Stereotactic Body Radiation Therapy: Planning and Delivery

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2016 AAPM Therapy Educational Course

Disclosure

I have no conflicts of interest to disclose.

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Challenges for SBRT

How to accurately define target?

---4D imaging

How to accurately localize target?

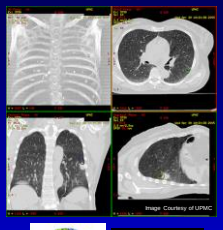
---IGRT

How to obtain conformal dose and steep dose gradients?

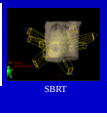
---3DCRT, Inverse Planning, IMRT, VMAT…

How to reduce irradiated volume of critical organs for a moving target?

--- Gating, Tracking…



Intracranial SRS

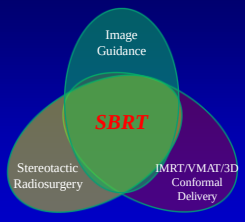


SBRT

SBRT Planning

- Inhomogeneous dose inside PTV
- Sharp dose fall-off outside PTV
- High fractional dose --- High BED

✓*Target definition*
✓*Motion management*
✓*3DCRT or IMRT/VMAT*
✓*Interplay effect*
✓*Dose calculation*
✓*Prescription and Dose constraints*



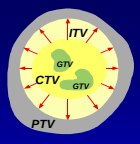
AAPM Task Group N0. 101

Target Definition

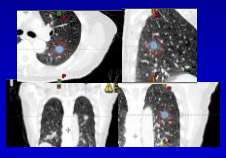
Static Target: ***PTV = CTV+ setup margin***

Moving Target: ***ITV = ∑ CTVi or CTV_MIP (for Lung)***
PTV = ITV+ 3~5mm setup margin

- *Larger margin for irregular breathing*
- *MIP/MinIP only for target definition*



Target Definition (ICRU 62)



Lung example

Pancreas example

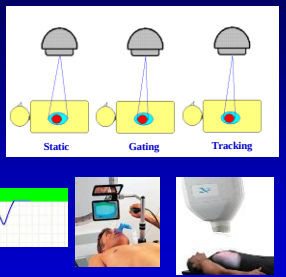
PTV : ITV +2~3mm margin

Motion Management (Delivery)

- Gating Technique
- Breath-holding Technique
- Tracking Technique

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

Respiratory Gating *(motion>5mm)*

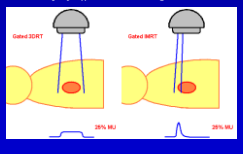


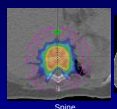
Breath-holding technique

Tracking technique

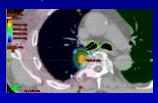
3DCRT vs. IMRT/VMAT

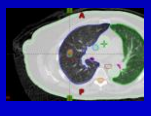
- Spine/Prostate/Pancreas/HN ----- *IMRT/VMAT*
- Some Lung/Liver ----- *3DCRT*
  - Advantages:
    - ✓ *Better dose conformity*
    - ✓ *Easy to control/constrain dose to OARs*
  - Disadvantages:
    - ✓ *Higher MU, longer treatment time*
    - ✓ *Interplay effect between target and MLC motion*



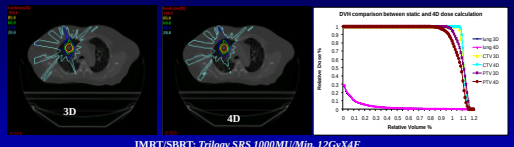

Spine


Pancreas

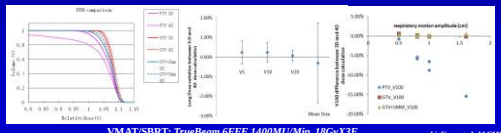

Lung: Central


Lung: Peripheral

Interplay Effect



IMRT/SBRT: ***Trilogy SRS 1000MU/Min, 12GyX4F***

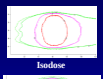


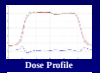
VMAT/SBRT: ***TrueBeam 6FFF 1400MU/Min, 18GyX3F***

