Which Planning CT Should be Used for Lung SBRT?

Ping Xia, Ph.D.
Head of Medical Physics
in Radiation Oncology
Cleveland Clinic

Outline

- Image quality and image dose
- Free breathing CT, 4DCT, and synthetic CT
- Choice of Planning CT for SBRT Lung
- How to align the planning CT and CBCT
- 3D CBCT and 4D CBCT

4DCT Acquisition

- 4DCT is acquired either in cine mode or helical mode.
- In cine mode, the table position remains fixed for at least the temporal length of one breath cycle.
- In helical mode, the table position is moved to the next portion of anatomy.
- There is a data sufficient condition for 4DCT, introduced by Dr. Pan.

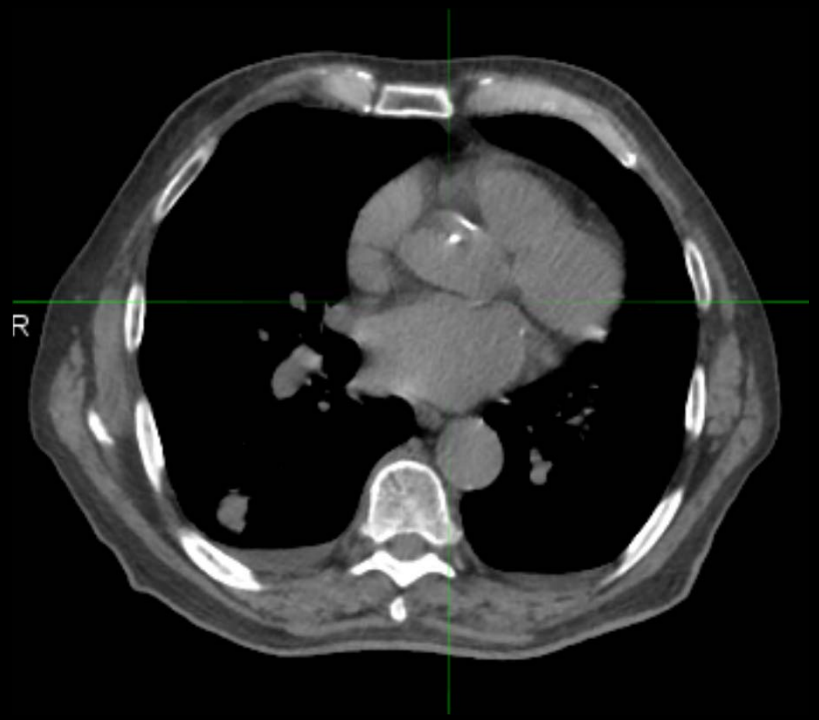
Pan T. Med. Phys. 2005; 32:627–34

Dose and Image Quality

- 4DCT generates ~ 20 times more image data than a standard helical CT.
- If the one rotation of CT gantry is 0.8 s, and one breathing cycle is 5 s, 4D CT dose is ~ 6 times more a standard helical CT.
- To reduce image dose, the acquisition parameters are adjusted, resulting in decrease of imaging quality.

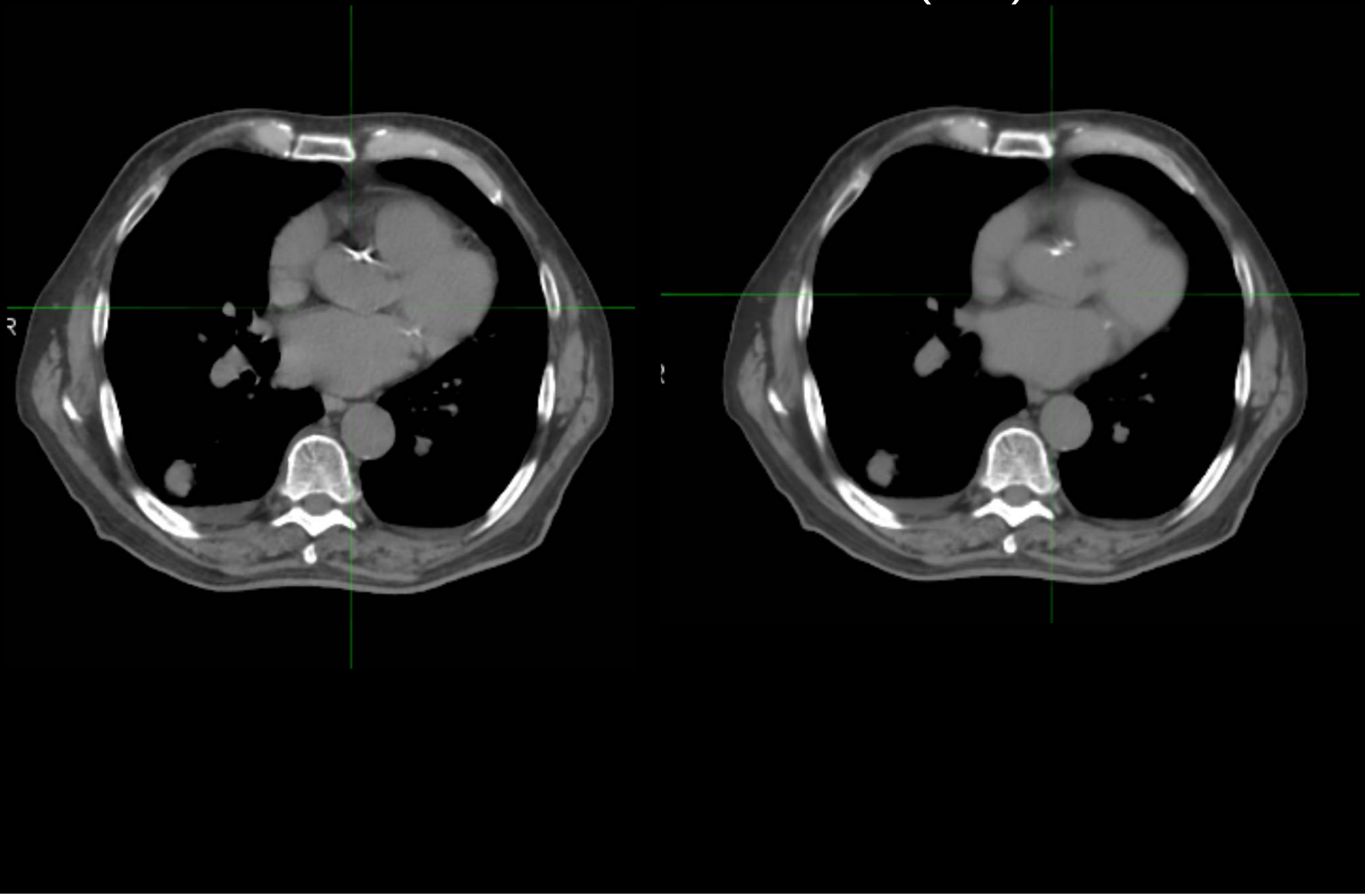
Free Breathing

50% Phase in 4D CT



Free Breathing

Average Intensity Projection (AIP) CT



Free Breathing

50% Phase in 4D CT

Free Breathing

Average Intensity Projection (AIP) CT

Tumor Motion Managements

- Understand tumor motion magnitude
  - 4D CT
  - Add the tumor motion range into planning margins as an internal target volume (ITV)
- Minimize Tumor motion magnitude
  - Abdominal compress
  - Breath-hold treatment
  - Motion tracking treatment

Immobilizing Patient

Use this method for:

Spine SBRT,
Liver SBRT,
Pancreatic SBRT

Abdominal Compression

Apply to lung SBRT case to reduce the tumor breathing motion < 1.0 cm

Gated Treatment – Breath Hold

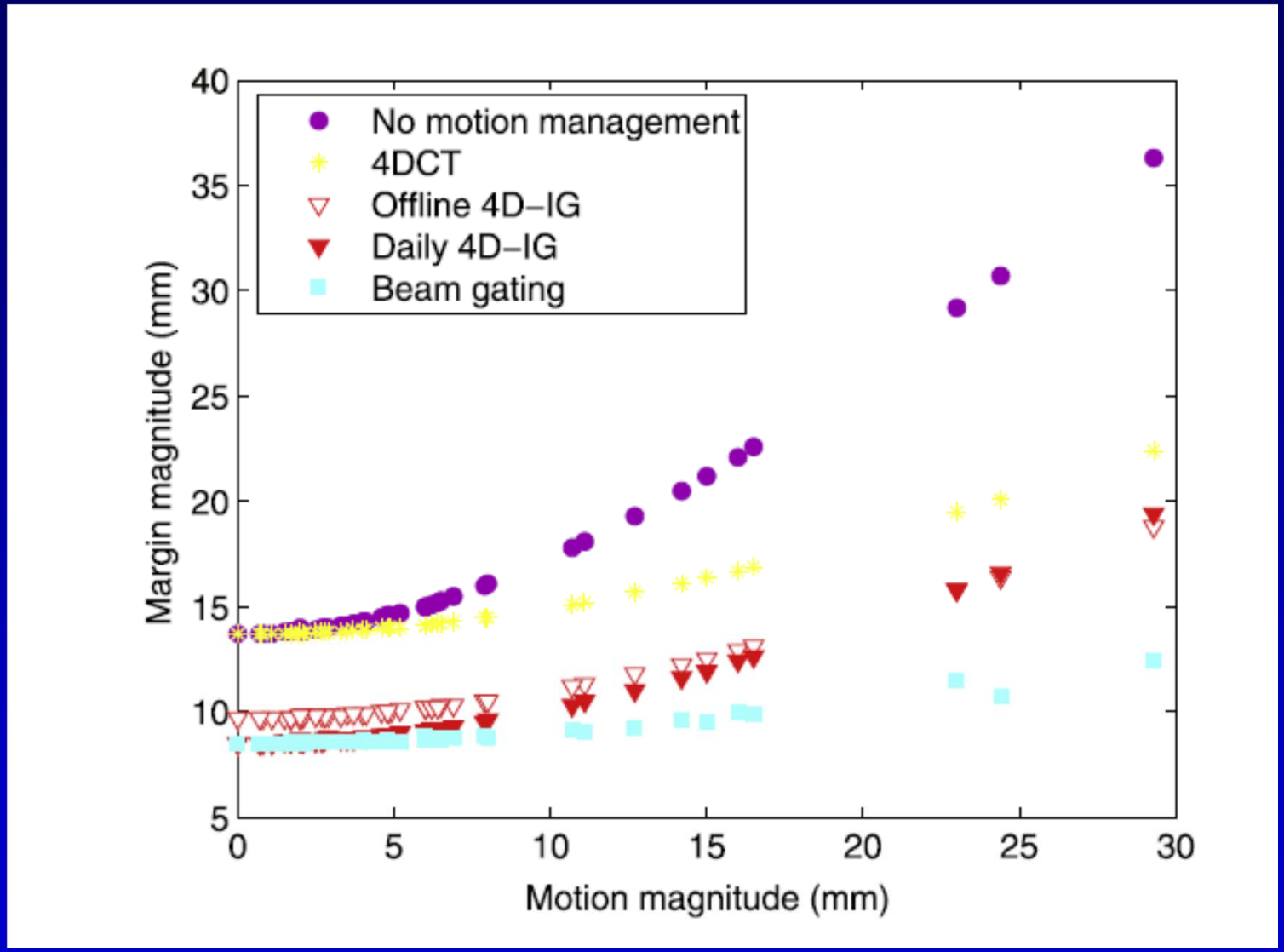
ABC device for:
Lung SBRT
Liver SBRT
Pancreatic SBRT

RPM Gating System

How Big Are Intra-fractional Margins?

