PPRIG Proton Physics Workshop 3

# Testing The Effect of Breathing Variability on Proton Therapy Plans and Motion Mitigation Techniques


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# Aim of the study

- To study the influence of interplay effect in spot scanning method in proton therapy
- To investigate the influencing parameters which alter the dose distribution
- To study the effects of the motion variability on the motion mitigation techniques

Background

# Lung Cancer and Conventional Radiotherapy

- Lung Cancer
  - Most common cancer around the world
  - 12.9% of new case diagnosed
- Radiotherapy
  - Medically inoperable, surgically inresectable disease or advanced lesions
  - Poor overall survival, due to high local relapse rate and development of metastasis
  - Dose to critical organs are high, limiting the dose to tumour

Background

# Proton Therapy

- Well-defined Bragg Peak
- Normal tissue beyond the range can be spared
- Active spot scanning
  - A series of narrow, nearly monoenergetic pencil beams in a single layer
  - Altering energy layer by layer

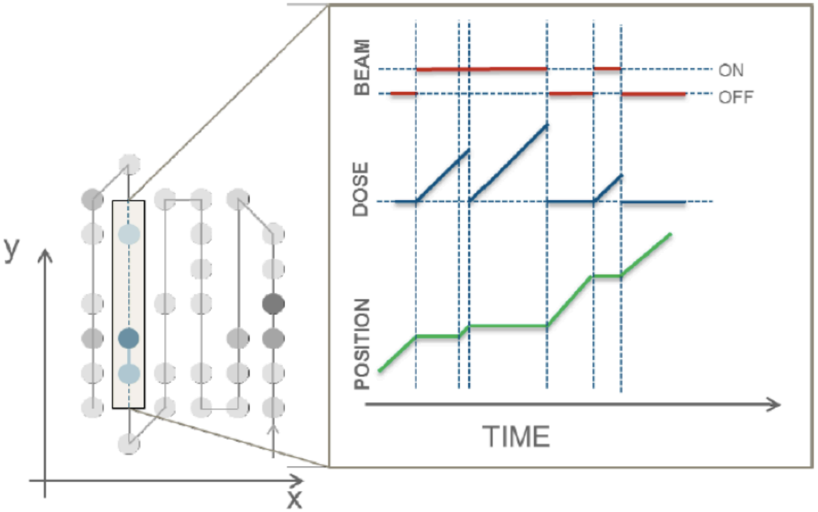
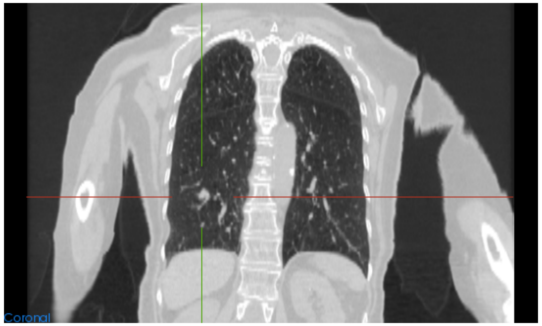


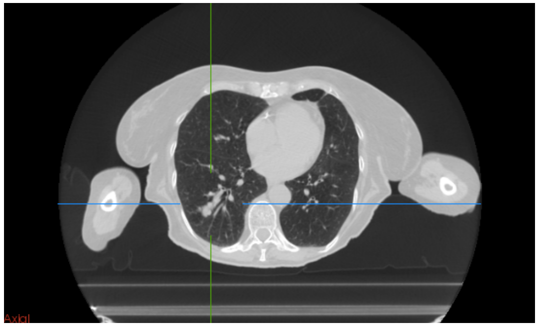

Figure source: Varian ProBeam™ System User Menu

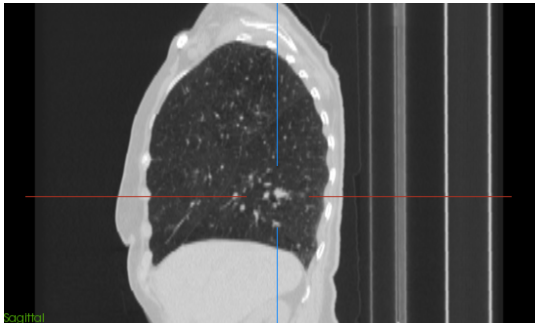
## Background

# Lung Motion

- The position change due to respiration can be ranging from 7 mm to 38.2 mm in supine position
- 40% of the lung tumor moved more than 5mm