Li, Yang et al, JACMP, 2013

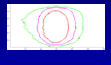
Interplay Effect: Gated RapidArc

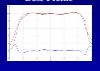

3cm 1D motion, 4.0s period


Isodose


Dose Profile

5mm residual motion

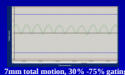




10mm residual motion

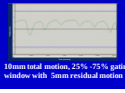

Quasar phantom with real patient data

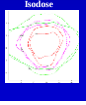
Case 1


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


Isodose

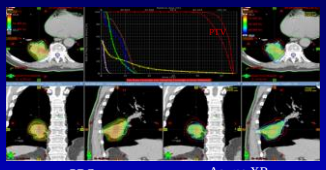
Case 2


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



Riley, Yang et al, Med. Phys. 2014

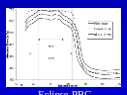
Inhomogeneity Correction



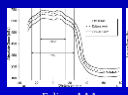
PBC Acuros XB

- *Dose difference for targets from PBC and AcurosXB could be more than 10%*
- ***PBC should not be used for lung SBRT***

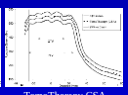
RPC Thorax Phantom



Eclipse PBC



Eclipse AAA



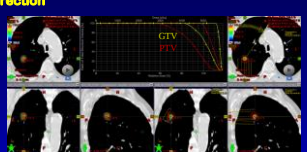
TomoTherapy CSA

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

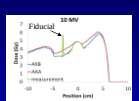
Inhomogeneity Correction

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

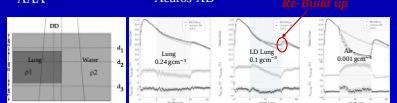
- *Beam energy*
- *Target size*
- *Lung density*
- *Target location*



AAA Acuros XB



Courtesy of Amy Yu, Ph.D.



Re-Build up

6 MV 4.0 cm x 4.0 cm photon beam

Bush et al, Med Phys 38, 2011

Prescriptions and Dos Constraints

- **AAPM TG 101 Table III**
- **ROTG Protocols**
  - Lung: 0236, 0618, 0813 and 0915
  - Spine: 0631
  - Liver: 0438, 1112

These protocols specify detailed requirements for treatment planning:

Dose Prescription
Target Coverage
Dose Constraints

RTOGs: Lung

	0236	0618	0813	0915
Prescribed Dose	60Gy/3f	60Gy/3f	50Gy/5 f	34Gy/1f vs. 12Gy/4f
Location	Peripheral	Peripheral	Central	Peripheral
Allow IMRT?	No	Yes	Yes	Yes
Inhomogeneity Correction?	No	No	Yes	Yes

Timmerman's definition of centrality

Dose Constraints

OAR/Regimen	1 Fraction	3 Fractions	4 Fractions	5 Fractions
Spinal Cord	14 Gy	18 Gy (6 Gy/fx)	26 Gy (6.5 Gy/fx)	30 Gy (6 Gy/fx)
Esophagus	15.4 Gy	30 Gy (10 Gy/fx)	30 Gy (7.5 Gy/fx)	32.5 Gy (6.5 Gy/fx)
Brachial Plexus	17.5 Gy	21 Gy (7 Gy/fx)	27.2 Gy (6.8 Gy/fx)	30 Gy (6 Gy/fx)
Heart/ Pericardium	22 Gy	30 Gy (10 Gy/fx)	34 Gy (8.5 Gy/fx)	35 Gy (7 Gy/fx)
Great Vessels	37 Gy	39 Gy (13 Gy/fx)	49 Gy (12.25 Gy/fx)	55 Gy (11 Gy/fx)
Trachea & Proximal Bronchi	20.2 Gy	30 Gy (10 Gy/fx)	34.8 Gy (8.7 Gy/fx)	32.5 Gy (6.5 Gy/fx)
Rib	30 Gy	30 Gy (10 Gy/fx)	30 Gy (7.5 Gy/fx)	32.5 Gy (6.5 Gy/fx)
Skin	26 Gy	30 Gy (10 Gy/fx)	36 Gy (9 Gy/fx)	40 Gy (8 Gy/fx)
Stomach	12.4 Gy	27 Gy (9 Gy/fx)	30 Gy (7.5 Gy/fx)	35 Gy (7 Gy/fx)