- There are a lots of data, but inconsistent.
- For lung tumors, depending on the tumor size and tumor location.
  - Small tumor moves more
  - Tumor in the lower lobe or near diaphragm moves more.
- Intra-fraction margins are patient dependent and method/device dependent.

Planning Margins Vs. Tumor motion



Korreman, S, et. al. Red. Vol. 83, 1338-1343 (2012)

Lung Tumor Intra-Fraction Motion

- A study from UK included 12 patients, who had tumors visible fluoroscopically, and had intrafraction tumor movement assessed with and without ABC.

- N. Panakis et al. Radiotherapy and Oncology 87 (2008) 65–73

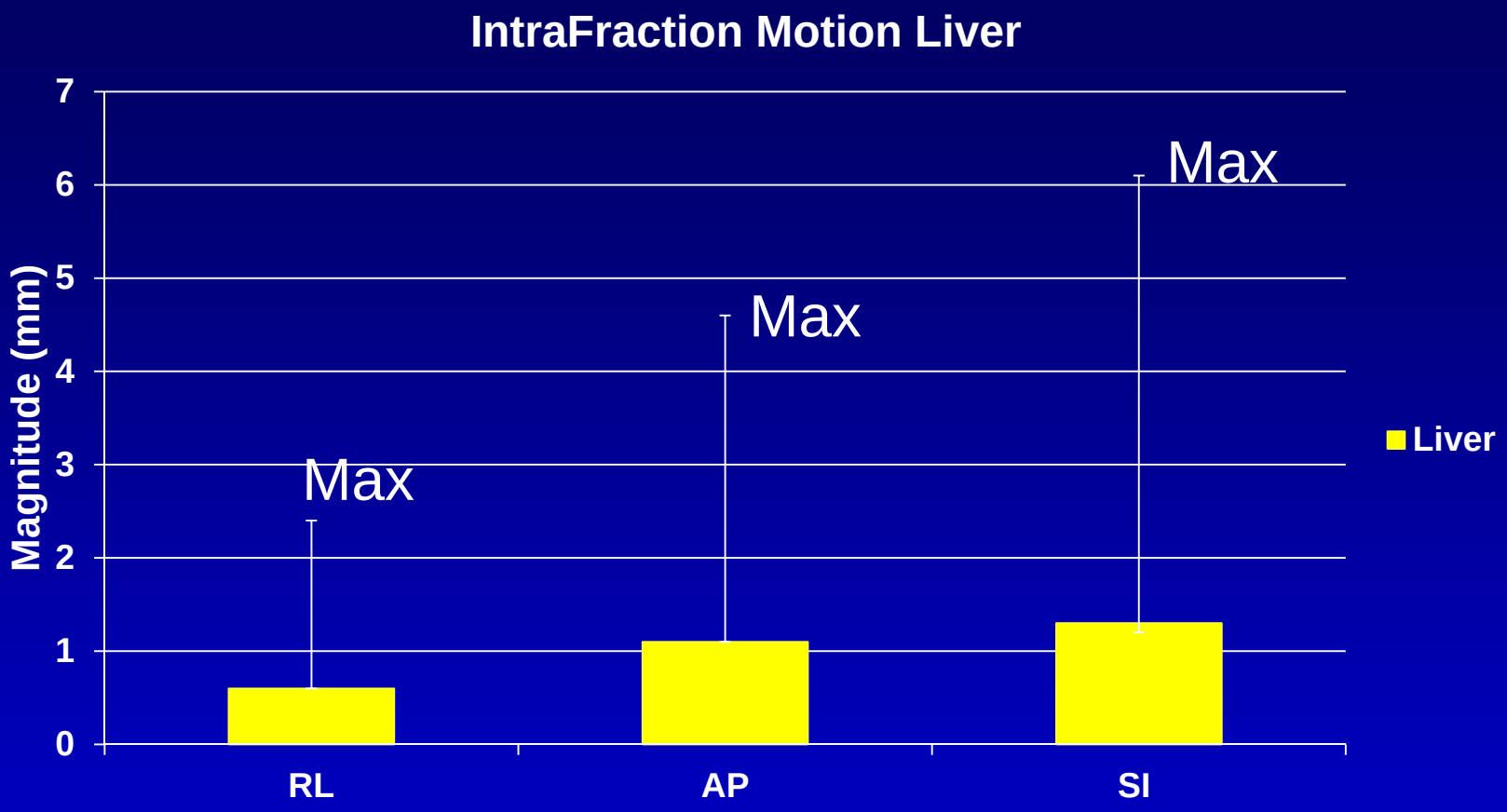
Breath Hold Reduces Intra-Fraction Tumor Motion

Table 3
Intrafraction variations of tumour movement with free-breathing and ABC in the 12 patients in Study 1

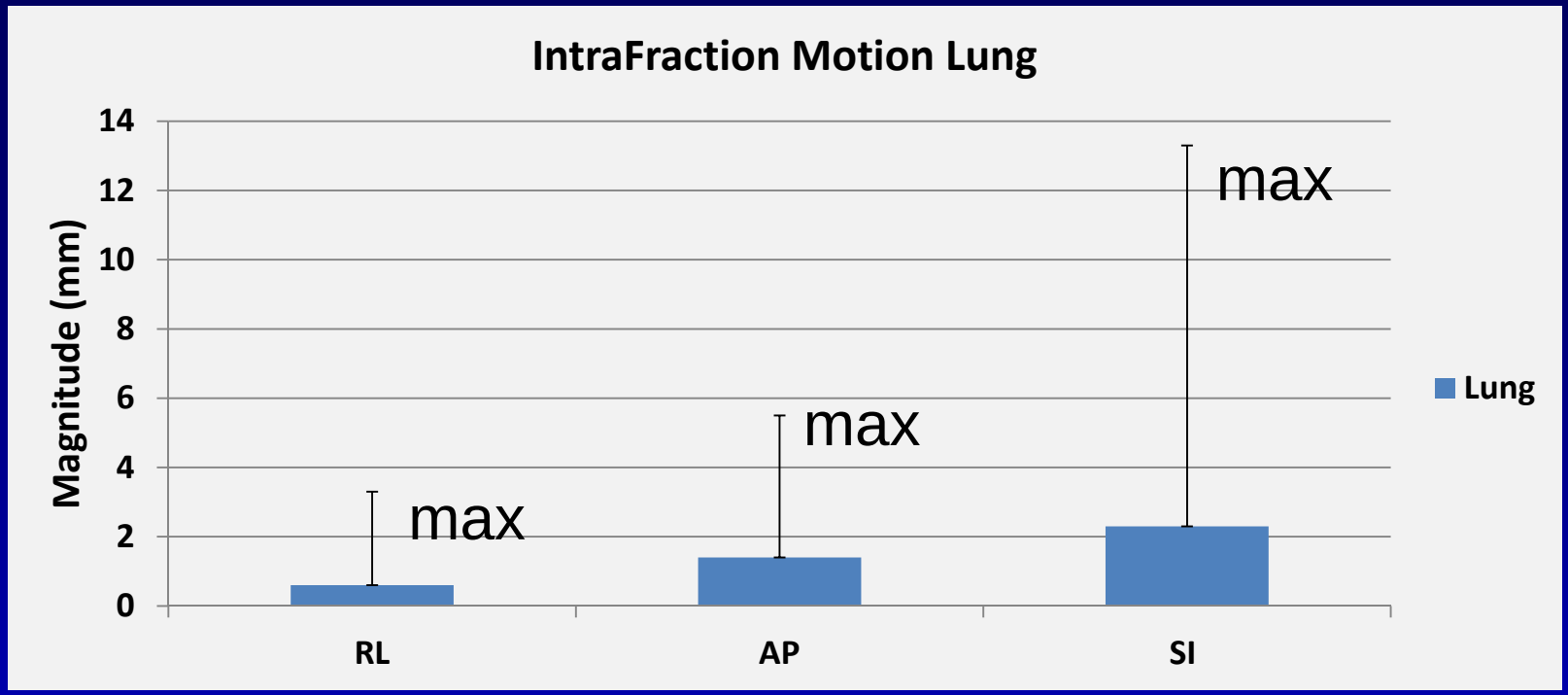
	Free-breathing			ABC			Reduction with ABC		
	x	*y*	*z*	*x*	*y*	*z*	*x*	*y*	*z*
Mean (mm)	4.2	8.0	5.1	0.6	0.3	0.6	3.6	7.7	4.5
SD (mm)	2.6	6.8	2.8	1.2	0.5	0.7			
Range (mm)	0–9	0–21	0–9	0–3	0–1	0–2	0–6	0–21	0–9
SD max/3 (mm)	0.9	2.3	0.9	0.4	0.2	0.2			

Table key: *x*, right–left direction; *y*, superior–inferior direction; *z*, anterior–posterior direction; SD, ±1 standard deviation; SD max/3, standard deviation of one-third of the peak-to-peak amplitude for each tumour.

Mean (mm)	**4.2**	**8.0**	**5.1**	**0.6**	**0.3**	**0.6**	**3.6**	**7.7**	**4.5**
SD (mm)	2.6	6.8	2.8	**1.2**	**0.5**	**0.7**			



14 SBRT liver patients obtained 3CTs with three separate breath holds during simulation.



11 SBRT lung patients obtained 3CTs with three separate breath holds during simulation.

Pitfalls of Using Free Breathing CT

Pitfalls of Using a Free Breathing CT

- The free breathing CT did not record the average target position.
- The PTV (even with 1 cm margin from CTV) from the free-breathing CT was not representative of actual volume needing treatment.