Background

# Interplay Effect

- Targets move during irradiation, which causes the intrafractional motion uncertainty

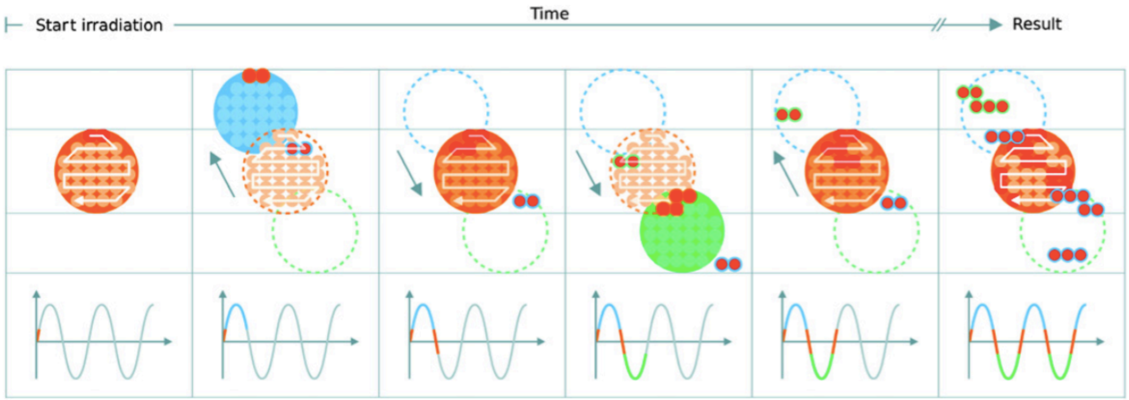



Figure source:
Bert et.al, 2008

- Decreases both the conformity and homogeneity
- May be smoothed out after all 30-35 fractions
- Severe impact on hypofractionation treatment

Background

# Rescanning Methods

- Scanning the treatment fields several times per fraction, with decreased weighting for each scan
- Statistical averaging of the interplay effect
- Three rescanning strategies used:
  - Layered rescanning
  - Volumetric rescanning (without gantry angle repetition)
  - Volumetric rescanning (with gantry angle repetition)

Background

# Problems in Current Proton Therapy Planning

- Current Management
  - Based on photon therapy treatment
  - Target volume is contoured on the MIP images of 4DCT
  - Doses are calculated and evaluated on the AVG images of 4DCT
- Problems
  - Neglecting the interplay effect
  - Hiding the “realistic” dose
  - Leading to under-dosage of target / over-dosage in critical organs

## Background

# Respiratory Motion Model

- Measuring the displacement of internal anatomy using deformable image registration
- Approximating the relationship between the internal motion and the surrogate signal
- Predicting a new cine CT volume image set corresponding to the chosen respiratory parameters

