AAPM Spring Clinical Meeting 2015
Treatment Planning Fundamentals:
Lung Cancer

Indrin J. Chetty
Henry Ford Health System, Detroit MI
Disclosure

My department receives research support from:

- NIH/NCI
- Varian Medical Systems
- Philips HealthCare
Learning Objectives/Outline

To review the fundamentals of treatment planning for lung tumors, including motion management and margin assessment, planning strategies, the physics of lung dose calculations, and the interplay effect.
Managing motion and forming planning margins
The number of datasets used to create the ITV will impact the planning margin.

Axial view:
- 4 phases
- 10 phases
- 2 phases

Coronal view:
- 10 phases
- 2 phases
- 4 phases
Does abdominal compression help reduce motion?

*Heinzerling et al, IJROBP 70(5):1571–1578, 2008*

**Note:** *high compression force* approx 90N, or approx 22 pounds, reduced diaphragm sup-inf motion from approx. 15 mm to 8 mm on average – *S/I motion reduced to less than 1 cm in most cases.*
## Margins: what is being done in the field?

<table>
<thead>
<tr>
<th>Institution</th>
<th>ITV</th>
<th>CTV (mm)</th>
<th>PTV (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$\text{GTV}_1 \cup \text{GTV}<em>2 \cup \ldots \cup \text{GTV}</em>{10}$</td>
<td>ITV + 5</td>
<td>CTV + 5 (IGRT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CTV + 10 (no IGRT)</td>
</tr>
<tr>
<td>B</td>
<td>$\text{GTV}$ from MIP</td>
<td>ITV</td>
<td>SBRT: ITV + 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>STD Fx: ITV + 10</td>
</tr>
<tr>
<td>C</td>
<td>$\text{GTV}_1 \cup \text{GTV}_2 \cup \ldots \cup \text{GTV}_4$</td>
<td>SBRT: ITV</td>
<td>CTV + 6 (IGRT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STD Fx (no 4D): GTV + 10</td>
<td>CTV + 5 (no IGRT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STD Fx (4D): ITV + 5</td>
<td>CTV + 10 (no IGRT)</td>
</tr>
<tr>
<td>D</td>
<td>$\text{GTV}$ from MIP or expected percentiles (gating)</td>
<td>SBRT: ITV</td>
<td>CTV + 5 (IGRT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>STD Fx: ITV + 5</td>
<td>CTV + 7 (no IGRT)</td>
</tr>
</tbody>
</table>

Adapted from “Lung Panel”, Kestin et al. ASTRO State of the Art Meeting, 2011
Soft-tissue visualization with CBCT

Planning CT/CBCT alignment

Correction of systematic shifts

Purdie et al. (PMH)
Red Journal ’07
Daily CBCT reduces margins for locally advanced lung CA

Less-than-daily CBCT-based IG protocols incurred ≥ 5mm residual setup errors in 20–43% of fractions; daily IG reduced this to 6% (n=100) [Higgins et al. (PMH) Red Journal, 2011]

Table 5. Population-based setup margins using van Herk margin recipe (2.5Σ + 0.7σ)

<table>
<thead>
<tr>
<th>Imaging protocol</th>
<th>ML</th>
<th>CC</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>No IG</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>First 5-day IG</td>
<td>7</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Weekly IG</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Alternate day IG</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Daily CBCT reduces margins for SABR/SBRT

(a) margins needed if localization was based on the skin tattoos
N = 150

(b) margins needed based on residual errors after CBCT alignment

Courtesy: E. Mayyas, PhD: Henry Ford Hospital
1. According to an article by Higgins et al. on the use CBCT imaging for localizing advanced stage lung tumors, which of the following statements is True?

A. With CBCT imaging for only the first 5-days of treatment, margins were reduced to less than 5 mm.
B. With weekly CBCT imaging, margins were reduced to less than 5 mm.
C. With daily CBCT imaging, margins were reduced to less than 5 mm.
D. With alternate day CBCT imaging, margins were reduced to less than 5 mm.
E. With no CBCT imaging margins were less than 3 mm.
According to an article by Higgins et al. on the use of CBCT imaging for localizing advanced stage lung tumors, which of the following statements is True?

20% 1. With CBCT imaging for only the first 5-days of treatment, margins were reduced to less than 5 mm.

20% 2. With weekly CBCT imaging, margins were reduced to less than 5 mm.

20% 3. With daily CBCT imaging, margins were reduced to less than 5 mm.

20% 4. With alternate day CBCT imaging, margins were reduced to less than 5 mm.

20% 5. With no CBCT imaging, margins were less than 3 mm.
Answer: 3 - With daily CBCT imaging, margins were reduced to less than 5 mm.