Courtesy of Steve Jiang

Motion Artifacts

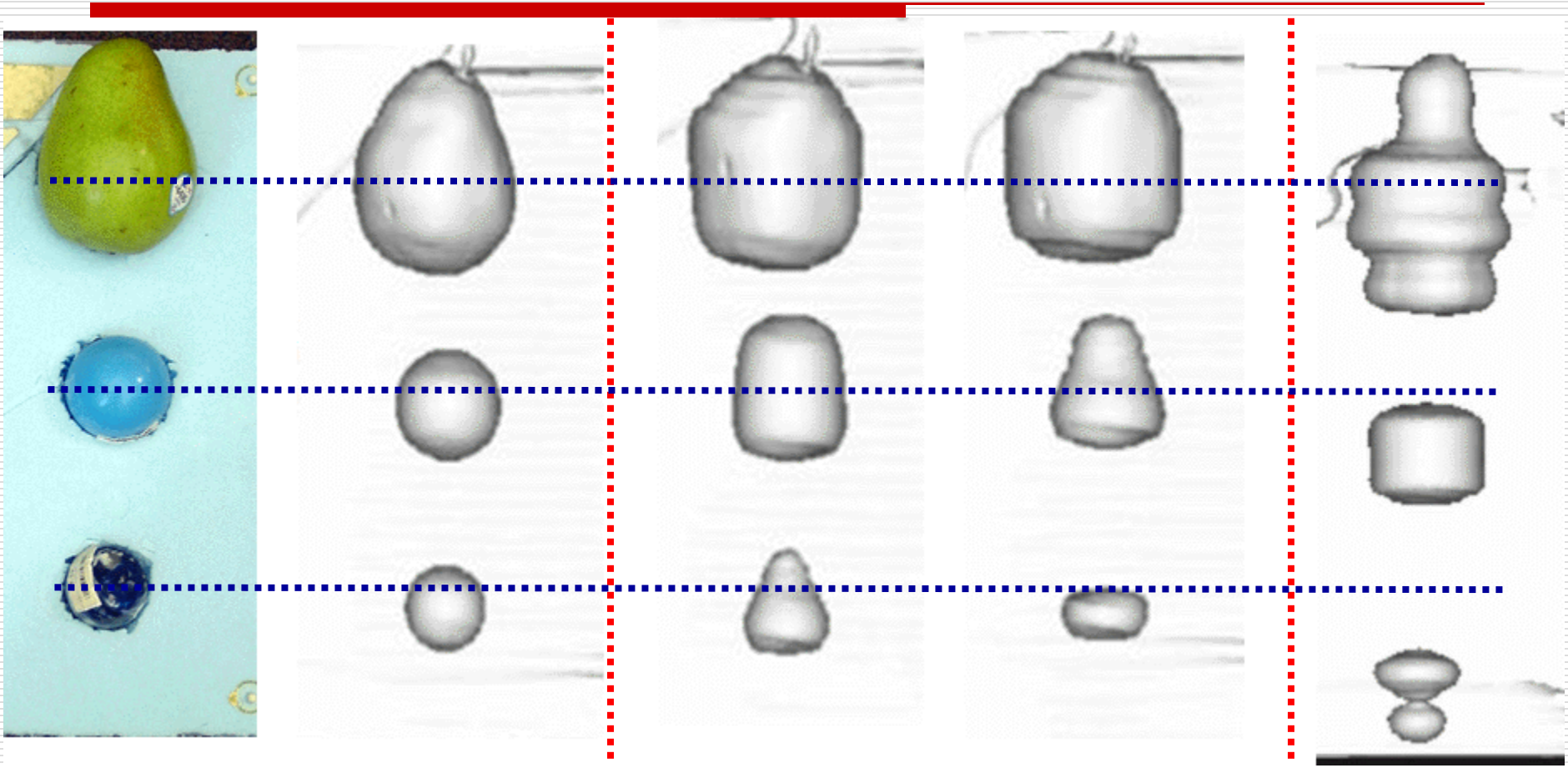


Photo **Static** **Moving / HS mode** **HQ**

Pitfalls of Using Free Breathing CT

- Respiratory organ motion can cause severe geometrical distortion in free breathing CT.
- Distortions along the axis of motion could either lengthen or shorten the target at random fashion.
- In addition to shape distortion, the center of the imaged target can be displaced by as much as the amplitude of the motion.

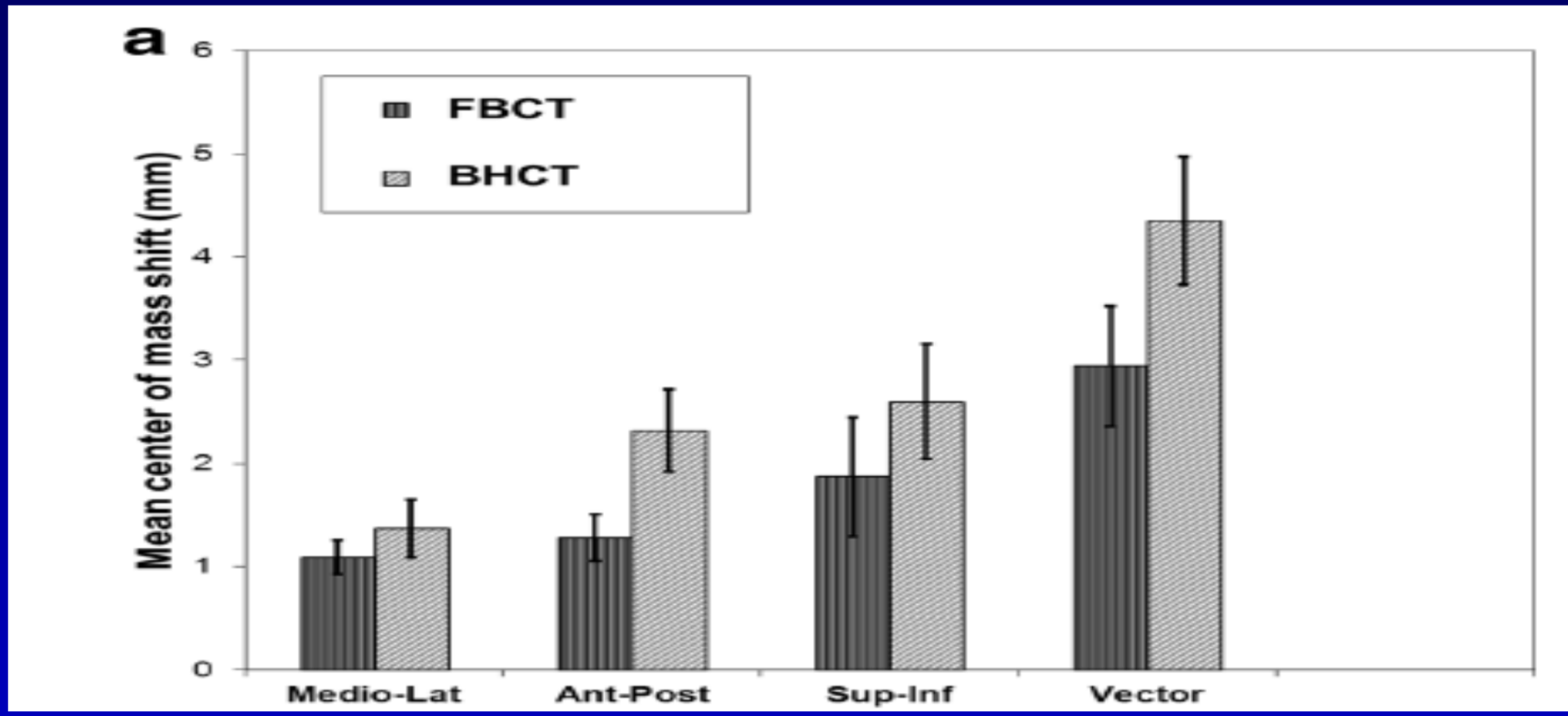
Table 1. Volume of liver and lung tumor obtained by manual contouring on helical CT scan and 4D-CT volumes

Scan/phase	Liver tumor volume (cm^3)	Lung tumor volume (cm^3)
Helical CT, light breathing	296.68	24.35
4D-CT 0%	246.38	19.10
4D-CT 20%	275.46	21.20
4D-CT 40%	248.53	19.65
4D-CT 60%	257.22	23.94
4D-CT 80%	253.68	24.91

Abbreviation: 4D-CT = four-dimensional computed tomography.

Rietzel E, et. al. Red J. Vol. 61, 1535-1550 (2005)

COM Shifts Between FBCT and AIP-CT



During practice transition from using multiple BHCTs to 4DCT to create ITV, we acquired FBCT, multi-phase BHCT, and 4D CT for 30 patients.

Neil M. Woody, et. al. J Radiat Oncol (2015) 4:185–191

Which CT Should be Used for Lung SBRT Planning?

- Using FB CT to contour the GTV and add a standard margin – 1.0 cm in SI direction and 0.5 cm in other directions.
- Using FB CT while acquiring two extreme breathing CTs to obtain a patient specific ITV.
- Using FB CT for planning while acquiring a short ranged 4D CT to contour a patient specific ITV.

Which CT Should be Used for Lung SBRT Planning?

- Using a mid-ventilation CT from 4DCT
- Using AIP (average intensity projection) CT, which is derived from 4DCT.
- Using MIP (maximum intensity projection) CT, which is another synthetic CT, derived from 4DCT.

Free Breathing CT Only Represents a Snapshot of GTV location

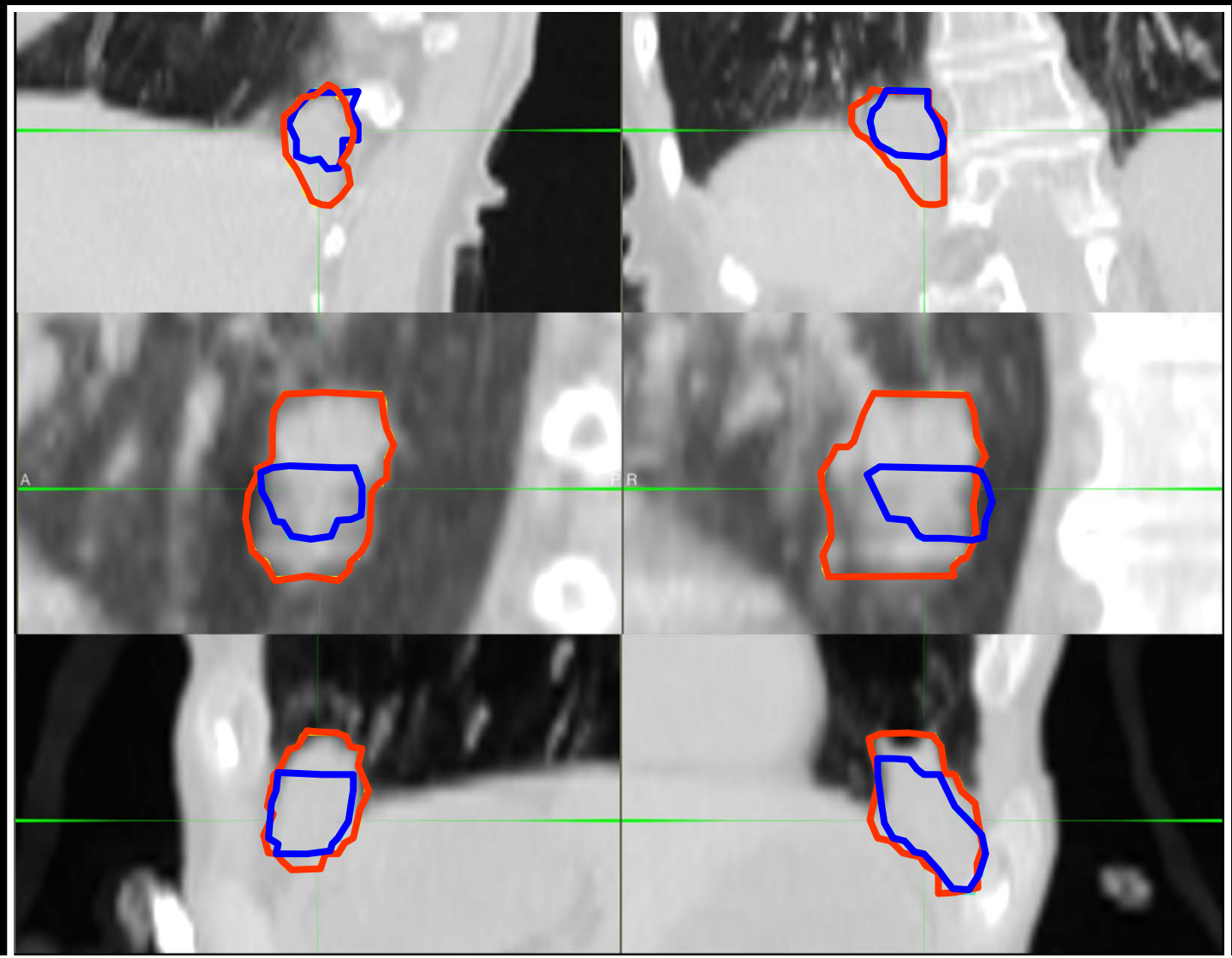
MIP-ITV

FB-GTV

Patient 1

Patient 2

Patient 3



History of Motion Management

- In early 2000's, 4D CT was not available.
- A typical practice was to acquire multiple CTs: one free breathing CT, one deep inhale CT, and one deep exhale CT.
- Obtain the maximal envelope of the motion, added as internal target volume to account for tumor motion.