0813 and 0915 Table1

Table 1: Conformality of Prescribed Dose for Calculations Based on Deposition of Photon Beam Energy in Heterogeneous Tissue

PTV Volume (cc)	Ratio of Prescription Isodose Volume to the PTV Volume		Ratio of 50% Prescription Isodose Volume to the PTV Volume, $R_{50\%}$		Maximum Dose (in % of dose prescribed) @ 2 cm from PTV in Any Direction, D_{2cm} (Gy)		Percent of Lung Receiving 20 Gy Total or More, V_{20} (%)	
	Deviation		Deviation		Deviation		Deviation	
	None	Minor	None	Minor	None	Minor	None	Minor
1.8	<1.2	<1.5	<5.9	<7.5	<50.0	<57.0	<10	<15
3.8	<1.2	<1.5	<5.5	<6.5	<50.0	<57.0	<10	<15
7.4	<1.2	<1.5	<5.1	<6.0	<50.0	<58.0	<10	<15
13.2	<1.2	<1.5	<4.7	<5.8	<50.0	<58.0	<10	<15
22.0	<1.2	<1.5	<4.5	<5.5	<54.0	<63.0	<10	<15
34.0	<1.2	<1.5	<4.3	<5.3	<58.0	<68.0	<10	<15
50.0	<1.2	<1.5	<4.0	<5.0	<62.0	<77.0	<10	<15
70.0	<1.2	<1.5	<3.5	<4.8	<66.0	<86.0	<10	<15
95.0	<1.2	<1.5	<3.3	<4.4	<70.0	<89.0	<10	<15
126.0	<1.2	<1.5	<3.1	<4.0	<73.0	<91.0	<10	<15
163.0	<1.2	<1.5	<2.9	<3.7	<77.0	<94.0	<10	<15

Note 1: For values of PTV dimension or volume not specified, linear interpolation between table entries is required.
Note 2: Protocol deviations greater than listed here as "minor" will be classified as "major" for protocol compliance (see Section 6.7).

Stanford: *Volume-Adapted SABR*

	Peripheral			Central		
	<=10 mL	>10 & <=30 mL	>30 mL	<=10 mL	>10 & <=30 mL	>30 mL
Rx dose (covering 95% PTV)	25 Gy in 1 fxn	50 Gy in 4 fxns	54 Gy in 3 fxns	40 Gy in 4 fxns	50 Gy in 4 fxns	60 Gy in 8 fxns
Max. dose (centered in GTV)	>=30 Gy	>=60 Gy	>=64.8 Gy	>=48 Gy	>=60 Gy	>=72 Gy
Ratio of Rx isodose vol to PTV vol	Ideal: <1.2 Required: <1.5	Ideal: <1.2 Required: <1.5	Ideal: <1.2 Required: <1.5	Ideal: <1.2 Required: <1.5	Ideal: <1.2 Required: <1.5	Ideal: <1.2 Required: <1.5
Max dose in PTV+2cm (% of Rx)	Ideal: <55% (13.75 Gy) Required: <65% (16.25 Gy)	Ideal: <64% (32 Gy) Required: <82% (41 Gy)	Ideal: <72% (43.2 Gy) Required: <90% (54 Gy)	Ideal: <55% (22 Gy) Required: <65% (26 Gy)	Ideal: <64% (32 Gy) Required: <82% (41 Gy)	Ideal: <72% (43.2 Gy) Required: <90% (54 Gy)