Planning the Treatment
Lung SBRT planning: General Guidelines

Appropriate planning margins and treatment planning techniques following nationally accepted guidelines e.g. RTOG/NRG 0236, 0813, 0915

Planning guidelines:

Use as many beams as possible – greater number of beams results in better target dose conformity and dose fall-off away from the target. Typically use 7 or more beams. More beams = less skin toxicity

Include non-coplanar beam angles

Use “smart” beam angle selection
The block (BEV) margin for SBRT: small or none

- 7 non-coplanar beams
- Hotter hotspot in tumor with 0 mm BEV margin vs larger margin
- Steeper dose falloff in lung
- Lower NTCP

<table>
<thead>
<tr>
<th>Margin (mm)</th>
<th>Lung case NTCP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>2.5</td>
<td>9</td>
</tr>
<tr>
<td>0.0</td>
<td>5</td>
</tr>
</tbody>
</table>

Note: relative (not absolute) NTCP values

Courtesy: Brian Kavanagh, MD
2. For a SBRT treatment plan, the optimal distance from the PTV to MLC edge for most cases will be:

A. 0 mm
B. 5 mm
C. 10 mm
D. At the edge of the CTV
E. At the edge of the ITV
SAM’s Question No. 2

For a SBRT treatment plan, the optimal distance from the PTV to MLC edge for most cases will be:

- 0%  1. 0 mm
- 0%  2. 5 mm
- 0%  3. 10 mm
- 0%  4. At the edge of the CTV
- 0%  5. At the edge of the ITV
Ref: Videtic et al. RTOG 0915 (NCCTG N0927) “A randomized phase II study comparing 2 stereotactic body radiation therapy (SBRT) schedules for medically inoperable patients with stage I peripheral non-small cell lung cancer.”
(http://www.rtog.org/ClinicalTrials/) (2009)
Lung SABR planning: what dose algorithm should be used?

Recommendation of AAPM TG Report No. 101 (Benedict et al Med Phys 37: 2010).....Algorithms accounting for 3D scatter (e.g. convolution/superposition) perform adequately in most situations, including (in many cases) under circumstances where there is a loss of e’ equilibrium such as lung/tissue interface or tumor margin in lung medium. Algorithms accounting for better transport, e.g. Monte Carlo are preferred for the most demanding situations, e.g. small, “island-like” tumors. *Pencil beam algorithms are not recommended*....

Minimum field size (3.5 cm) and energy (low X) constraints: RTOG 0236, 0813, 0915
Advanced stage disease: underdosage of the PTV

Comparison of the 100% IDLs, Pencil beam (dashed) and MC (solid)

Data from UMPLan, University of Michigan
Lateral Scattering of electrons in low density lung tissue carries energy/dose away from the tumor

Monte Carlo simulation, 10 MV pencil beam
Small Field Dosimetry: Loss of charged particle equilibrium (CPE)

In narrow field, CPE is lost and dose reduction can be severe
Small field central axis depth dose: slab phantom

“Build down effect” – severe dose reduction caused by scattering of electrons into the lung tissue
Dose builds up in the tumor resulting in underdosage at tumor periphery.
Implications for “island” tumors

“Ring” of underdosage gets larger for smaller tumors (as the tumor size approaches the electron range)
Lung SBRT dose calcs

PTV diam. = 5.2 cm
PTV vol. = 41.0 cc
Dose Volume Histograms (DVHs)

PTV diam. = 5.2 cm; PTV Vol. = 41.0 cc
The Energy Effect

“Ring” of underdosage gets larger with beam energy due to the increased electron range.

Ion chamber measurements: 2x2

ρ = 0.2

ρ = 1.0

“Ring” of underdosage “rebuildup” of dose
The Energy Effect

PTV DVHs (PB vs. AAA), 6 MV
PB: mean = 70.2 Gy
AAA: mean = 68.9 Gy
Diff. in min. PTV dose = 11%

PTV DVHs (PB vs. AAA)
PB: mean = 70.5 Gy
AAA: mean = 64.7 Gy
Diff. in min. PTV dose = 16%
Lung SBRT dose algorithm comparison

135 patients planned w/ 1D-pencil beam (1D-EPL, iPlan) retrospectively replanned using 3D-EPL (Eclipse), AAA (Eclipse), CCC (Pinnacle), Acuros (Eclipse), MC (iPlan)

D95 (of the PTV evaluated relative to 1D-EPL (D95 = 100%) : 12 Gy x 4 Fractions

<table>
<thead>
<tr>
<th>Location</th>
<th>FS (cm)</th>
<th>3D-EPL_D95</th>
<th>AAA_D95</th>
<th>CCC_D95</th>
<th>Acuros_D95</th>
<th>MC_D95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung-island</td>
<td>3≤FS&lt;5</td>
<td>95.1±2.1</td>
<td>80.2±4.3</td>
<td>80.0±6.0</td>
<td>76.6±6.9</td>
<td>79.7±5.9</td>
</tr>
<tr>
<td></td>
<td>5≤FS&lt;7</td>
<td>95.7±1.9</td>
<td>83.0±4.3</td>
<td>82.7±5.4</td>
<td>80.0±5.9</td>
<td>83.0±5.1</td>
</tr>
<tr>
<td></td>
<td>7≤FS&lt;10</td>
<td>92.8±0.3</td>
<td>84.5±0.8</td>
<td>85.3±0.7</td>
<td>83.5±1.2</td>
<td>85.7±1.4</td>
</tr>
<tr>
<td>N=39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung-central</td>
<td>3≤FS&lt;5</td>
<td>94.8±1.8</td>
<td>83.2±5.5</td>
<td>83.3±6.4</td>
<td>81.7±6.9</td>
<td>83.5±5.9</td>
</tr>
<tr>
<td></td>
<td>5≤FS&lt;7</td>
<td>95.3±2.1</td>
<td>86.1±5.8</td>
<td>86.8±6.5</td>
<td>85.0±7.1</td>
<td>86.8±6.1</td>
</tr>
<tr>
<td></td>
<td>7≤FS&lt;10</td>
<td>95.4±1.1</td>
<td>90.7±3.7</td>
<td>90.9±3.9</td>
<td>89.8±3.9</td>
<td>91.3±4.0</td>
</tr>
<tr>
<td>N=52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comprehensive investigation of dose calculation accuracy for lung stereotactic ablative radiation (SABR): Effects of tumor size and location and clinical recommendations

