned with IGRT**
- **Beam-level imaging is a necessary step to insure accurate SBRT delivery**

Question: ***Which following algorithm should NOT be used for a lung SBRT dose calculation?***

20%	1. Convolution/superposition
20%	2. Pencil Beam Convolution
20%	3. AcurosXB
20%	4. Monte Carlo
20%	5. None of above

10

Discussion

Correction Answer:

2. **Pencil Beam Convolution**

Reference:

S. E. Davidson, R. A. Popple, G. S. Ibbott, and D. S. Followill, "*Technical note: Heterogeneity dose calculation accuracy in IMRT: Study of five commercial treatment planning systems using an anthropomorphic thorax phantom*", Med. Phys. 35, 5434–5439 2008.

Question: ***What localization accuracy can be achieved in CBCT-guided spine SBRT?***

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

10

Discussion

Correction Answer:

2. **1~3mm**

Reference:

P. C. Gerszten et al, *"Prospective evaluation of a dedicated spine radiosurgery program using the Elekta Synergy S system"*, J Neurosurg. 113:236–241, 2010

1.1 ±0.7mm

E. L. Chang et al, "*Phase I clinical evaluation of near-simultaneous computed tomographic image-guided stereotactic body radiotherapy for spinal metastases*", Int. J. Radiat. Oncol., Biol., Phys. 59, 1288–1294 2004.

<1mm in AP, Lat, and SI direction