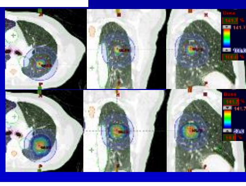
Clinical Investigation: Thoracic Cancer

Tumor Volume-Adapted Dosing in Stereotactic Ablative Radiotherapy of Lung Tumors

Nicholas Trakul, M.D., Ph.D., Christine N. Chang, B.S., Jeremy Harris, B.S., M.Phil., Christopher Chapman, B.A., Aarti Rao, B.A., John Shen, B.S., Sean Quinlan-Davidson, M.D., Edith J. Filion, M.D., Heather A. Wakelee, M.D., A. Dimitrios Colevas, M.D., Richard I. Whyte, M.D., M.B.A., Sonja Dieterich, Ph.D., Peter G. Maxim, Ph.D., Dimitre Hristov, Ph.D., Phuoc Tran, M.D., Ph.D., Quynh-Thu Le, M.D., Billy W. Loo, Jr., M.D., Ph.D., and Maximilian Diehn, M.D., Ph.D.

Trakul et al, IJROBP, 2011

- Global dose maximum > 120% and centered in GTV
- 100% of GTV receives 100% of prescription dose
- MU optimization
- Avoid beam entrance through the contralateral lung when possible



Conformity : Dose Volume vs. PTV Volume

Intermediate Dose Spillage: $R_{50\%}$ and D_{2cm}

RTOG 1112: Liver

- 27.5 – 50 Gy in 5 fx
- Prescription dose based on mean liver dose
- Cover 95% of PTV

Optional Constraint	Priority Constraint	Prescription Dose	
Liver Veff	Allowed Mean Liver Dose [MLD] (Gy)	Planned Prescription Dose (Gy)	If the maximum allowed MLD is exceeded at this planned dose
< 25%	13.0	50	Reduce to 45 Gy and re-evaluate
25 - 29%	15.0	45	Reduce to 40 Gy and re-evaluate
30 - 34%	15.0	40	Reduce to 35 Gy and re-evaluate
35 - 44%	15.5	35	Reduce to 30 Gy and re-evaluate
45 - 54%	16.0	30	Reduce to 27.5 Gy and re-evaluate
55 - 64%	17.0	27.5	Ineligible

Dose values in this table should be read as physical dose for photons, or RBE-weighted dose for protons (assuming RBE = 1.1).

Non-liver OARs	per protocol	variation acceptable	deviation unacceptable
Esophagus max (to 0.5 cc):	32 Gy	> 32 but ≤34 Gy	> 34 Gy
Stomach max (to 0.5 cc):	30 Gy	>30 but ≤32 Gy	> 32 Gy
Duodenum max (to 0.5 cc):	30 Gy	>30 but ≤32 Gy	> 32 Gy
Small bowel max (to 0.5 cc):	30 Gy	>30 but ≤32 Gy	> 32 Gy
Large bowel max (to 0.5 cc):	32 Gy	>32 but ≤34 Gy	> 34 Gy
SpinalCord_05 + 5 mm max (0.5cc):	25 Gy	>25 but ≤28 Gy	> 28 Gy
Kidneys: Bilateral mean dose	≤10 Gy	>10 but ≤12 Gy	> 12 Gy

Dose values in these tables should be read as physical dose for photons, or RBE-weighted dose for protons (assuming RBE = 1.1).

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- 22Gy-60Gy in 1~5F
- Mean liver dose<10Gy
  500cc liver <7Gy
  700cc liver <12Gy

RTOG 0631: Spine

Prescription: 16 or 18 Gy in 1 fx
Dose constraints:
Spine Cord: Dmax (0.03cc)<14 Gy
V10<3.5cc
Esophagus: Dmax (0.03cc)<16 Gy
D(5 cc)<11.9 Gy