History of Motion Management at CCF

- Patients were treated with quiet breathing, and free breathing CTs were used for treatment planning.
- With ITVs to count for tumor motions, patients were aligned to bony anatomy, using stereotactic x-ray images (i.e. ExacTrac).

Changes in Technology

- 4D CT became available.
- KV-CBCT was also equipped with the Novalis TX LINAC, but acquisition was slow, about more than 1 minute, capturing the tumor at an average position.
- The question was if we change to use KV-CBCT for verification, what planning CT, free breathing CT (FBCT) or average intensity project CT (AIP-CT) should be used for planning and as a reference CT for KV-CBCT IGRT?

What is AIP CT ?

- AIP CT is a synthetic CT, derived from 4D CT using average intensity projects.

If FBCT, How to Align to KVCBCT

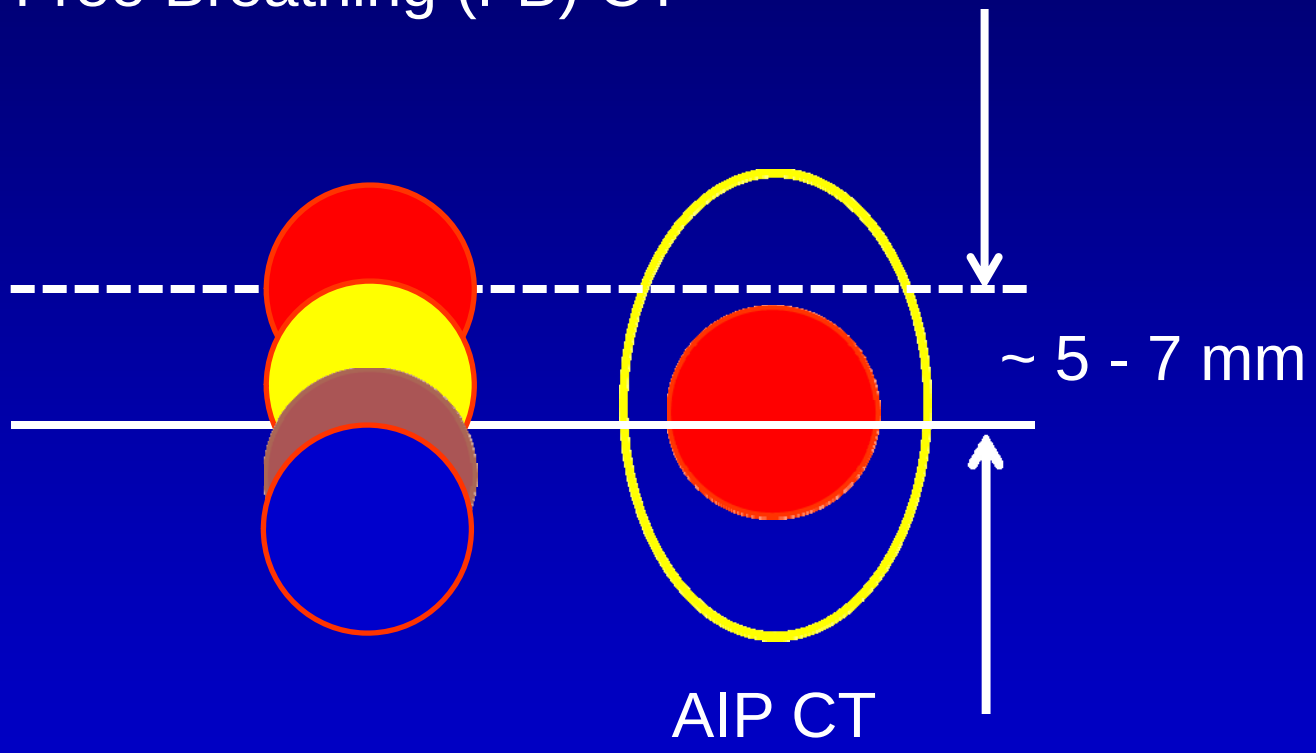
- On KV-CBCT, the peripheral lung tumors were easily seen.
- If not, implanted markers can be a surrogate for the tumor.
- Why not directly align to the tumor between FBCT and KV-CBCT, or align to the implanted markers?
- .

Why Not Align Tumors Between FBCT to KVCBCT?

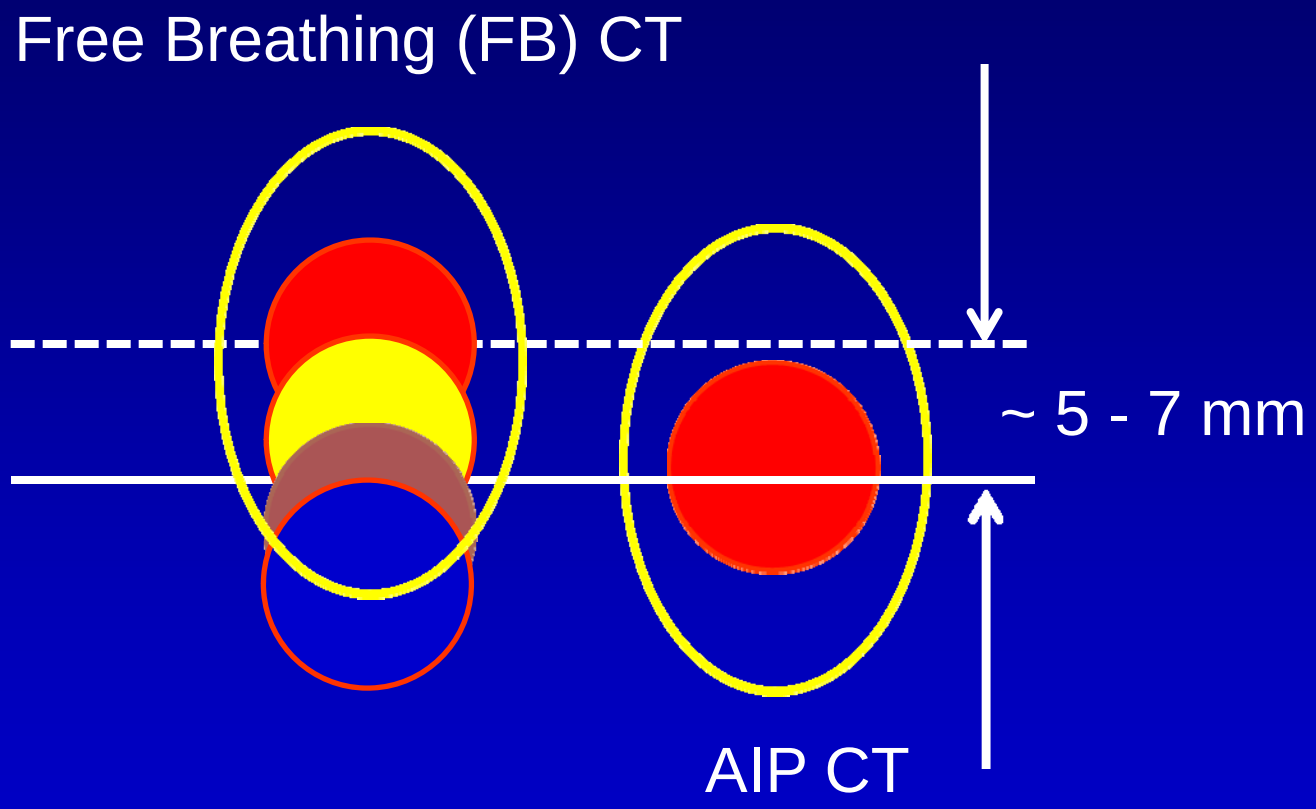
- Directly aligning to the tumor or implanted markers seems a better idea than aligning to the bony anatomy as what we did using ExacTrac system.

Different Between FB CT vs. AIP CT

Free Breathing (FB) CT



Different Between FB CT vs. AIP CT



Use AIP CT as a Planning CT

- If aligning to the tumor between the CBCT and the reference CT, AIP-CT as a planning CT is recommended.

Cautious with Potential Mis-alignment Between CBCT and FBCT

- If align to tumor between the CBCT and FBCT, the iso-center could be potentially mis-aligned, depending on which breathing phase of the tumor was captured in FBCT.

