Motion management and IGRT

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NEW YORK PROTON CENTER

Motion evaluation: quantification

- Water Equivalent Thickness (WET) statistical analysis:

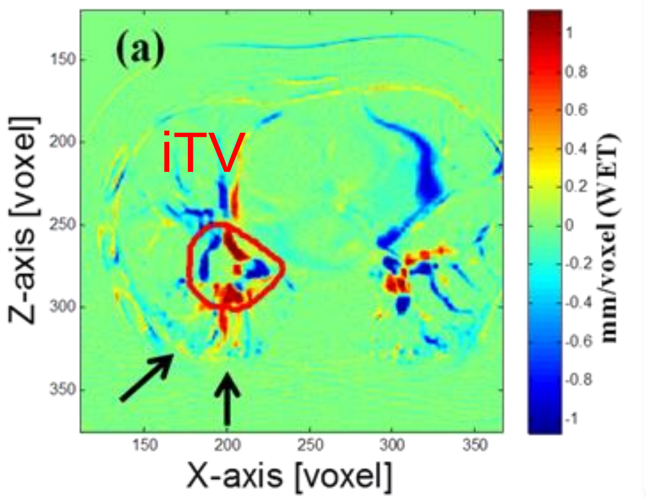
  CT0(inhale)-CT50(exhale)

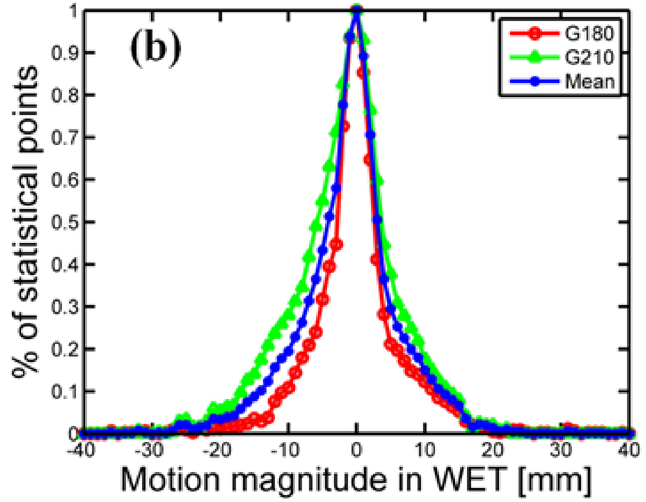
$$\Delta \mathrm{WET}_{x,y,z} = \int_{\mathrm{skin}}^{\mathrm{Depth}} \Delta \mathrm{rsp}(x,y,z)\,dz \qquad (1)$$

$$\Delta \mathrm{rsp}(x,y,z) = \left(\frac{\rho_m}{\rho_w}\frac{\overline{S_m}}{\overline{S_w}}\right)_{\mathrm{CT0}} - \left(\frac{\rho_m}{\rho_w}\frac{\overline{S_m}}{\overline{S_w}}\right)_{\mathrm{CT50}} \qquad (2)$$

Target Motion:

quasi-Gaussian distribution

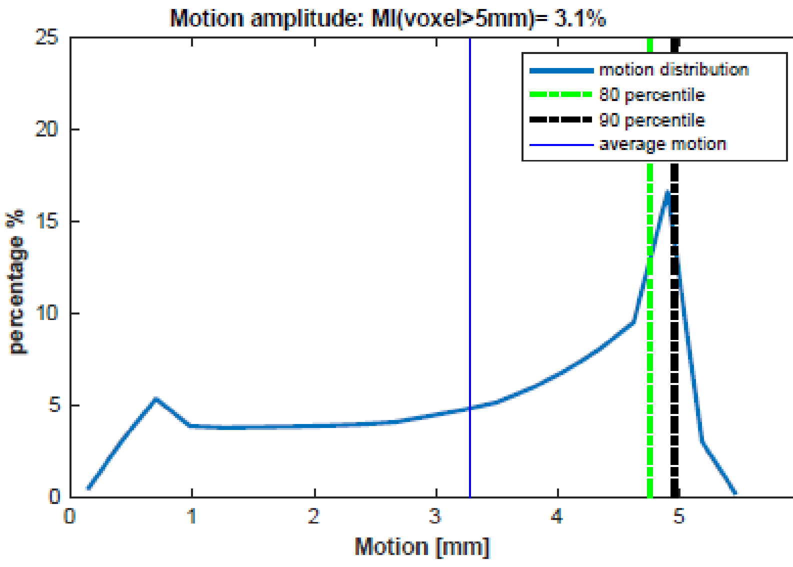


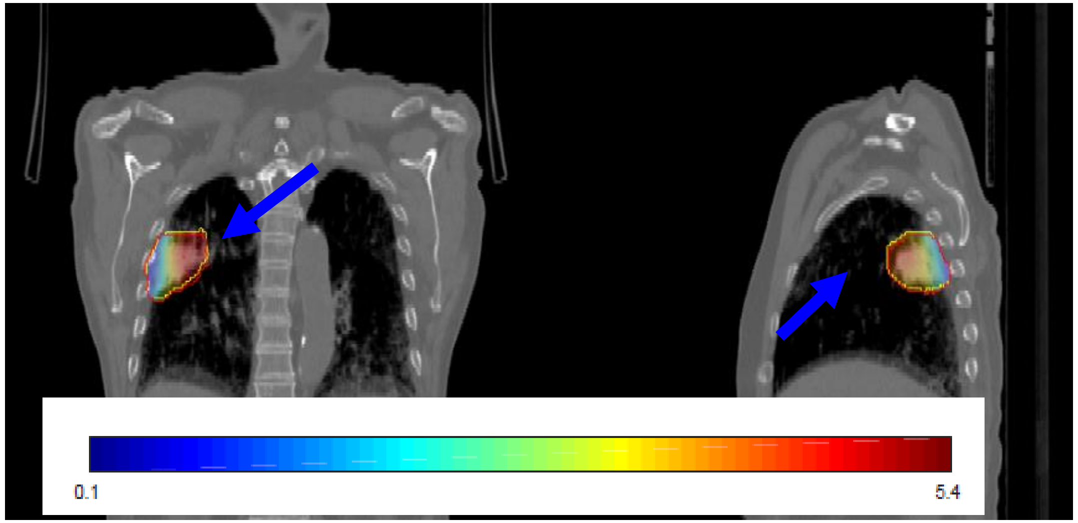


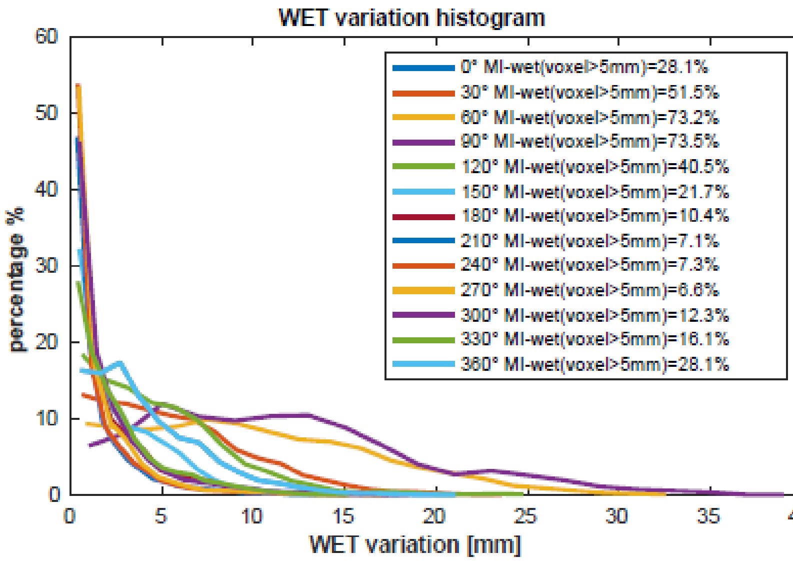
Kang, Lin and Simeone 2nd, et al., Acta Oncologica, 2017

Motion evaluation: tools

- **Fast motion evaluation**
  - Deformable registration to obtain WET map between inhale and exhale
  - Calculate the target WET variation against beam angles
  - Beam angle optimization
  - Better estimation tumor motion amplitude allowing treat very large motion tumor based on WET histogram







Kang, Lin and Simeone 2nd, et al., Acta Oncologica, 2017

Motion evaluation: tools

- ❑ Fast motion evaluation
- ❑ Geometry motion and WET histogram

Motion analysis

Target volume increase (ITV vs.CTV) : 8%

Target center motion [mm] : 0.1 (left-right), 0.9 (ant-post), 2.6 (sup-inf), 2.7 (3D)

Average motion [mm] : 0.4 (left-right), 1.2 (ant-post), 3 (sup-inf), 3.3 (3D)

Maximum motion [mm] : 0.8 (left-right), 2.8 (ant-post), 5.1 (sup-inf), 5.4 (3D)

80-percentile motion [mm] : 0.6 (left-right), 1.5 (ant-post), 4.5 (sup-inf), 4.8 (3D)

90-percentile motion [mm] : 0.7 (left-right), 1.8 (ant-post), 4.7 (sup-inf), 5 (3D)

Geometry motion amplitude

Average WET variation [mm] : 4.1 (0°), 5.7 (30°), 10 (60°), 12 (90°), 4.8 (120°), 2.7 (150°), 2.1 (180°), 1.5 (210°), 1.5 (240°), 1.7 (270°), 2.1 (300°), 2.5 (330°), 4.1 (360°)

Maximum WET variation [mm] : 21.4 (0°), 24.1 (30°), 33.3 (60°), 39.8 (90°), 25.3 (120°), 18.3 (150°), 17.7 (180°), 13.7 (210°), 15.2 (240°), 17.3 (270°), 18.9 (300°), 15.5 (330°), 21.4 (360°)

80-percentile WET variation [mm] : 6.5 (0°), 9 (30°), 15.6 (60°), 17.2 (90°), 7.5 (120°), 4.8 (150°), 3.5 (180°), 2.4 (210°), 2.4 (240°), 2.6 (270°), 3.3 (300°), 4 (330°), 6.5 (360°)

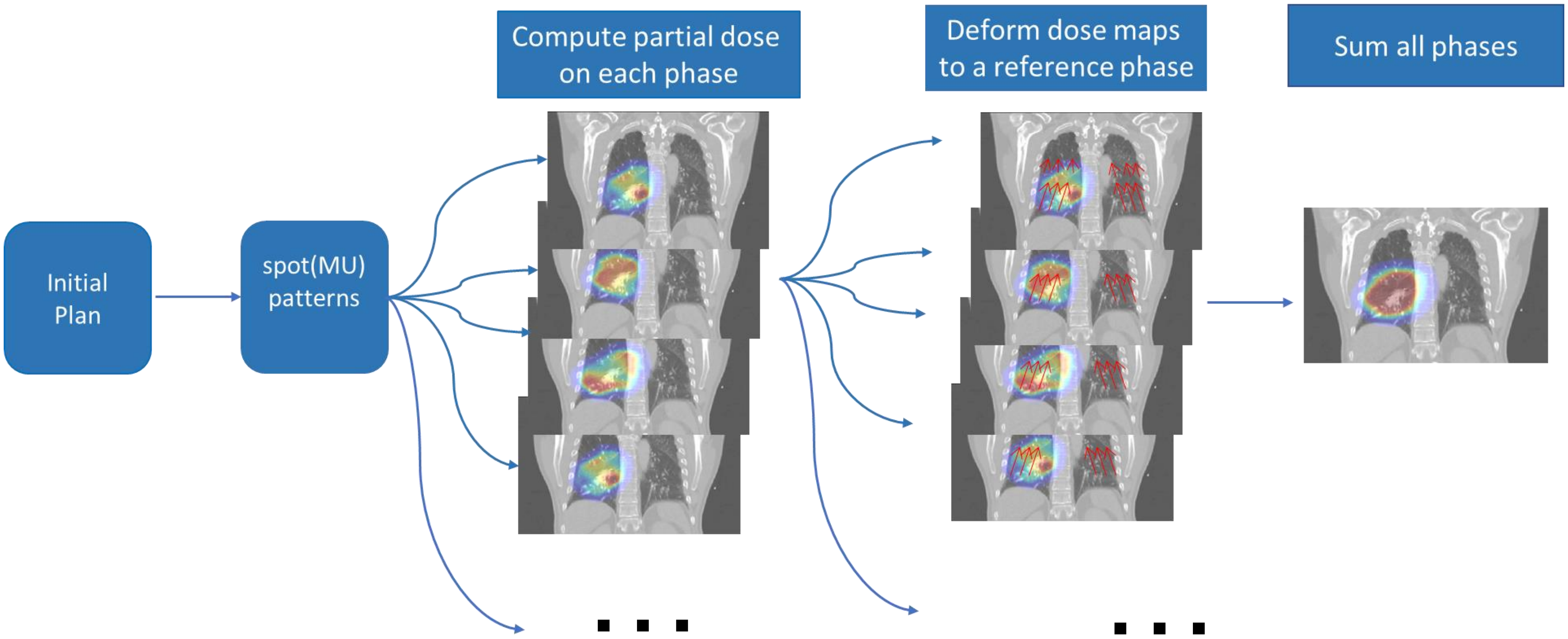
90-percentile WET variation [mm] : 8.4 (0°), 11.5 (30°), 19.2 (60°), 22.4 (90°), 9.7 (120°), 6.3 (150°), 5.5 (180°), 4 (210°), 3.9 (240°), 4.1 (270°), 5.4 (300°), 6.1 (330°), 8.4 (360°)