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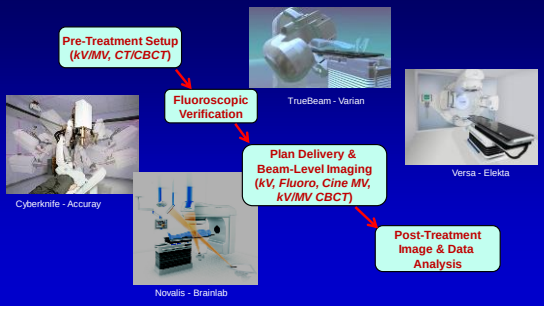
Prescription: 18 or 20 Gy in 1 fx
24 or 27 Gy in 3 fx
Dose constraints:
Spine Cord:
1fx: Dmax <14 Gy, V10<0.35cc
3fx: Dmax<20 Gy, V15<1cc
Esophagus:
1fx: Dmax <10 Gy, V5<1cc
3fx: Dmax <20 Gy, V12<1cc

Table 1: One Fraction Dose Constraints for Arms 1 and 2

Serial Tissue	Volume	Volume Max (Gy)	Endpoint (≥ Grade 3)
Spinal Cord	Less than or equal to 0.35cc	10 Gy	myelitis
	AND		
Spinal Cord	Less than or equal to 10% of the partial spinal cord	10 Gy	myelitis
	AND		
Spinal Cord	Less than or equal to 0.03cc	14 Gy	myelitis
Cauda Equina	<0.03 cc <5 cc	16 Gy 14 Gy	neuritis
Sacral Plexus	<0.03 cc <5 cc	18 Gy 16.4 Gy	neuropathy
Esophagus*	<0.03 cc <5 cc	16 Gy 11.9 Gy	stenosis/fistula
Ipsilateral Brachial Plexus	<0.03 cc <3 cc	17.5 Gy 14 Gy	neuropathy
Heart/Pericardium	<0.03 cc <15 cc	22 Gy 16 Gy	pericarditis
Great vessels*	<0.03 cc <10 cc	37 Gy 31 Gy	aneurysm
Trachea* and Larynx	<0.03 cc <4 cc	20.2 Gy 10.5 Gy	stenosis/fistula
Skin	<0.03 cc <10 cc	26 Gy 23 Gy	ulceration
Stomach	<0.03 cc <10 cc	16 Gy 11.2 Gy	ulceration/fistula
Duodenum*	<0.03 cc <5 cc	16 Gy 11.2 Gy	ulceration
Jejunum/Ileum*	<0.03 cc <5 cc	15.4 Gy 11.9 Gy	enteritis/obstruction
Colon*	<0.03 cc <20 cc	18.4 Gy 14.3 Gy	colitis/fistula
Rectum*	<0.03 cc <20 cc	18.4 Gy 14.3 Gy	proctitis/fistula
Renal hilum/vascular trunk	<20% volume	18.6 Gy	malignant hypertension
Parallel Tissue	**Critical Volume (cc)**	**Critical Volume Dose Max (Gy)**	**Endpoint (≥ Grade 3)**
Lung (Right & Left)	1000 cc	7.4 Gy	Pneumonitis
Renal cortex (Right & Left)	200 cc	8.4 Gy	Basic renal function

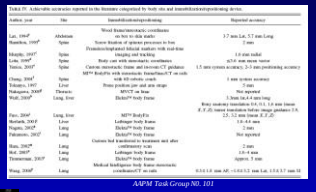
*Avoid circumferential irradiation

Target Localization & Plan Delivery



Pre-Treatment Setup

	Accuracy
Spine	*1~3 mm*
Lung	*<5mm*
Abdomen	*<5mm*



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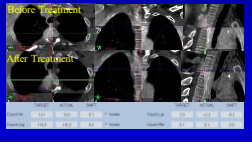
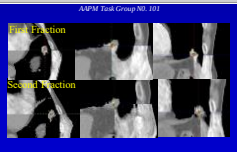
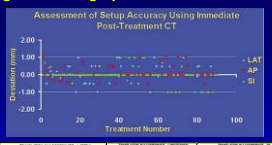




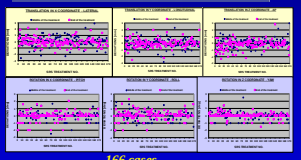
Target Positioning: *Spine*



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.