- Neil M. Woody, et. al. J Radiat Oncol (2015) 4:185–191

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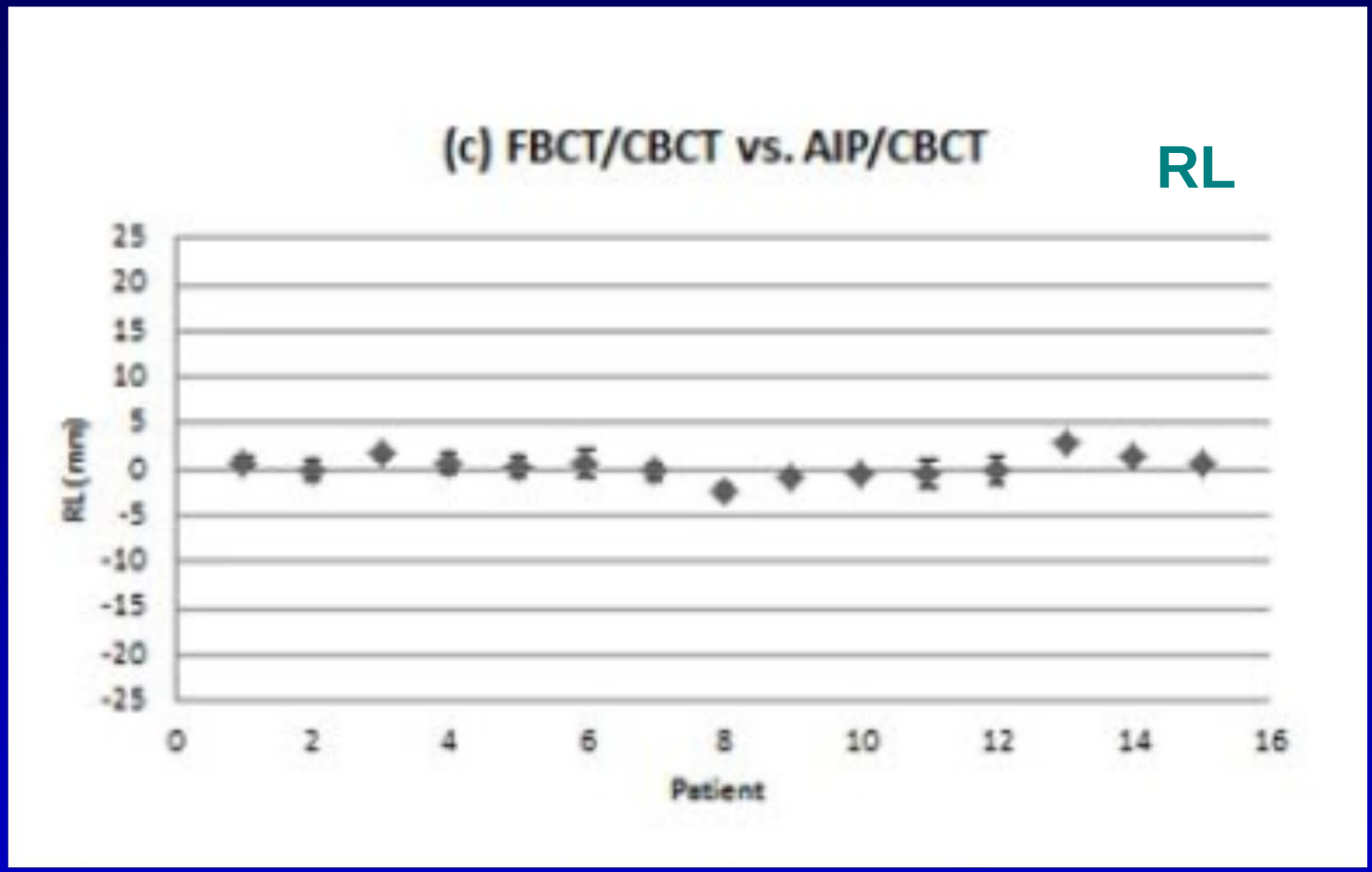
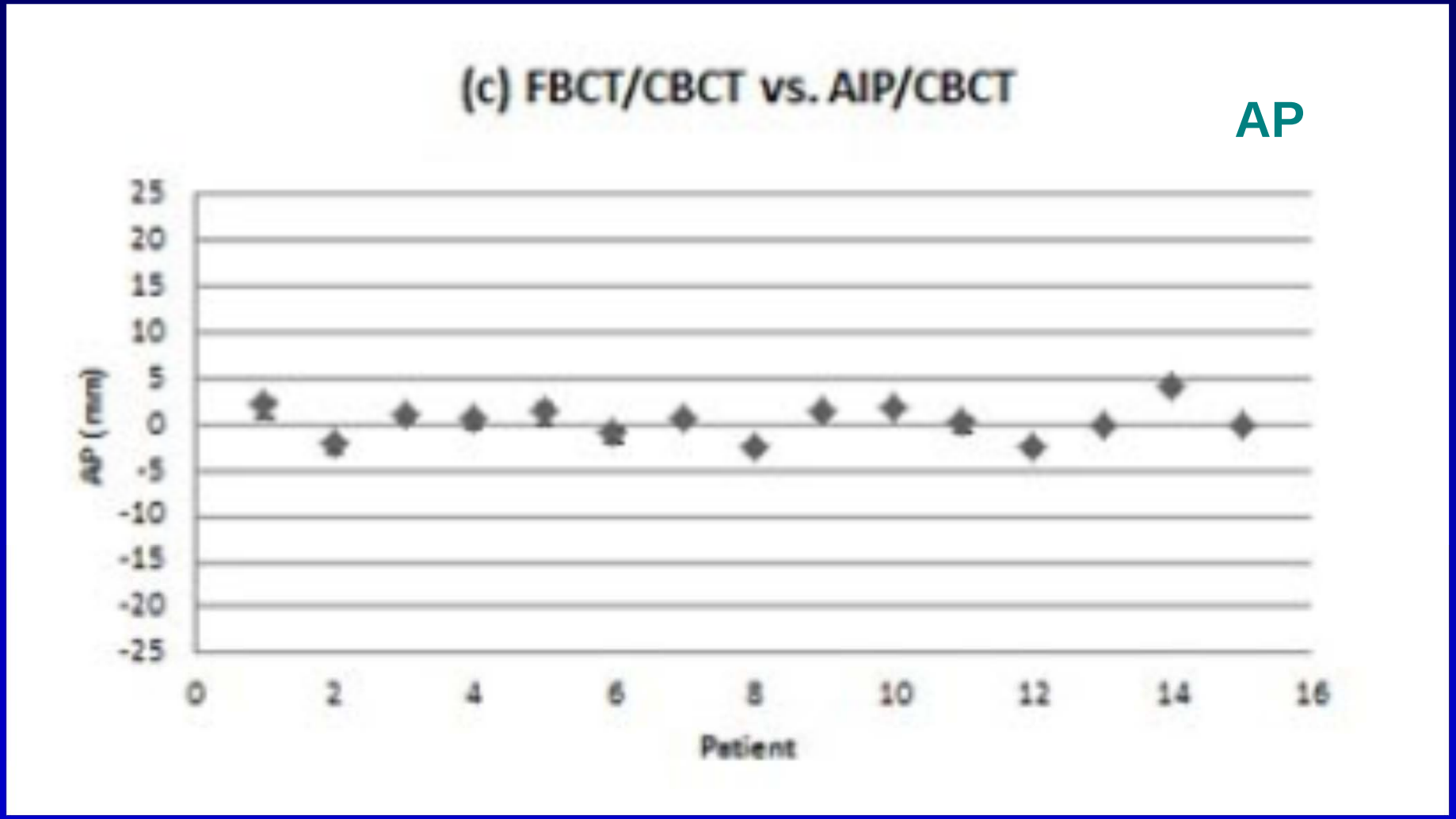
Potential systematic uncertainties in IGRT when FBCT reference images are used for pancreatic tumors

Ahmad Amoush, May Abdel-Wahab, Mohamed Abazeed, Ping Xia[a]
Department of Radiation Oncology, Cleveland Clinic, Cleveland, OH, USA
xiap@ccf.org

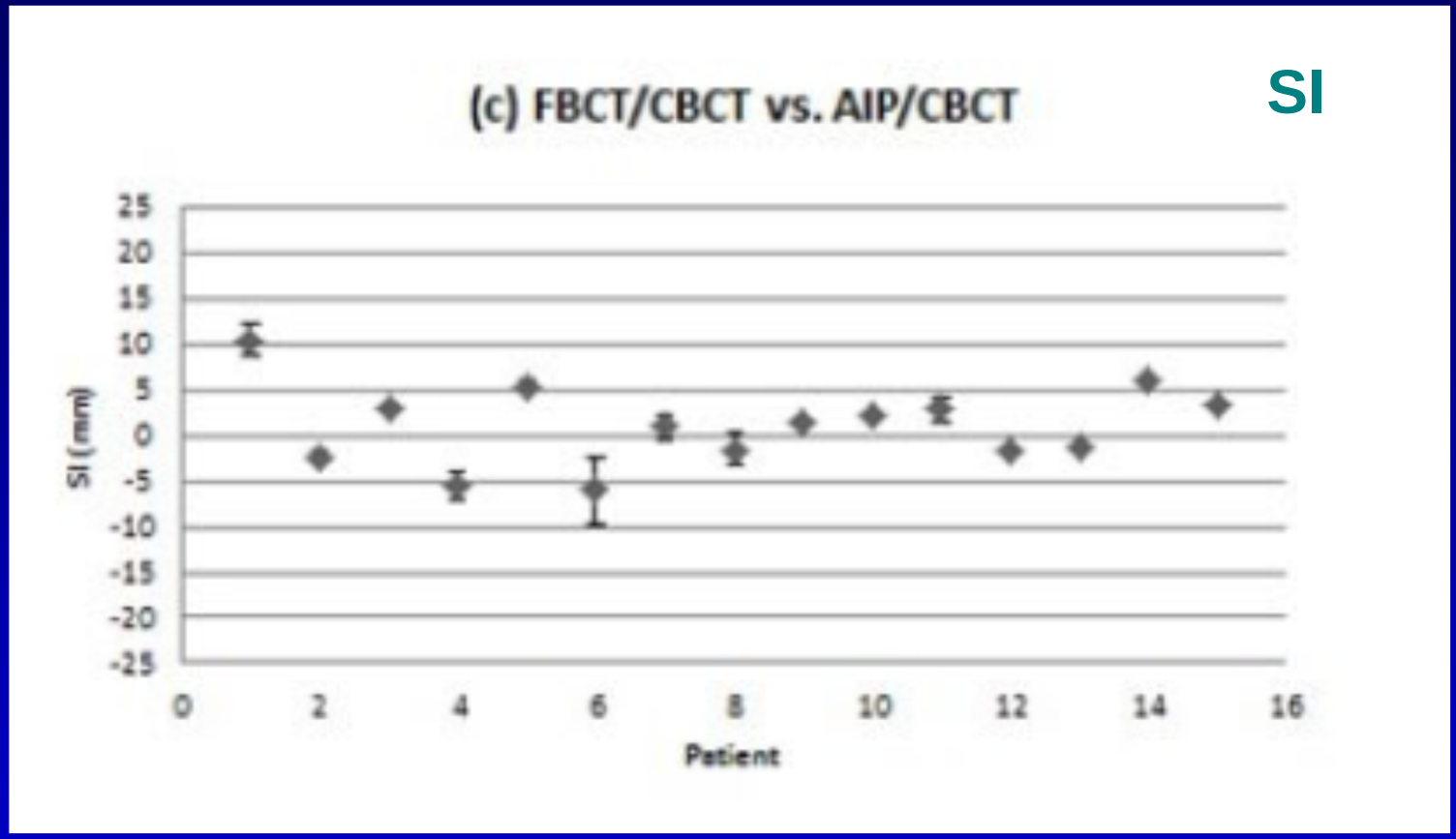
- For a total of 15 patients treated with conventional fractionation, with stent or implant markers.
- Bothe FBCT and 4D CT were acquired.
- The absolute mean discrepancies in iso-center shifts by aligning the markers between FBCT/CBCT and AIP/CBCT were,, and in RL, AP, and SI, respectively.


(c) FBCT/CBCT vs. AIP/CBCT
RL
RL (mm)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
2
4
6
8
10
12
14
16
Patient

1.1 mm ± 0.8 mm


(c) FBCT/CBCT vs. AIP/CBCT
AP
AP (mm)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
2
4
6
8
10
12
14
16
Patient

1.3 mm ± 0.9 mm


(c) FBCT/CBCT vs. AIP/CBCT
SI
SI (mm)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
2
4
6
8
10
12
14
16
Patient

3.3 mm ± 2.6 mm

Successful Result

- Early stage lung tumors were treated this method successfully.
- Videtic et. al. from CCF reported 93% local control at three years.