WET motion amplitude

Lin, Souris, Kang, et al., Medical Physics, 2017

Motion evaluation: tools

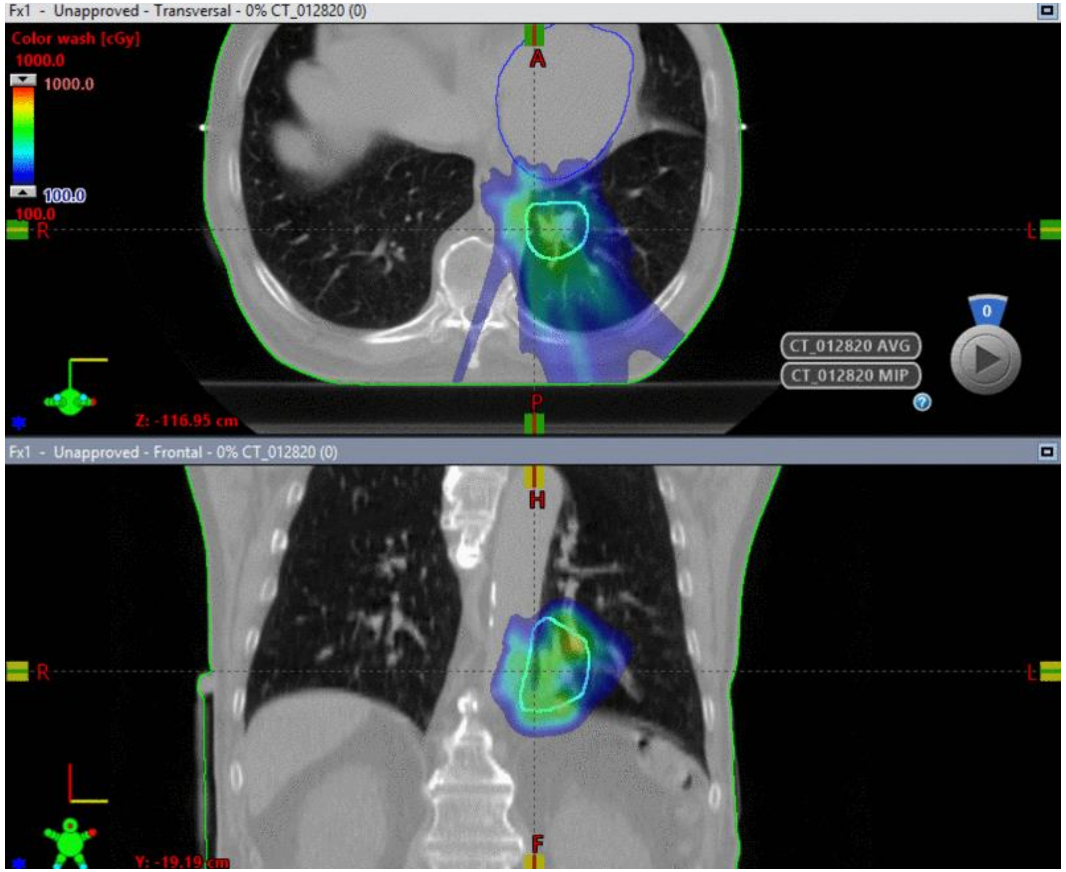
❑ 4D dynamic dose(4DDD)



Lin, Souris, Kang, et al., Medical Physics, 2017
Kang, Lin and Simeone 2nd, et al., Acta Oncologica, 2017

Motion evaluation: tools

- 4D dynamic dose(4DDD)