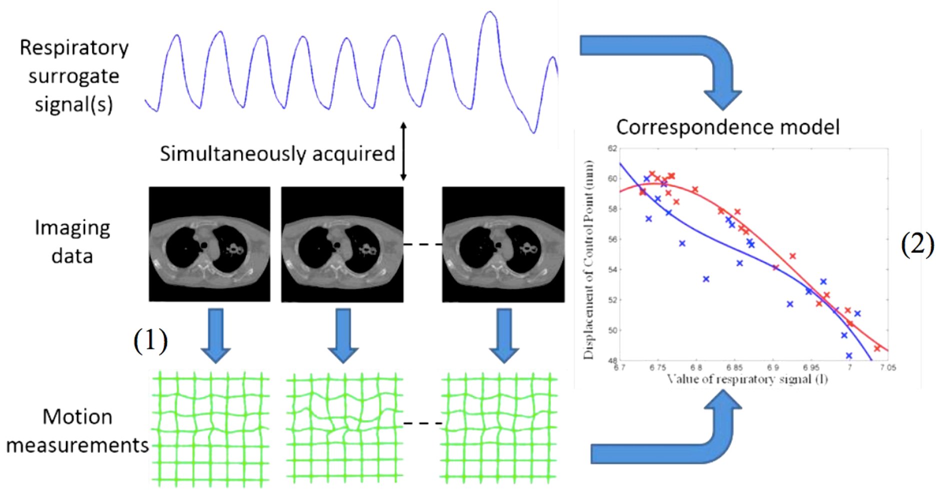
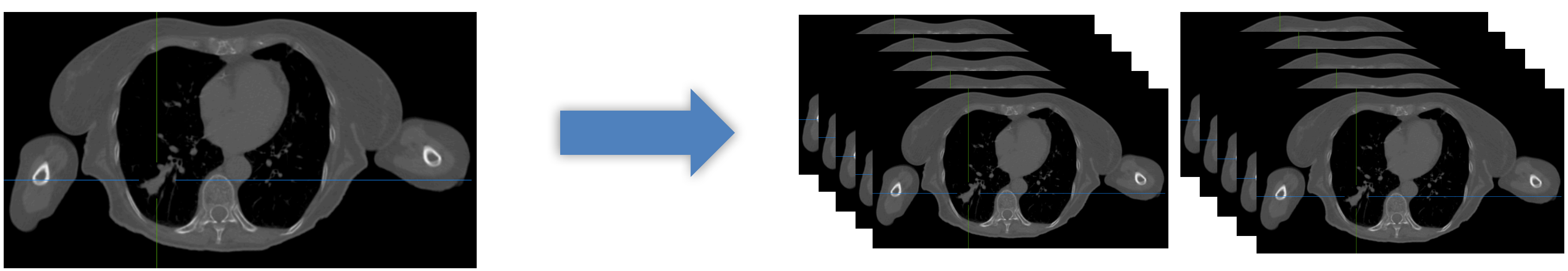



Figure source: McClelland, 2011

## Methods and Materials

# CT Image Generation

- One set unsorted 4DCT images and corresponding surrogate signal was obtained from UCH
- A B-spline transformation model developed by CMIC, UCL was employed
- 10 equal phases of artifact-free CT images, together with the deformation map, were generated