Videtic GM, et. al. Int J. Radiat Oncol Biol Phys 2010;77:344-349

International Journal of
Radiation Oncology
biology • physics

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Clinical Investigation: Thoracic Cancer

Study of 201 Non-Small Cell Lung Cancer Patients Given Stereotactic Ablative Radiation Therapy Shows Local Control Dependence on Dose Calculation Algorithm

Kujtim Latifi, PhD,* Jasmine Oliver, BS,*,† Ryan Baker, BS,‡ Thomas J. Dilling, MD,* Craig W. Stevens, MD, PhD,* Jongphil Kim, PhD,§ Binglin Yue, MS,§ MaryLou DeMarco, MS, CMD,* Geoffrey G. Zhang, PhD,* Eduardo G. Moros, PhD,* and Vladimir Feygelman, PhD*

*Department of Radiation Oncology, Moffitt Cancer Center, †Department of Physics, University of South Florida, ‡University of South Florida School of Medicine, and §Department of Biostatics and Bioinformatics, Moffitt Cancer Center, Tampa, Florida

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Different Clinical Outcomes

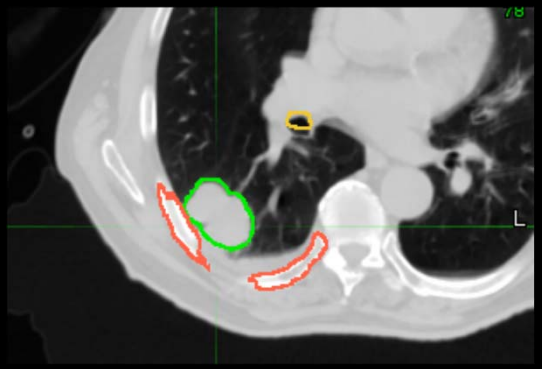
- 78% local control was compared to 93% of Videtic study.
- The same Rx dose, planning system, and treatment unit between the two studies
- Both studies used free-breathing CTs
- One small difference was: one aligned to the implanted markers and one aligned to the bony anatomy.

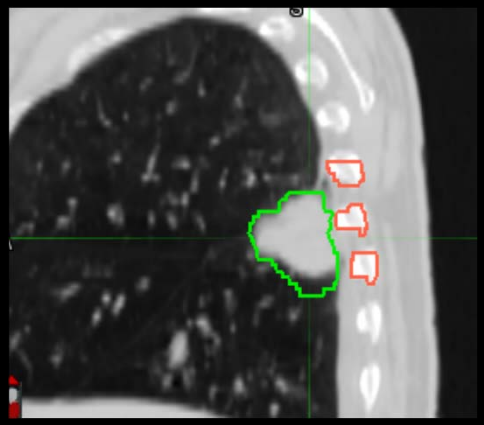
Case 1

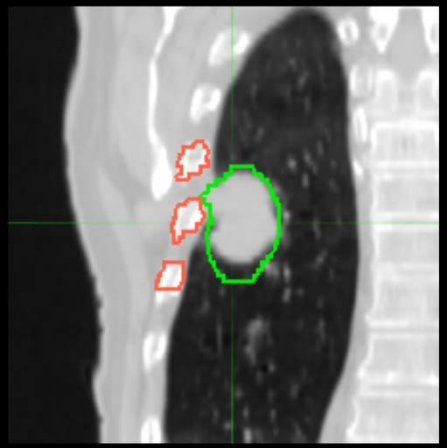
- A 73 year old male patient had early staged lung caner at right lower lung and was treated with 12 Gy x 4 fraction SBRT.
- Daily AP shifts were 1 cm.