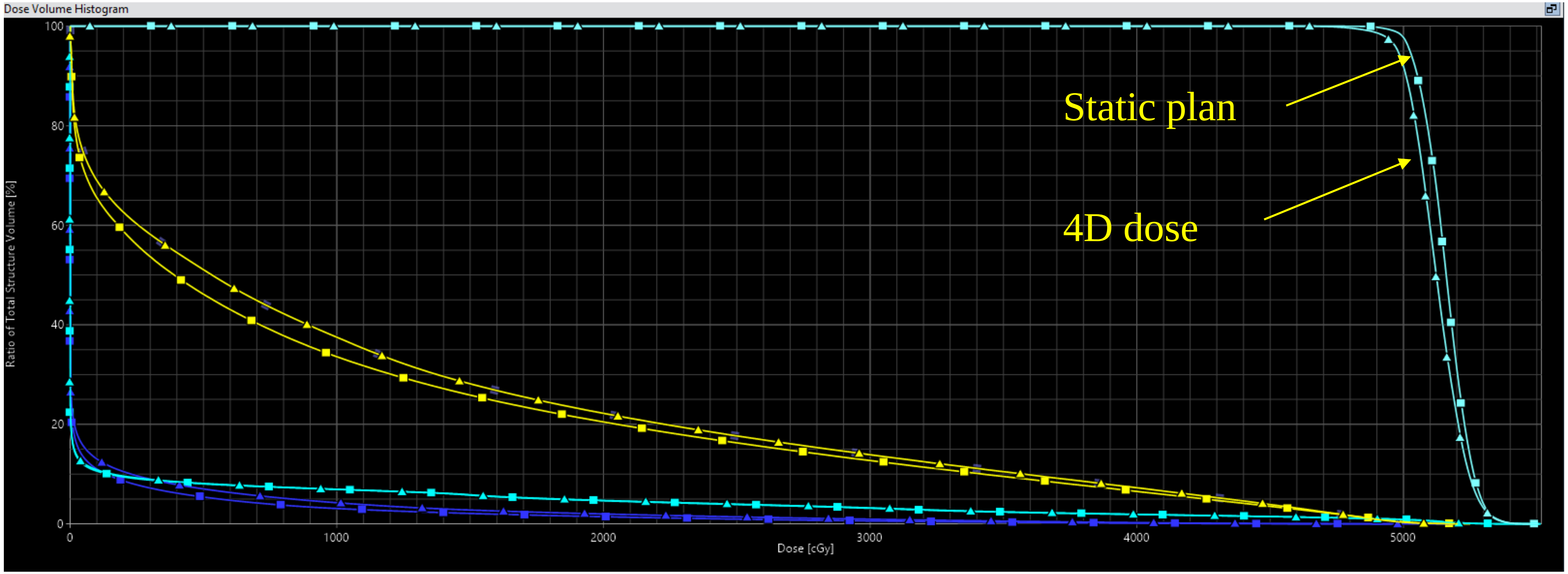


Spot dose to each phase

4D dose sum

Motion evaluation: tools

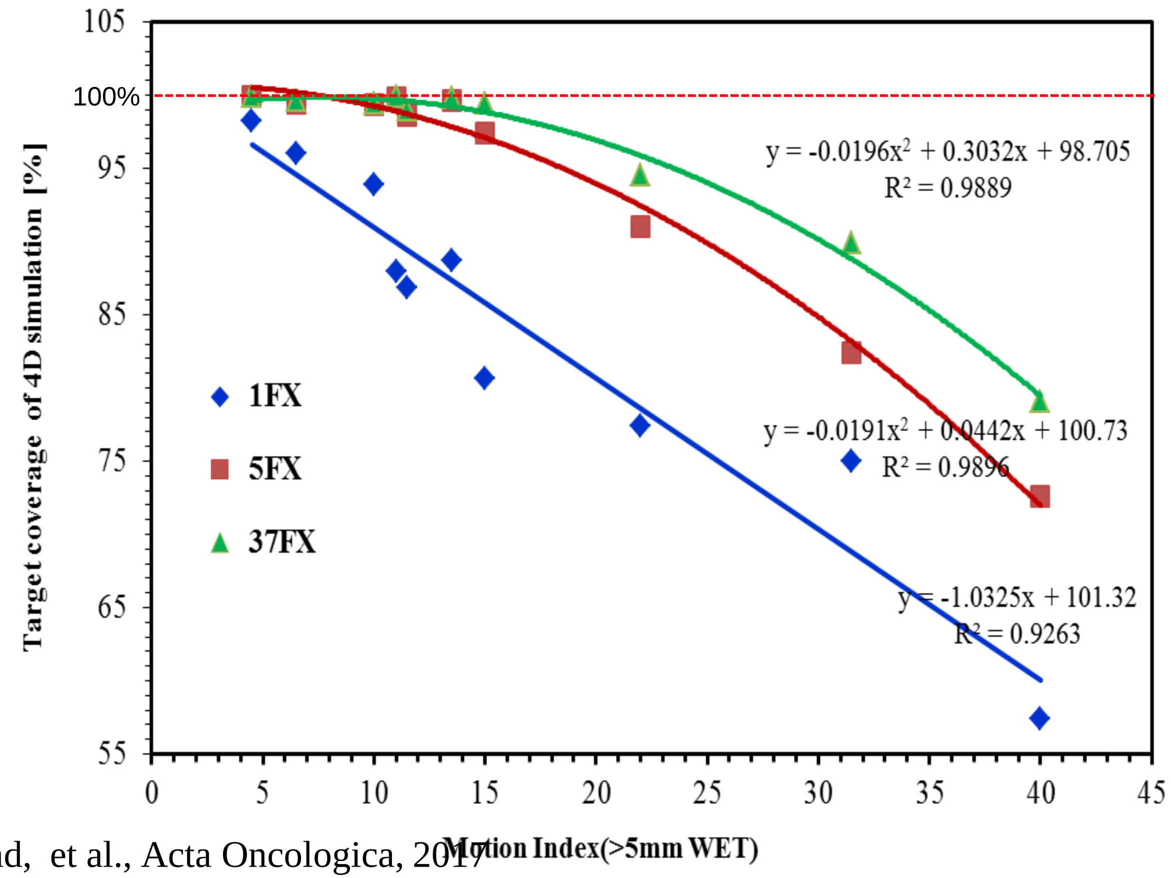
- 4D dynamic dose(4DDD)



Motion evaluation: motion vs. dose coverage

❑ Lung

- ➢ Target coverage : the percentage of the lung ITV receiving the prescription dose. The original static plans have ~ 100% coverage.
- ➢ The magnitude of target underdose in single fraction plans is proportional to the MI (>5 mm WET)



Kang, Lin and Simeone 2nd, et al., Acta Oncologica, 2017

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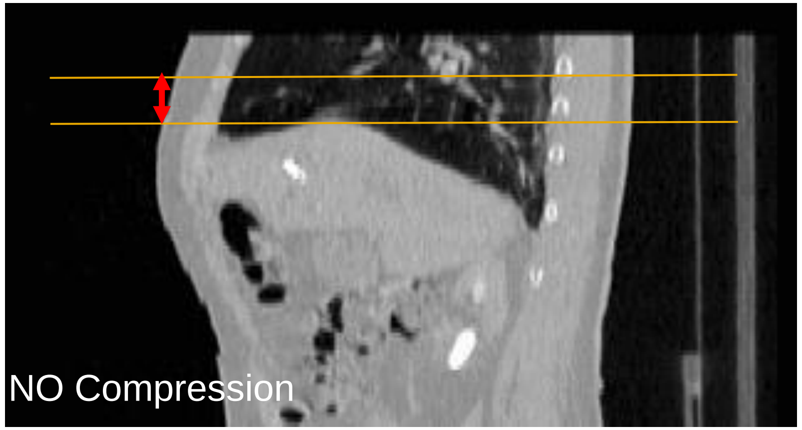
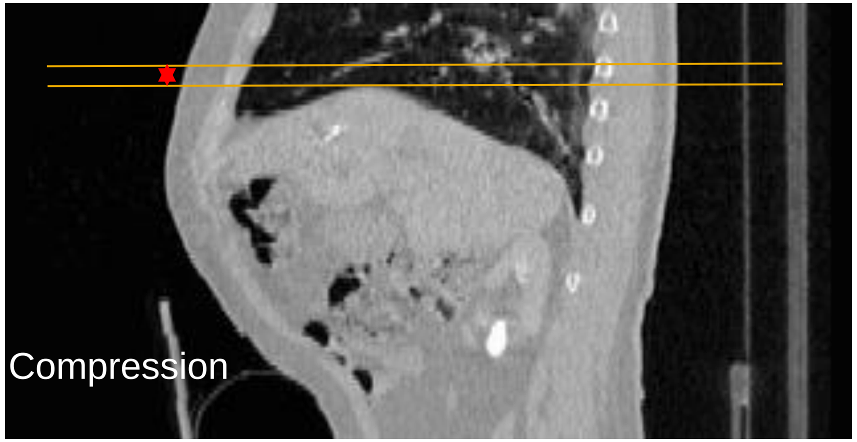
Motion mitigation