Methods and Materials

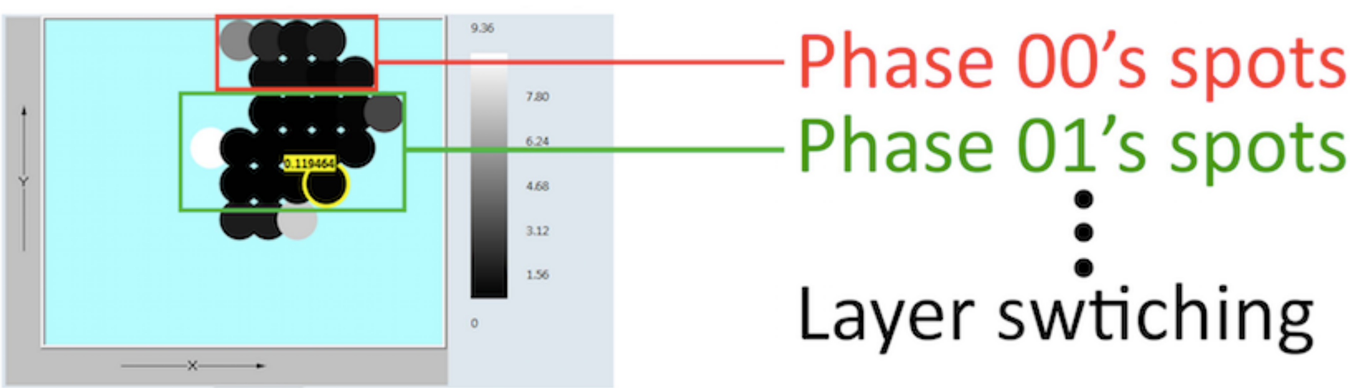
# Treatment Plan Generation

- GTV was contoured in MIP CT images, overriding with 70HU
- OARs were contoured on AVG CT images
- Prescription: 70Gy in 35fr
- Three-field arrangement, equal in weighting
- Single Field Optimization

## Methods and Materials

# Scanning Spots Distribution

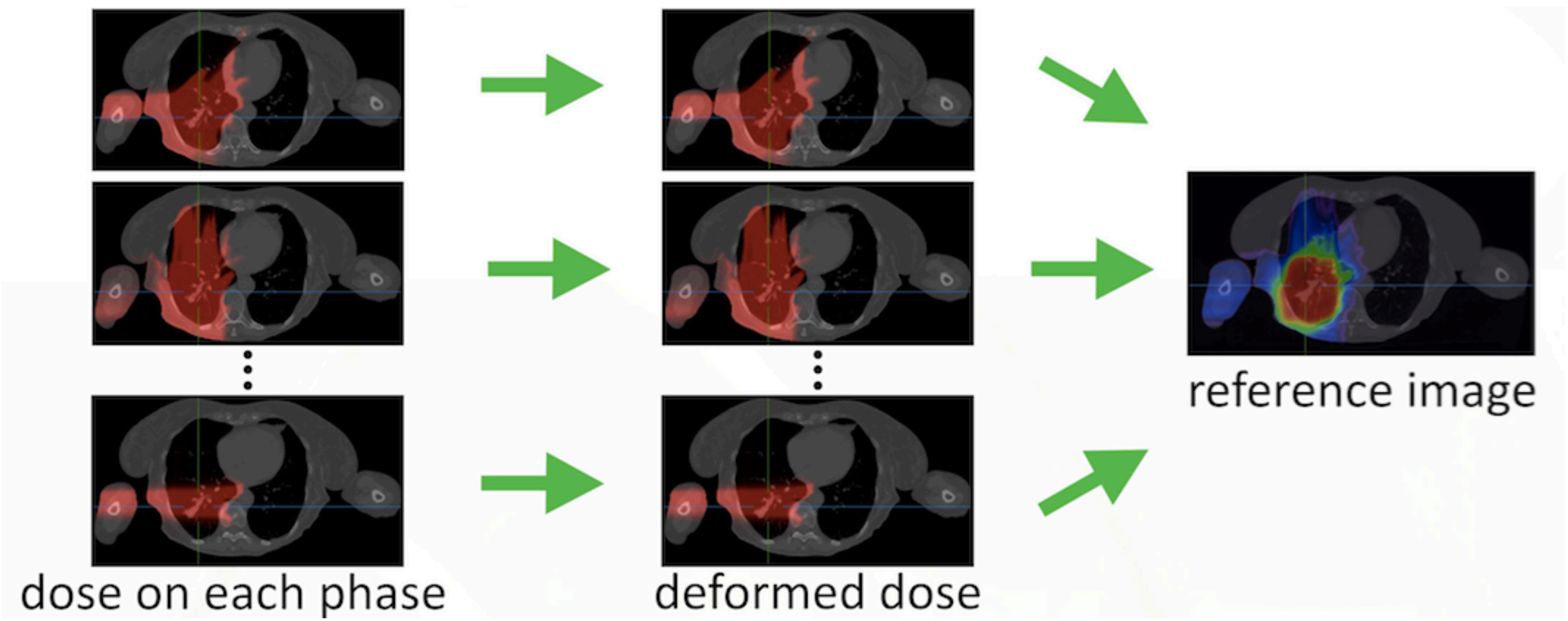
- All the weighted spots were partitioned in to different phases, according to their sequences and duration
- Layer switching time and Gantry rotation time included
- Assumption:
  - Breathing cycle was 4s
  - No time gap between spots
  - Delivery started at phase 0