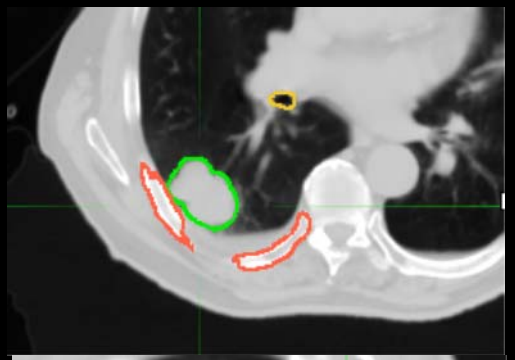
Free-Breathing CT

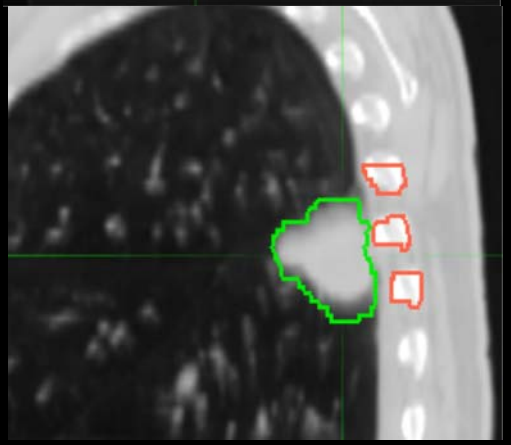
AIP-CT

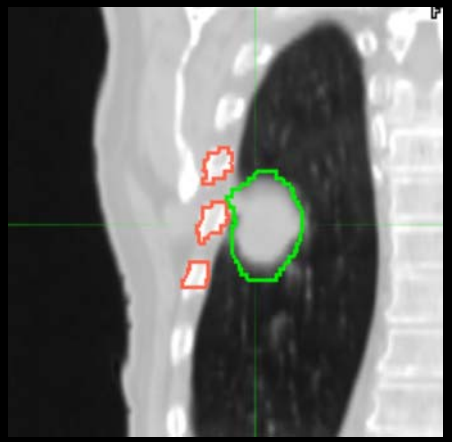






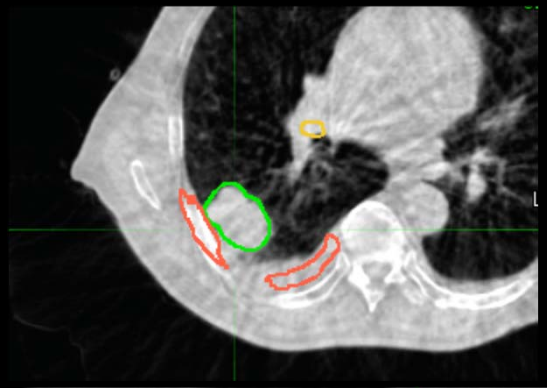


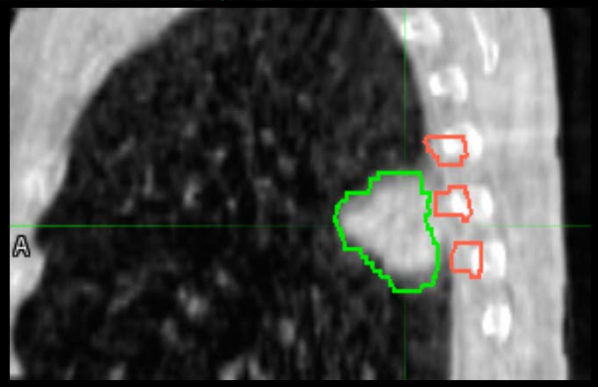


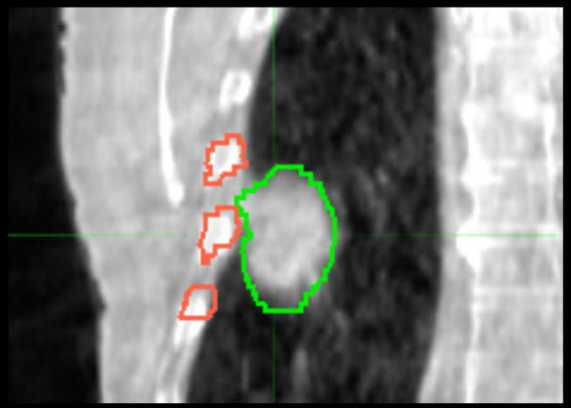


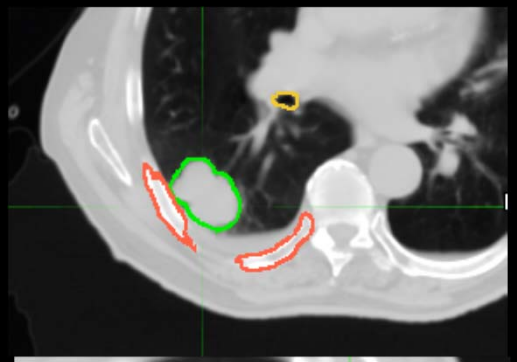
CBCT

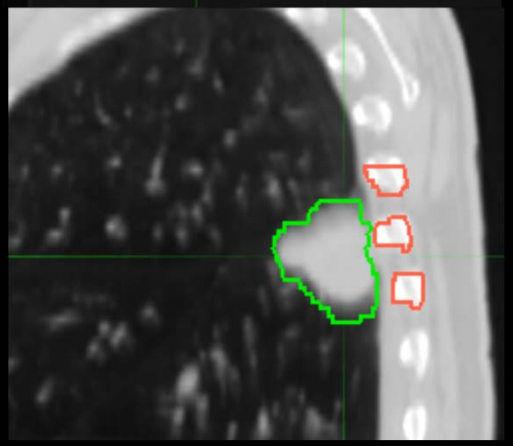
AIP CT

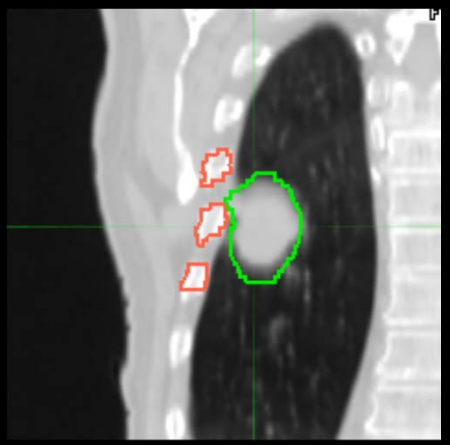


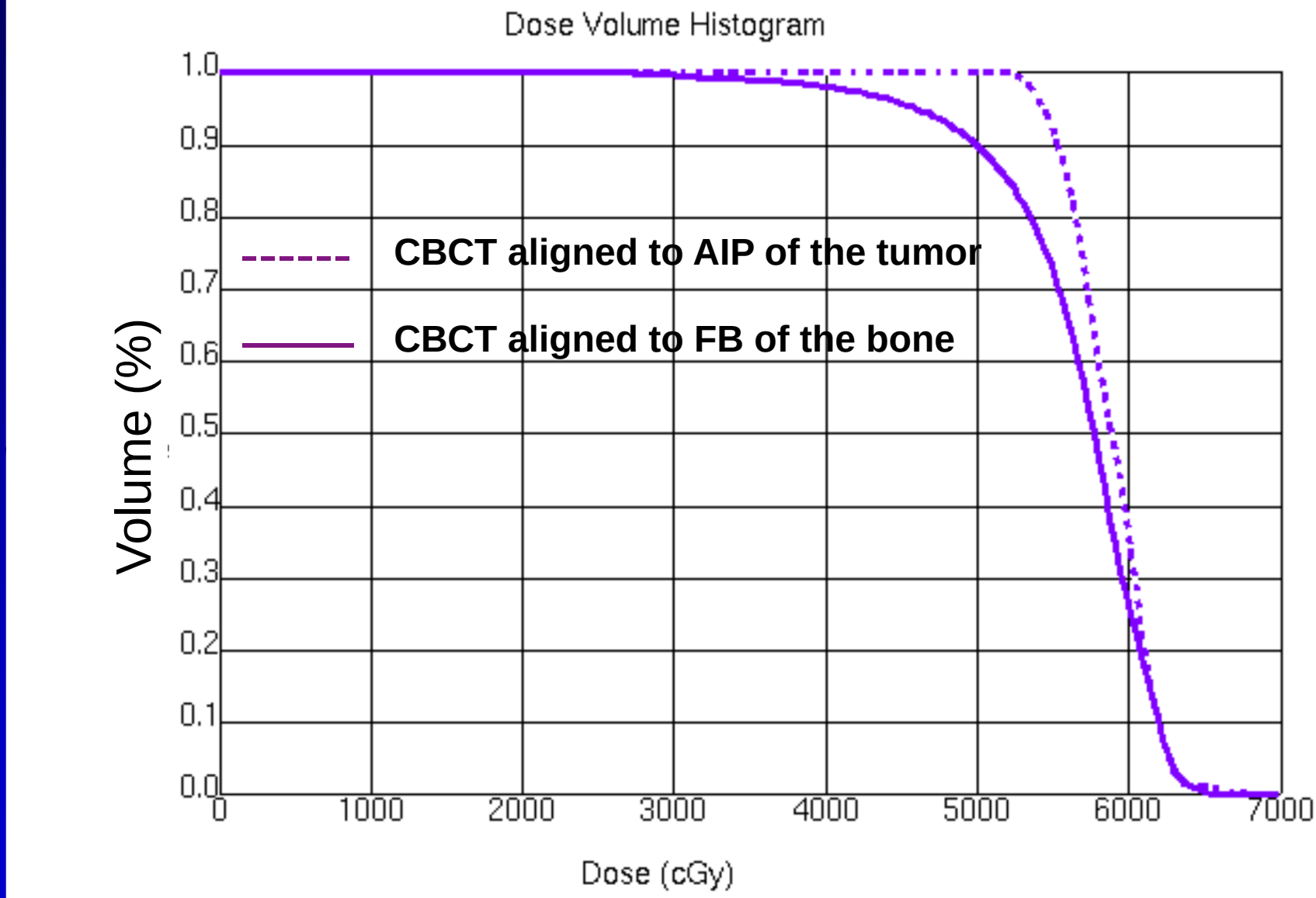










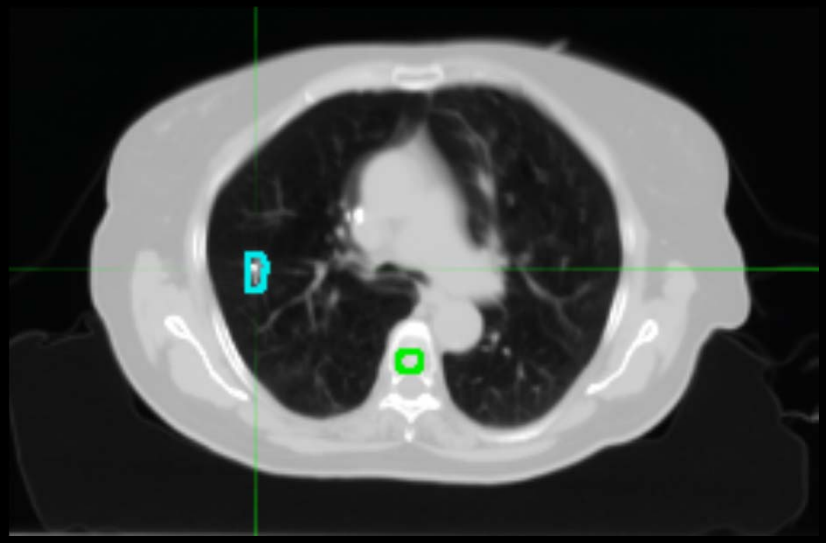

Dose Volume Histogram
Volume (%)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CBCT aligned to AIP of the tumor
CBCT aligned to FB of the bone
0
1000
2000
3000
4000
5000
6000
7000
Dose (cGy)

CBCT align to tumor of AIP

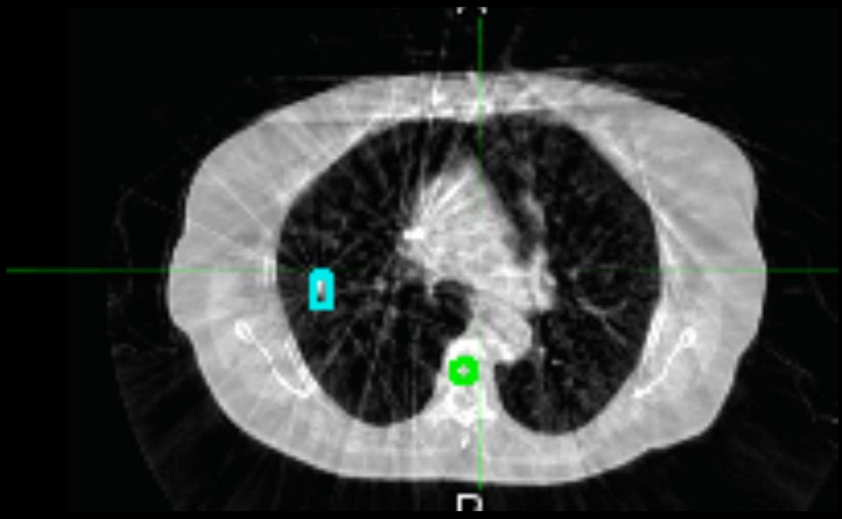
CBCT align to bone of FB

Case 2

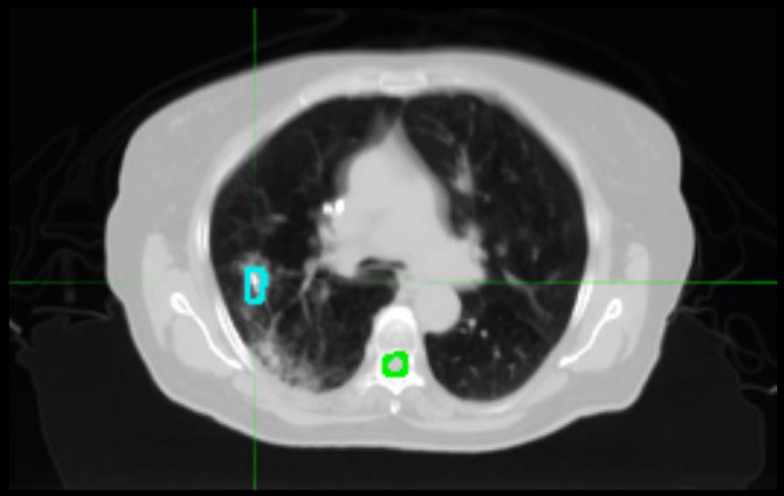
- 73 year old female patient had early stage lung cancer at right upper lung and was treated with SBRT with 12 Gy x4 Fractions.
- She was simulated on 3/14 and treated on 4/2/2018.
- After aligning to the marker using AIP and 3D-CBCT, the shift was 2 cm in AP direction.
- A verification 4D CT was acquired on 4/2 to verify no marker migration, but the tumor location moved.