- **Three common ways for motion management**
  - Add motion margin – iCTV, ITV
  - Restrict the motion amplitude – abdominal compression
  - Breath hold techniques – SDX

- **Motion during treatment is important for spot scanning. Other motion mitigation approaches:**
  - Rescanning or re-painting: delivery the same beam multiple times
  - Use “big” spot with large air gap

Motion mitigation: abdominal compression



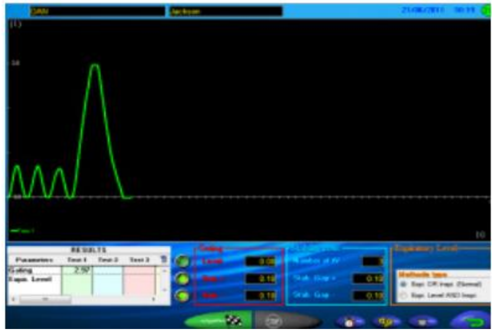


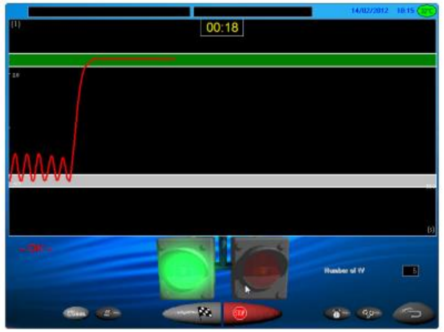
Lin, Souris, Kang, et al., Medical Physics, 2017

Motion mitigation: breath hold

❑ SDX

- A small **clip** is placed on the patient's nose to avoid accidental breathing through the nose. Treatment machine is only on while the patient is holding their breath (**voluntary**)
- Diaphragmatic motion is limited

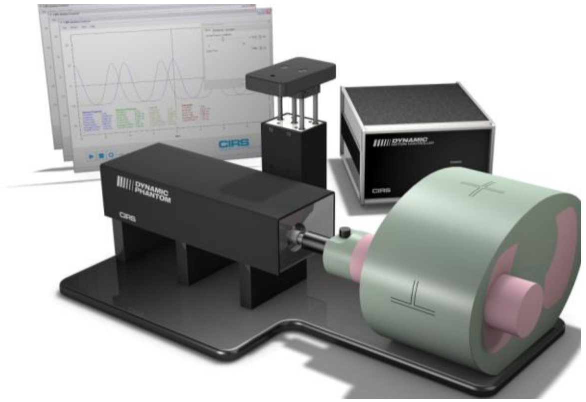




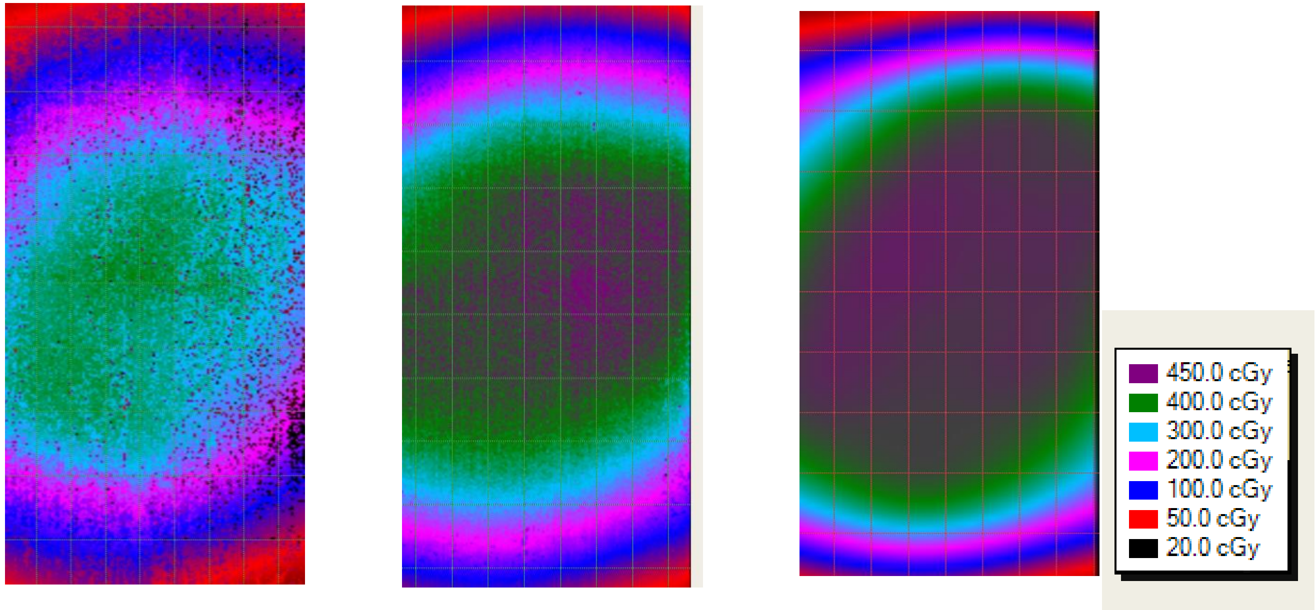
- The patient breathes freely through the spirometer until instructed to take a full inspiration.
- The SDX calculates a target inspiration zone, which is a percentage of the patient's maximum inspiration capacity. This ensures the patient can comfortably maintain repeated breath holds of 20- 25 seconds. The result is a repeatable breath hold, taken with the same inspiration volume every time.