## Methods and Materials

# Scanning Spots Distribution

- Doses were recalculated on each phases
- Calculated doses were deformed on the reference image
- Accumulative dose was shown on reference image

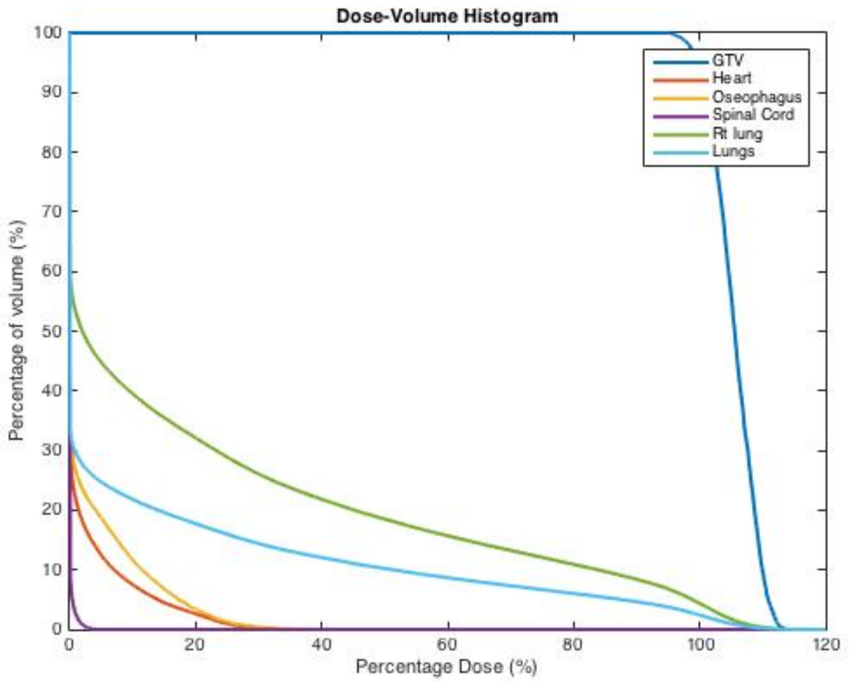


## Methods and Materials
# Analysis Methods

- Target Volume
  - D1-D99, D5-D95
  - Homogeneity index

$$H_d = 1 - \frac{1}{\bar{D}}\sqrt{\frac{\sum_i (D_i - \bar{D})^2}{N-1}}$$

- Critical Organs
  - Spinal cord
    - Max dose
  - Lungs
    - V5, V20



## Methods and Materials

# Various Scenarios

| Scenario | | Purpose |
|---|---|---|
| 1 | Nominal dose distribution | Demonstrating the dose distributions generated by routine clinical planning method |
| 2 | Dynamic Dose<br>(No rescanning) | Demonstrating the interplay effect on the 4DCT |
| 3 | Rescanning<br>3a – layer rescanning<br>3b – volumetric rescanning<br>(Without gantry angle repetition)<br>3c – volumetric rescanning<br>(With gantry angle repetition) | Demonstrating the interplay compensation on the CT, when simple rescanning strategies was employed |