	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

166 cases

Gerszten et al, *J Neurosurg , V113, 2010*

Target Positioning: *Lung*

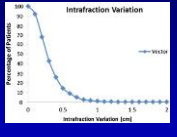
Table 4

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
a-cradle	8.3 ± 5.0	2.2 ± 1.3	3.0 ± 1.7	71.6%	10.0%	3.0 ± 1.7	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 ± 2.8	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 ± 1.6	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%	3.3 ± 1.7	4.5	5.7	6.2	4.2	5.1	5.8

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

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



Intra-fraction variation (*mm*)	
AP	0.0±1.7
ML	0.6±2.2
SI	-1.0±2.0
3D	3.1±2.0

Shah C, et al, PRO, 2013

Fluoroscopy Verification

Fluoroscopic imaging to verify target motion and gating window:

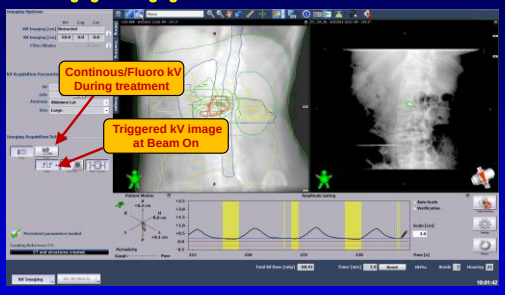
Yellow: in gating window, Beam-on;

Green: out gating window, Beam-Off.

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

Pre-Treatment 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*

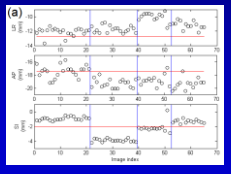
Disadvantage:
- *MLC blocks image*
- *Image quality*

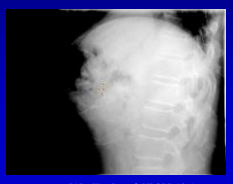
3D tracking if combined with kV imaging

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

Post-Tx Data Analysis: Beam-Level kV Triggered Imaging

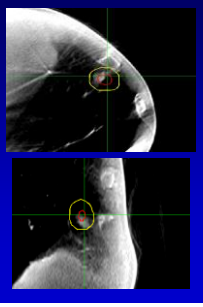
Verification of Intra-fraction geometric accuracy of SABR
- 20 SABR patients (lung/liver/pancreas)
- RPM-based gating treatment
- Geometric error: 0.8 mm on average; 2.1 mm at 95th percentile

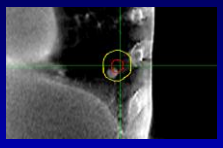




Li R , Xing L, et al. IJROBP, 2012

Post-Tx Data Analysis: Beam-Level kV Volumetric Imaging

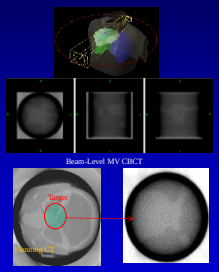




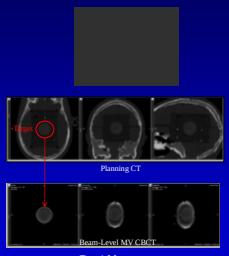
- Continuous fluoroscopy during dose delivery
- In-house program for CBCT reconstruction
- 20 lung SABR patients
- Treatment verification
- Routine clinical use

Li R, Xing L et al, IJROBP, 2013

Post-Tx Data Analysis: Beam-Level MV Volumetric Imaging



Dynamic Arc

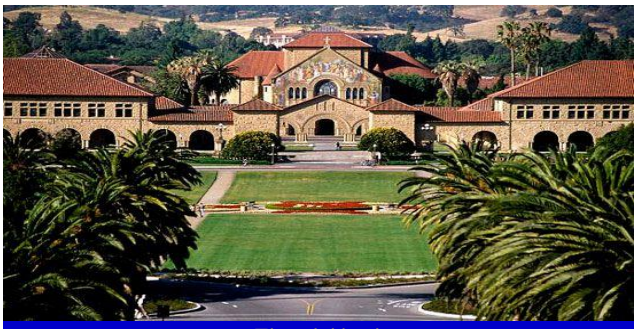


RapidArc

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



Thank You!