PBS for moving target: re-painting

- Re-painting experimental study
  - S-I motion amplitude: **10 mm**
  - Breathing period: 5 seconds



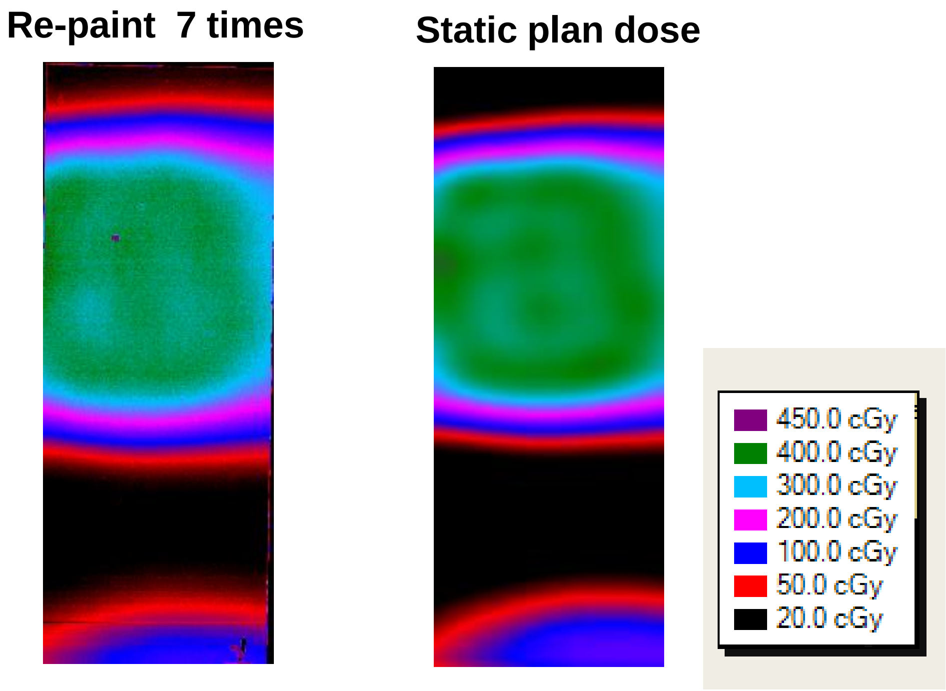
Single delivery **Re-paint 3 times** **Static plan dose**



PBS for moving target: re-painting

❑ Re-painting experimental study

- S-I motion amplitude: 15 mm
- Breathing period: 5 seconds

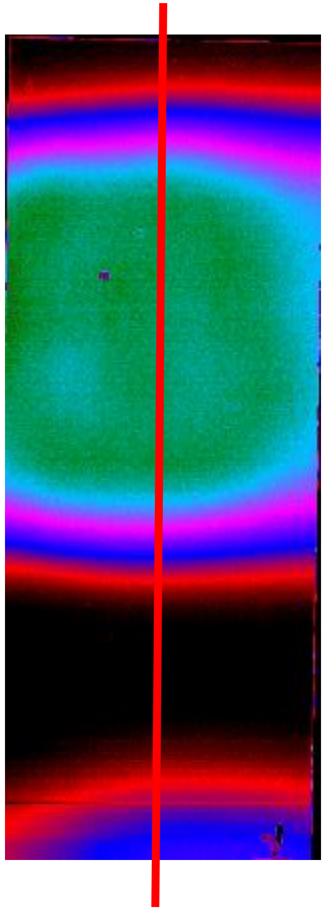


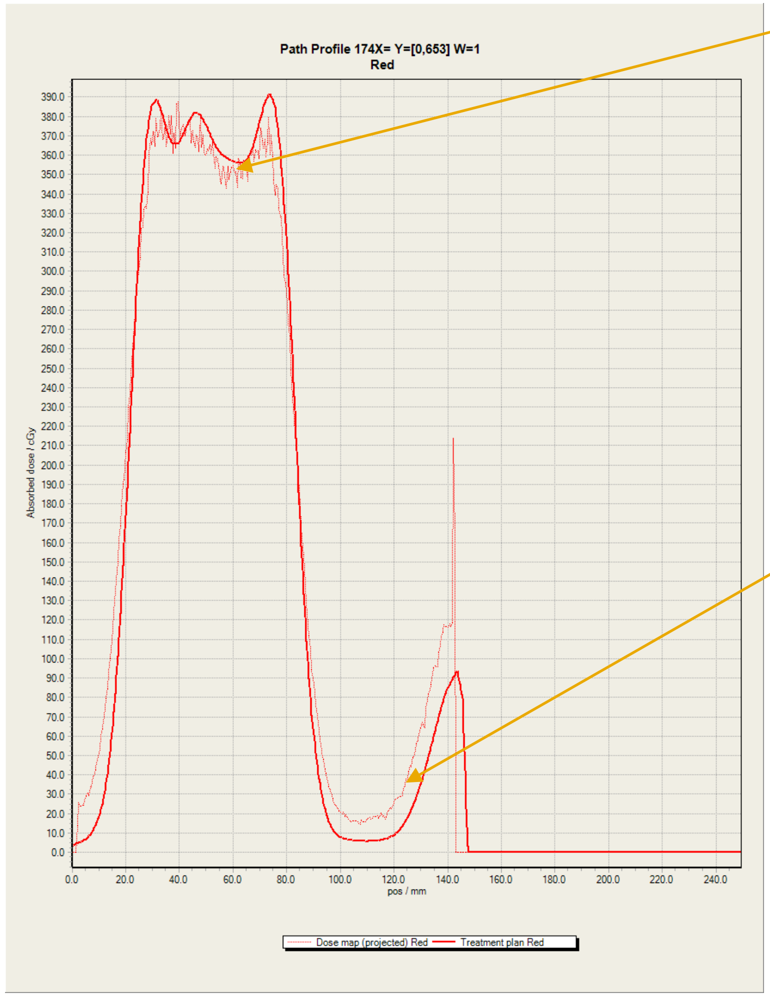
- **Due to very large motion, the measured dose distribution has blurring edge compared to the planning dose.**