## Results

# Target Doses

| Scenario | | D1-D99 | D5-D95 | Max | Min | Hom.Ind |
|---|---|---|---|---|---|---|
| Nominal dose | | 11.830 | 8.280 | 113.524 | 96.889 | 0.976 |
| Dynamic dose | | 15.111 | 11.198 | 113.563 | 95.569 | 0.967 |
| Rescanning 2 times | Layered | 14.582 | 10.843 | 113.015 | 94.860 | 0.968 |
| | Volumetric | 11.955 | 8.643 | 111.449 | 98.070 | 0.974 |
| | Volumetric (RGA) | 10.991 | 8.871 | 107.958 | 94.723 | 0.971 |
| Rescanning 3 times | Layered | 14.486 | 10.982 | 112.627 | 94.893 | 0.968 |
| | Volumetric | 6.067 | 4.475 | 106.450 | 99.111 | 0.987 |
| | Volumetric (RGA) | 11.979 | 9.700 | 117.249 | 102.565 | 0.972 |

*All are in percentage of prescribed dose of 70Gy

## Results

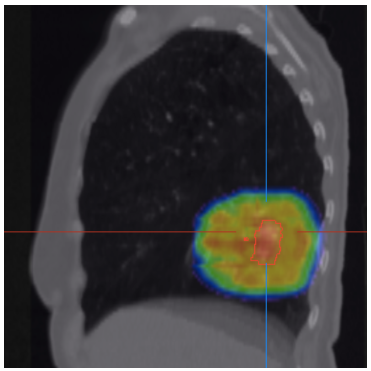
# Critical Organ Dose

| Scenario | | Body_Max | Spine_Max | lungs_V5 | lungs_V20 |
|---|---|---|---|---|---|
| Nominal dose | | 113.600 | 4.017 | 22.977 | 14.016 |
| Dynamic dose | | 118.529 | 4.247 | 23.289 | 14.757 |
| Rescanning 2 times | Layered | 118.525 | 4.275 | 23.306 | 14.788 |
| | Volumetric | 112.522 | 4.298 | 23.275 | 14.891 |
| | Volumetric (RGA) | 112.253 | 4.227 | 23.480 | 14.955 |
| Rescanning 3 times | Layered | 119.578 | 4.261 | 23.349 | 14.803 |
| | Volumetric | 112.040 | 4.301 | 23.366 | 14.774 |
| | Volumetric (RGA) | 117.645 | 4.319 | 23.210 | 14.511 |

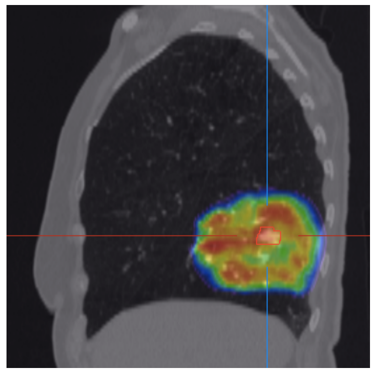
*Body_Max and Spine_Max are in percentage of prescribed dose of 70Gy
*Lungs_V5 and V20 are in percentage of lung volume