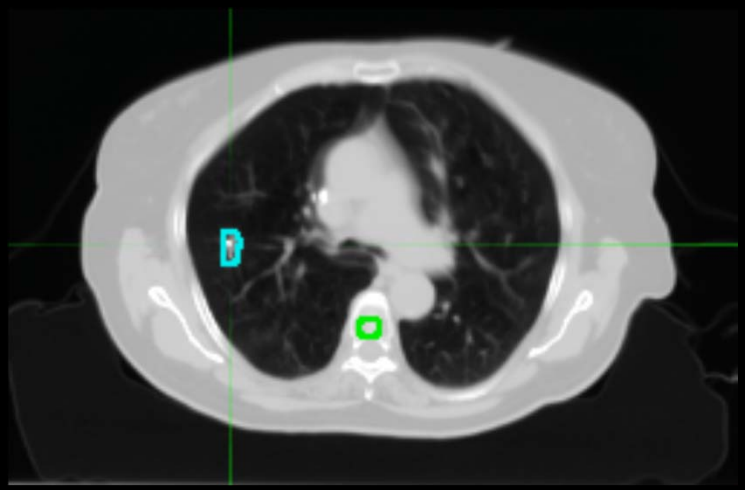
AIP 4/2



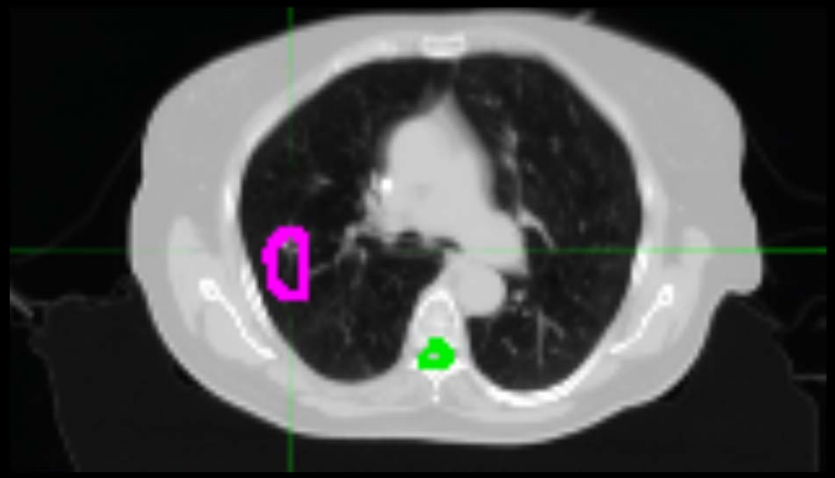
CBCT 4/2

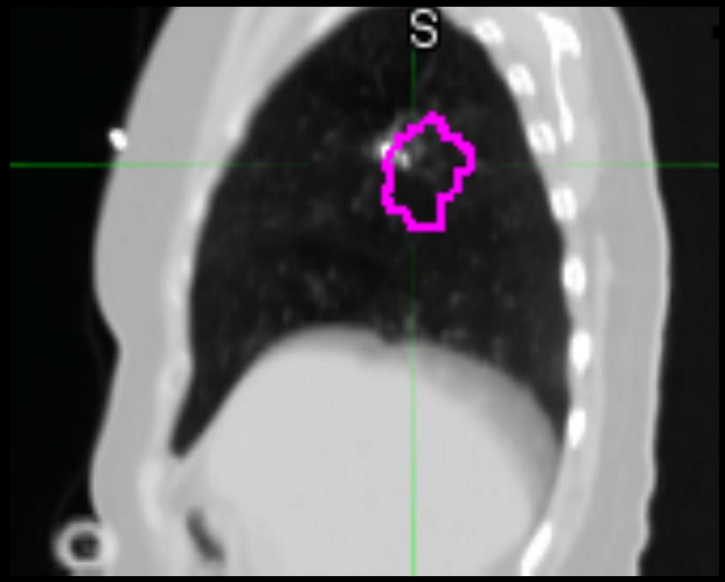


AIP 3/14

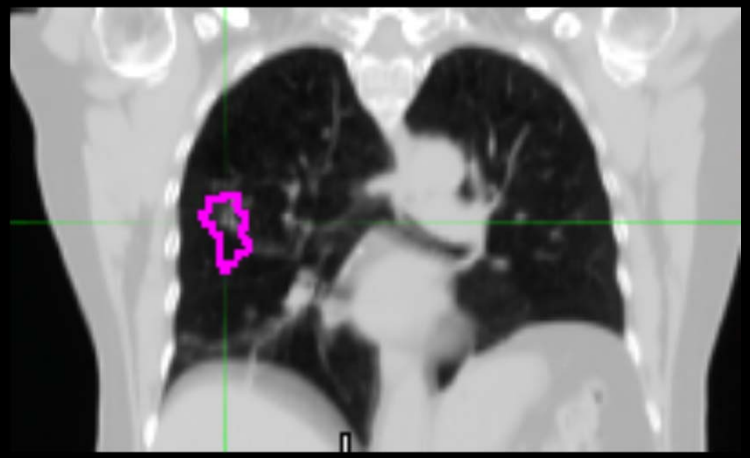


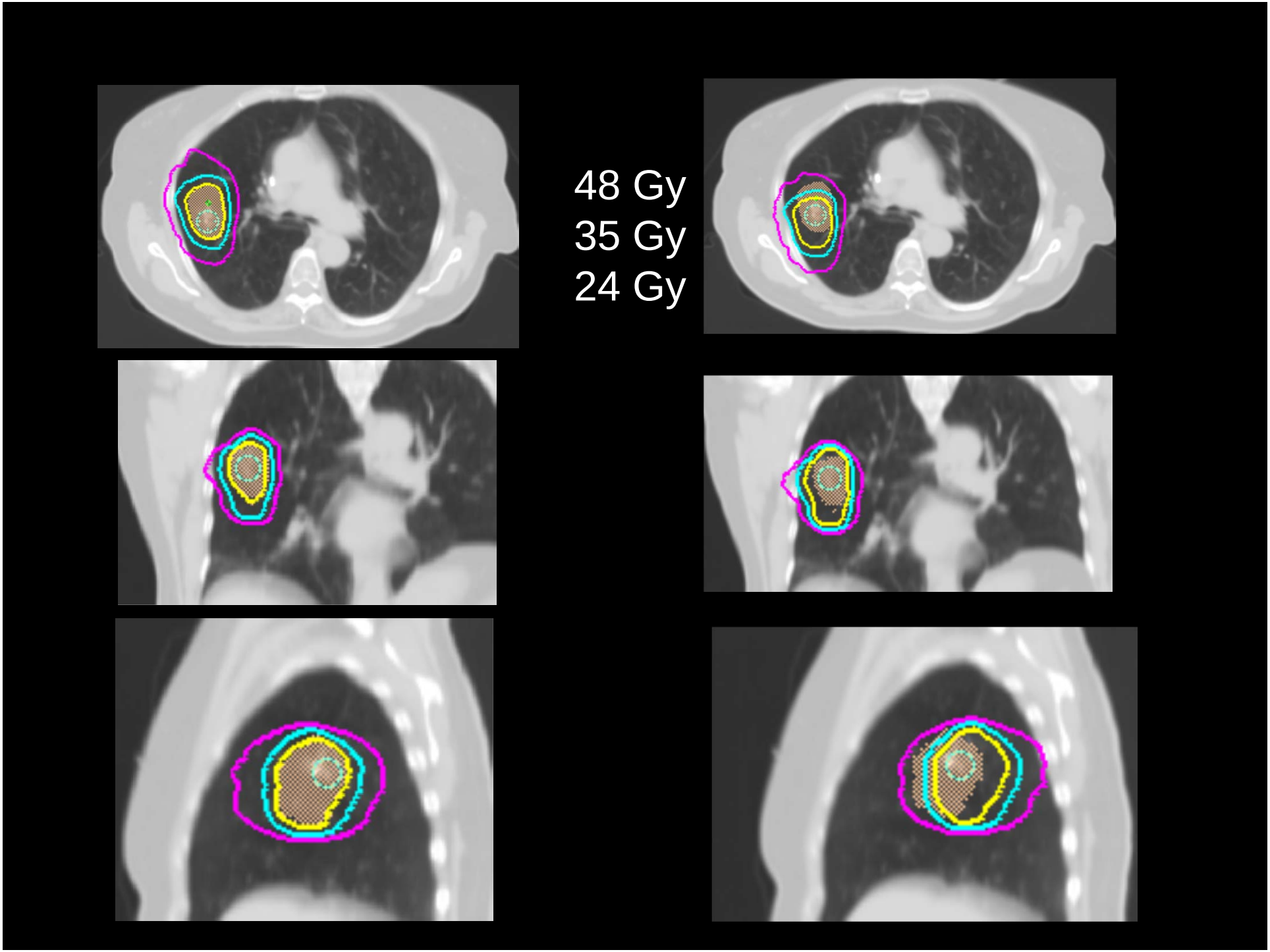
AIP 4/2

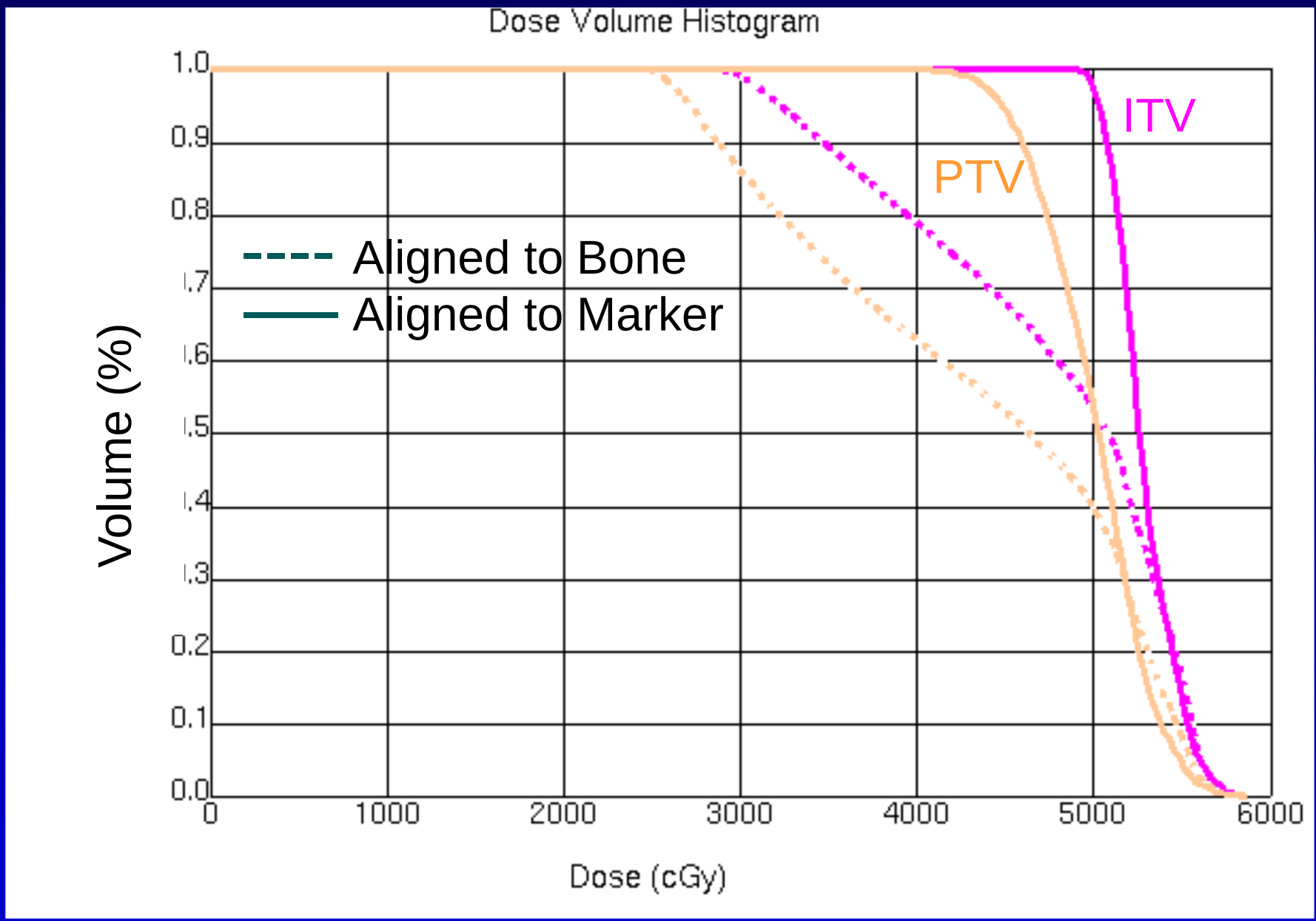




Verify AIP CT aligned
to Planning AIP CT based
on bony anatomy




48 Gy
35 Gy
24 Gy


Dose Volume Histogram
1.0
0.9
0.8
.7
.6
.5
.4
.3
0.2
0.1
0.0
Volume (%)
Aligned to Bone
Aligned to Marker
ITV
PTV
0
1000
2000
3000
4000
5000
6000
Dose (cGy)

4D-KVCBCT

- 

Elekta offers 4D-CBCT to check the reproducibility of breathing pattern on each treatment day

Commercial Available 4D-CBCT

- Implemented in Elekta Synergy Imaging System (XVI)
- 3D-CBCT: 360^0 rotation in 2 minutes (660 projections) with 40 mA tube current.
- 4D-CBCT: 200^0 rotation in 4 minutes (1320 projections with 20 mA tube current.
- Typical imaging dose for 3D-CBCT is 1-2 cGy compared to 6 cGy in 4D-CBCT

Thengumpallil, et. al. JACMP, vol 17 (2016)

4D-CBCT

- Provide a means to check changes in breathing patterns
- Improve CBCT image quality for patients with large breathing motion or for tumor located near diaphrame
- Potential phase shifts if the respiratory cycle is measured using a different device or method.
- Prolonged acquisition time.

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Int J Radiat Oncol Biol Phys. 2007 December 1; 69(5): 1634–1641.

Online target position localization in the presence of respiration: a comparison of two methods

Geoffrey D. Hugo, Ph.D., **Jian Liang, Ph.D.**, **Jonathan Campbell, B.S.**, and **Di Yan, D.Sc.**
Department of Radiation Oncology, William Beaumont Hospital, Royal Oak, MI, USA

Method (1): 4DCT aligned to 4D-CBCT
Method (2) : AIP-CT aligned to 3D-CBCT

Conclusions: Two methods are equivalent.
The second method is easy to implement.

Sweeney et al. Radiation Oncology 2012, 7:81
http://www.ro-journal.com/content/7/1/81

REVIEW Open Access

Accuracy and inter-observer variability of 3D versus 4D cone-beam CT based image-guidance in SBRT for lung tumors

Reinhart A Sweeney, Benedikt Seubert, Silke Stark, Vanessa Homann, Gerd Müller, Michael Flentje and Matthias Guckenberger*

- 21 consecutive patients treated with SBRT for early stage lung cancer.
- Use end of exhalation phase as the planning CT
- 4D-CBCT improved the accuracy of image-guidance by more precise target localization.

Comparing Three IG Methods

- 3D CBCT is manually aligned to ITV from the planning CT (IG-ITV)
- The end-exhale 4D-CBCT is aligned to the planning CT based on soft-tissue (IG-4D).
- AIP 3D-CBCT is automatically aligned to the planning CT based on soft-tissue (IG-3D)

Summary

- 4D-CT is useful to understand the profile of the intra-fraction tumor motion.
- Using abdominal compression, or breath-hold treatment to minimize intrafraction motion.
- Under CBCT guidance, using free breathing CT may introduce a mis-alignment if directly aligning to the tumor or implant markers.
- AIP CT is a better choice as planning CT under CBCT IGRT.

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