PBS for moving target: re-painting

❑ Re-painting experimental study

- S-I motion amplitude: 15 mm
- Breathing period: 5 seconds



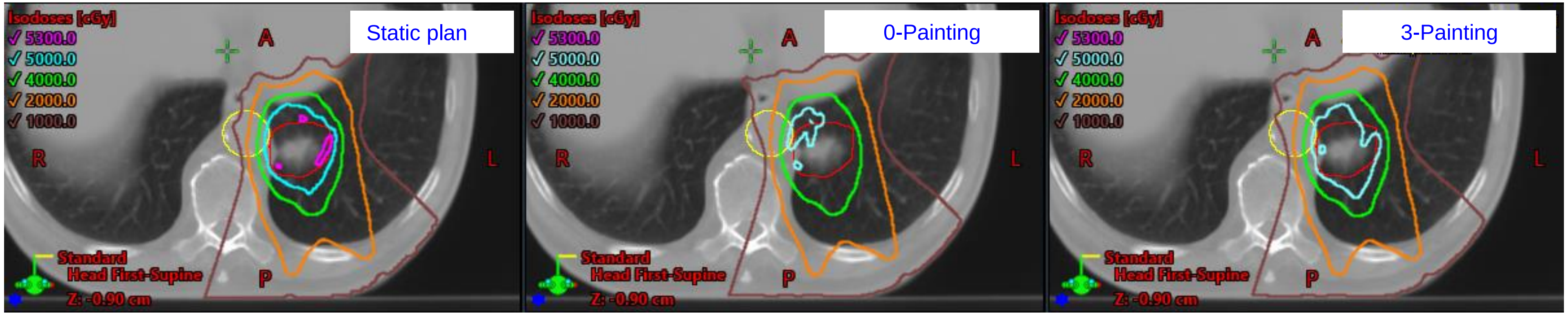


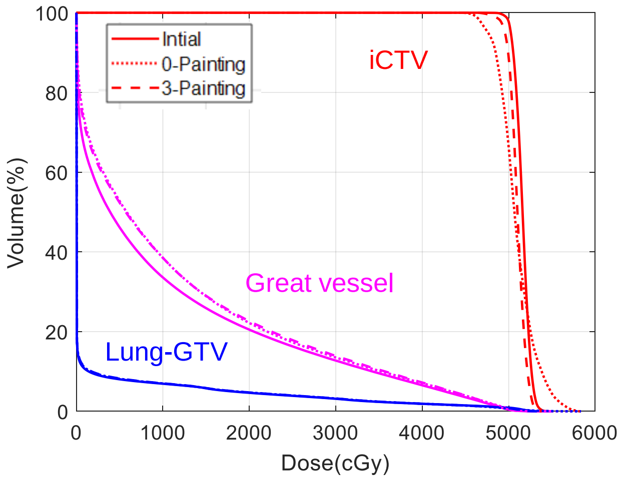
Due to 15 mm motion in SI direction, the measured dose got reduced for the target area.

The low dose area dose increased.