## Results

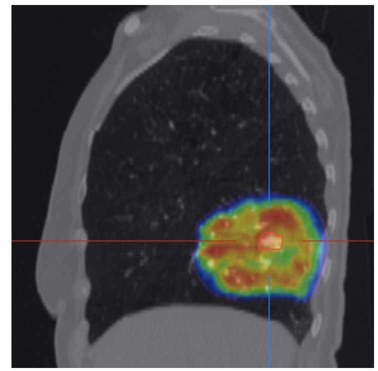
# Dose Distribution



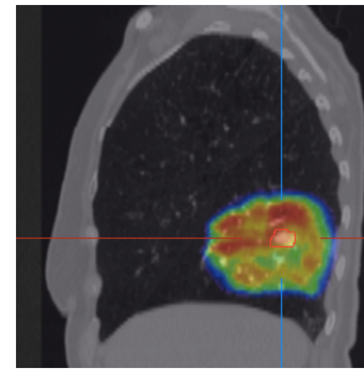
Nominal



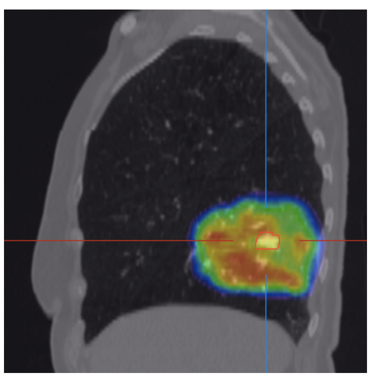
Dynamic



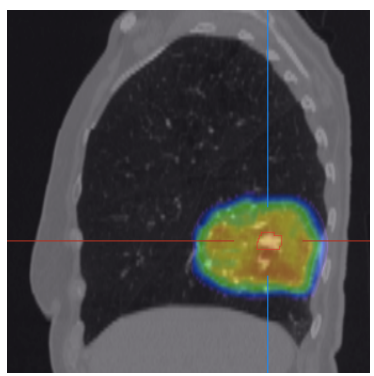
2x Layered rescanning



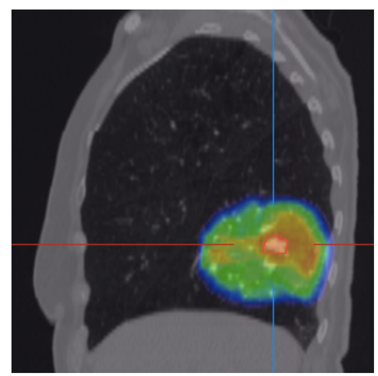
3x Layered rescanning



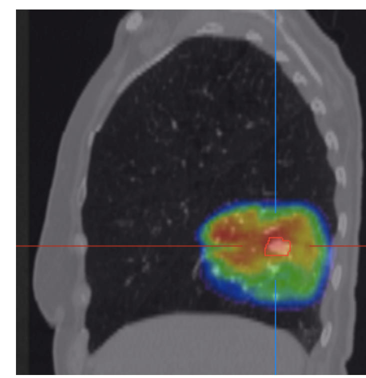
2x Volumetric rescanning



3x Volumetric rescanning



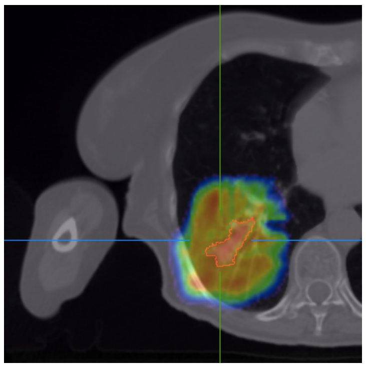
2x Volumetric rescanning (RGA)



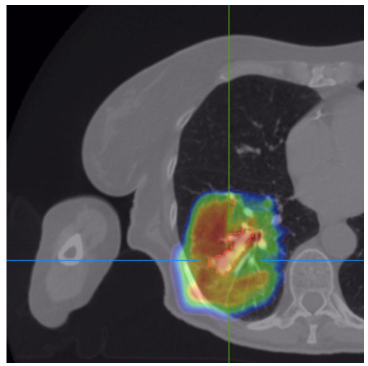
3x Volumetric rescanning (RGA)

## Results

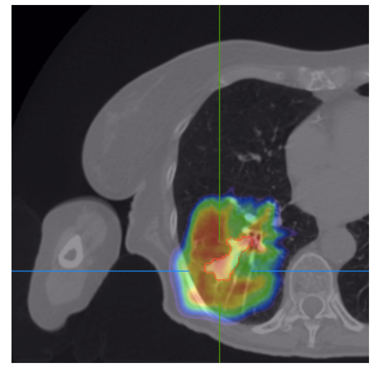
# Dose Distribution



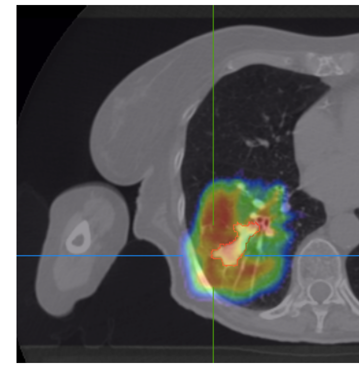
Nominal



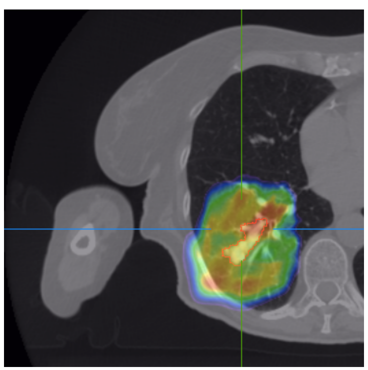
Dynamic



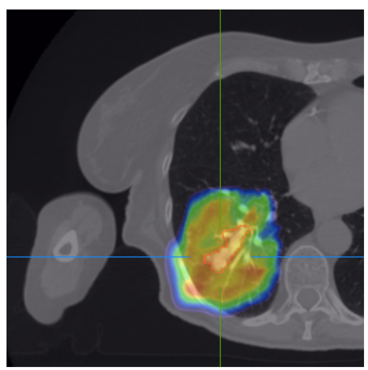
2x Layered rescanning



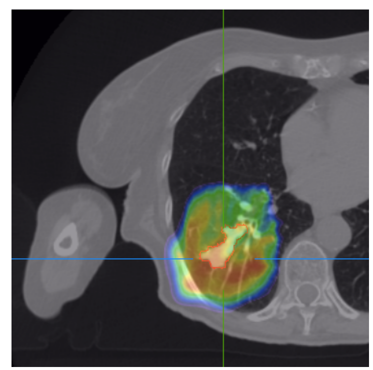
3x Layered rescanning



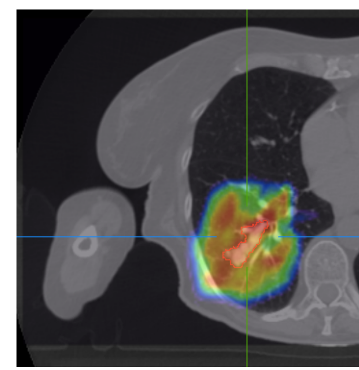
2x Volumetric rescanning



3x Volumetric rescanning



2x Volumetric rescanning (RGA)



3x Volumetric rescanning (RGA)

Discussion

# Realistic Dose

- Dynamic dose was shown when the time parameter was considered
- The interplay effect was not as large as expected in the experiment
  - Most of the energy layers were delivered within a single phase of image
  - Fast scanning of the new Varian system greatly reduced the interplay effect
  - Multiple beams – a kind of rescanning

Discussion

# Rescanning Methods

- Layered rescanning didn't improve the interplay effect
  - Fast beam delivery and no time gap between each spots, only a little change in the distribution of spots
- Volumetric rescanning improved the dose homogeneity
  - Extra layer switching time and gantry rotation time were added during distribution of spots
  - The spots with decreased weighting were distributed in more phases, and thus statistically averages out the interplay effect

# Limitation

- Only one set of patient data was employed
  - More data sets will increase the robustness of both motion model and treatment planning strategy
- Reproducible breathing assumed
- Assuming that the first spots was delivery at the beginning of breathing phase 0
  - Never perfectly achieved in clinical situation
- Dose rate of proton therapy is fluctuating during the beam delivery
  - corrected the dose rate for each spots accordingly

# Conclusion

- Interplay effect decrease the homogeneity of the proton therapy plans
- Novel motion model was used to generate artifact-free CT image and deform the doses
- Fast delivery of scanning spots can reduce the interplay effect
- If the treatment plan is good enough, and the beam delivery is fast, the interplay effect may not cause large impact in dose distribution

# Thank You