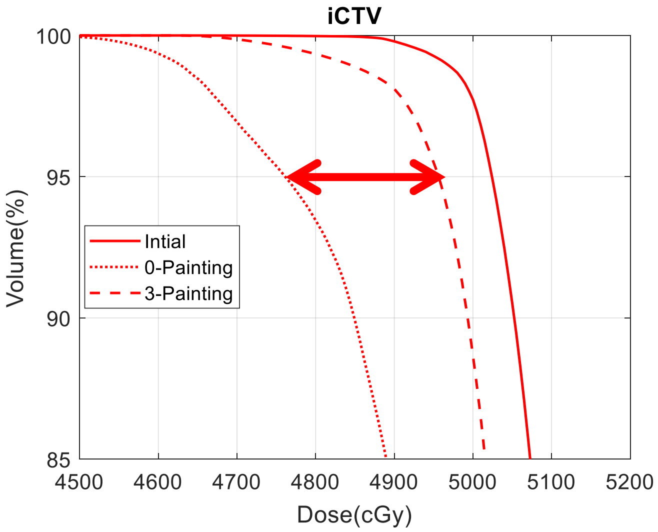
Motion evaluation: tools

❑ 4D dynamic dose(4DDD): Lung SBRT re-painting



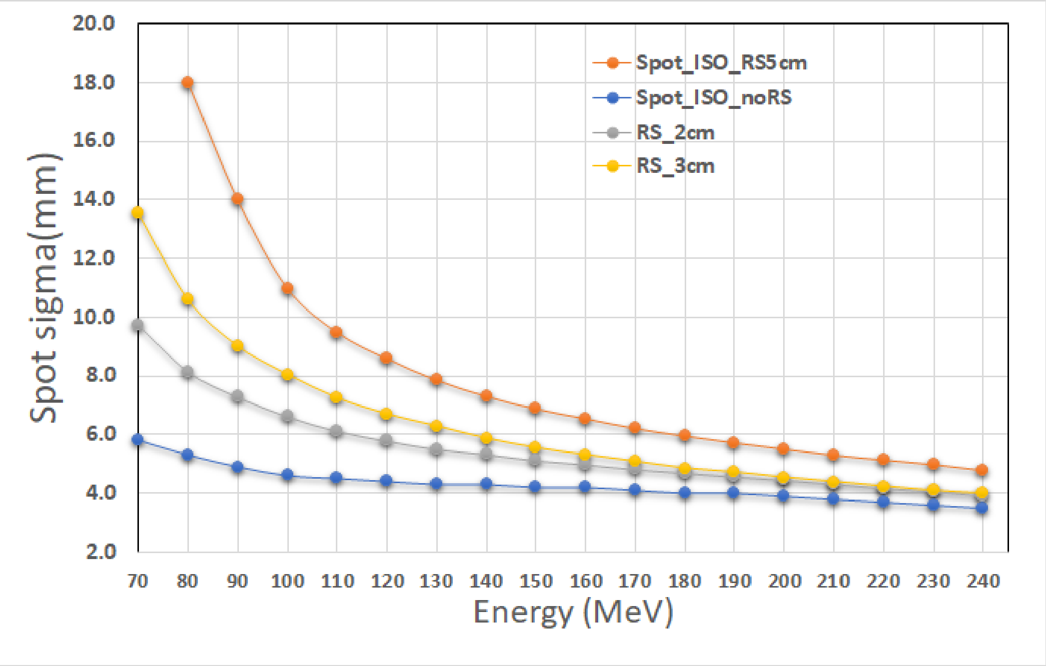


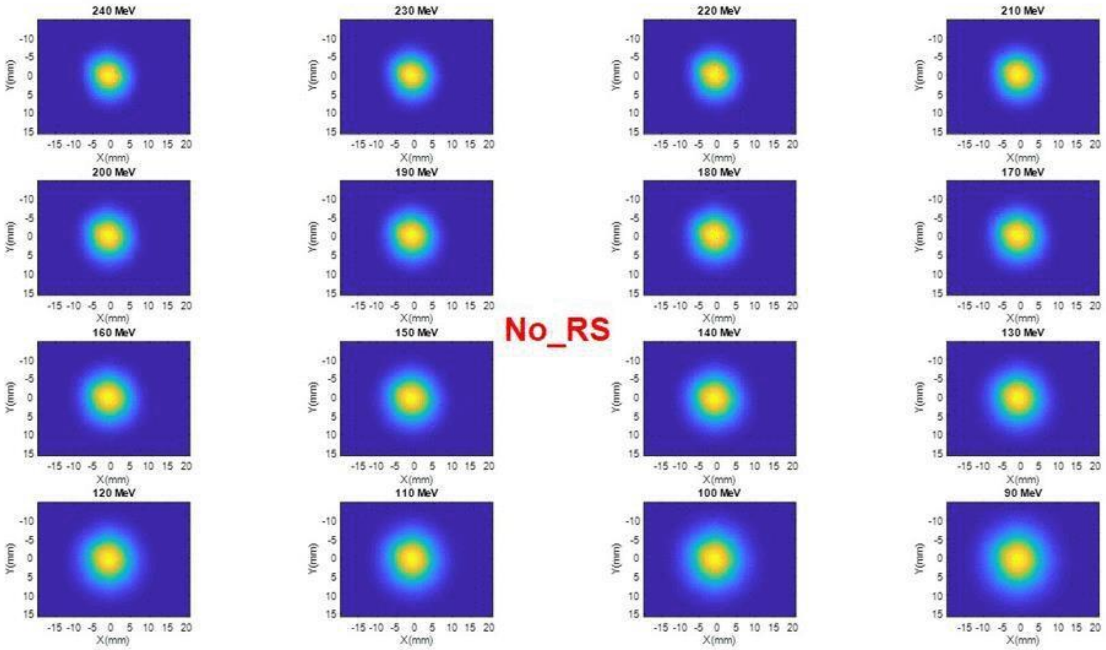
3-painting: D95 was increased from 47.6Gy to 49.6Gy



Motion mitigation: larger spot size

- ❑ ProBeam system has 3 range shifters(RS) with different thicknesses
- ❑ With changeable spot size when beam passing through different RS
- ❑ Spot size increases with air gap

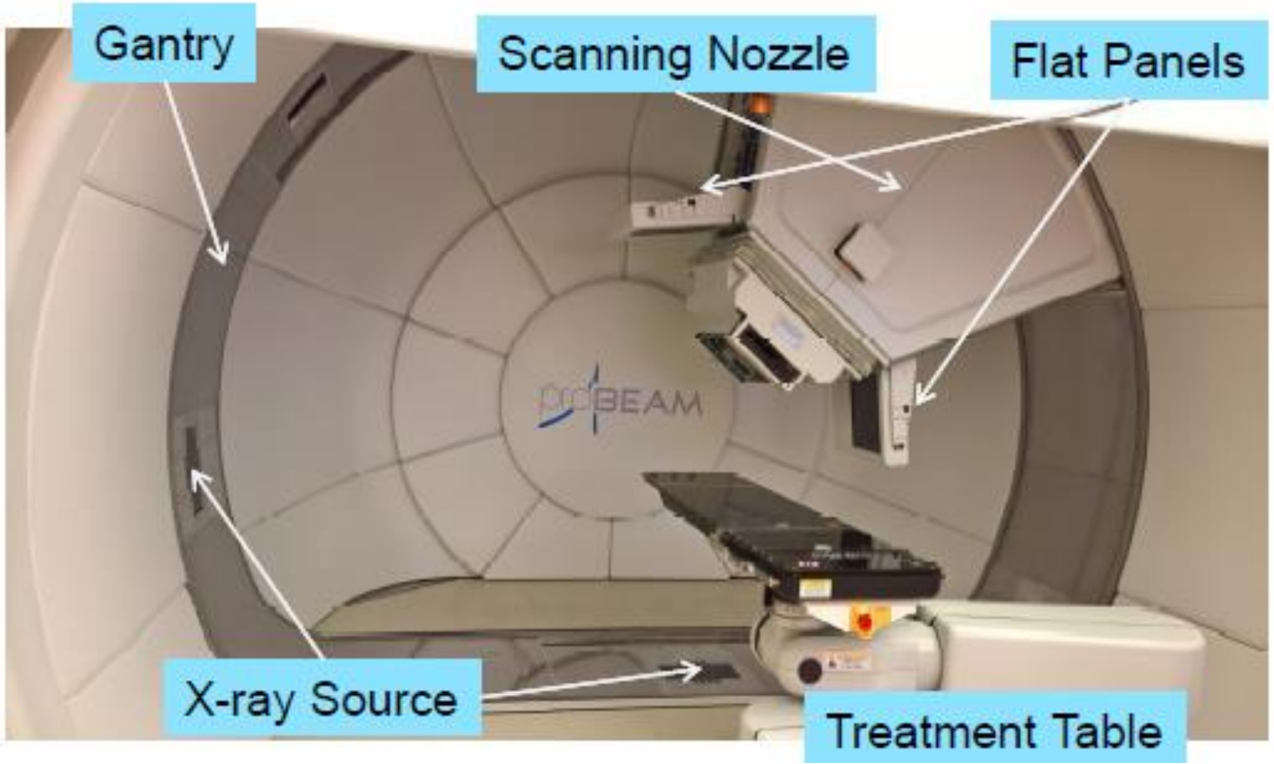




IGRT

- kV-kV bony alignment
  - Bony and Carina

- Daily CBCT
  - Target and soft tissue



IGRT

- kV-kV bony alignment
  - Bony and Carina
- Daily CBCT for target soft tissue
  - Target and soft tissue
- **3 mm** in CBCT alignment for SBRT

Xiong W. Internal training slides

Questions?

Thank you for your attention!