3. For the treatment of small lung tumors located peripherally using SBRT, which dose algorithm will result in a significant underdosage of the tumor relative to the tumor dose prescription:

A. Convolution
B. Superposition/Convolution
C. Monte Carlo
D. Acuros
E. Pencil Beam
SAM’s Question No. 3

For the treatment of small lung tumors located peripherally using SBRT, which dose algorithm will result in a significant underdosage of the tumor relative to the tumor dose prescription:

0% 1. Convolution
0% 2. Superposition/Convolution
0% 3. Monte Carlo
0% 4. Acuros
0% 5. Pencil Beam
SAM’s Question No. 3: Answer

Answer: 5 ï Pencil Beam algorithm

Practical Issues: *Understanding the details*

http://www.theeditorialcartoons.com/
Lung Cancer Treatment Planning: Practical Issues

How many phases should be used for definition of the ITV in the 4D-CT?

![Diagram](image)

Fig. 2. $D_{95}$ value as a function of the number of phases in the 4D CT image set used to calculate the ITV. All values were taken from 4D dose calculations and were normalized to the $D_{95}$ for $N = 10$ (i.e., normalized to current clinical practice). Each marker type is for a different patient. The solid line is the average.

Yakoumakis...and Court: JACMP: 13(6), 2012
Which phase is the most accurate for planning?

Table shows diffs in cGy and % between AVE-CT and full 4D plan (10 phases using deformable dose accumulation – phantom study)

<table>
<thead>
<tr>
<th>S-I Amplitude (cm)</th>
<th>Dose discrepancy (cGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GTV$_{\text{Min}}$</td>
</tr>
<tr>
<td>2</td>
<td>0.27 (0.30%)</td>
</tr>
<tr>
<td>3</td>
<td>0.56 (0.63%)</td>
</tr>
<tr>
<td>4</td>
<td>1.74 (1.99%)</td>
</tr>
<tr>
<td>2.7 cm diaphragm-tumor distance</td>
<td>0.81 (0.89%)</td>
</tr>
<tr>
<td>4.7 cm diaphragm-tumor distance</td>
<td>0.19 (0.22%)</td>
</tr>
</tbody>
</table>

What is the difference between the free-breathing (FB), average (AIP) and MIP-based CT datasets?

PTV doses (Gy) and abs. V20 (cc) averaged over 20 lung SBRT patients

<table>
<thead>
<tr>
<th>PTV doses in Gy</th>
<th>Abs V20 in CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_{mean}</td>
<td>FB</td>
</tr>
<tr>
<td>FB</td>
<td>50.3</td>
</tr>
<tr>
<td>MIP</td>
<td>50.9</td>
</tr>
<tr>
<td>AIP</td>
<td>50.4</td>
</tr>
<tr>
<td>D_{95}</td>
<td>FB</td>
</tr>
<tr>
<td>FB</td>
<td>47.3</td>
</tr>
<tr>
<td>MIP</td>
<td>48.1</td>
</tr>
<tr>
<td>AIP</td>
<td>47.5</td>
</tr>
</tbody>
</table>

- Dose characteristics are similar
- AIP has less artifact than FB
- AIP (ave. CT) is most favorable

What difference do density overrides make?

Different methods for overriding the densities compared with no density override (free breathing and average datasets)

Wiant...and Sintay: Med Phys: 41:081707 (2014)
What difference do density overrides make?

Comparison for 5 lung SBRT patients treated with VMAT

<table>
<thead>
<tr>
<th>Case</th>
<th>Plan type</th>
<th>ITV (cm³)</th>
<th>GTV motion (cm)</th>
<th>% PTV coverage</th>
<th>CI plan</th>
<th>Mean dose plan (Gy)</th>
<th>Max dose plan (Gy)</th>
<th>Mean dose 4DCT (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FBP</td>
<td>9.7</td>
<td>1.3</td>
<td>95.0</td>
<td>1.04</td>
<td>12.0</td>
<td>12.9</td>
<td>12.0 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>AVGP</td>
<td></td>
<td></td>
<td>95.4</td>
<td>0.99</td>
<td>11.5</td>
<td>12.1</td>
<td>11.6 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>PTVP</td>
<td></td>
<td></td>
<td>96.5</td>
<td>1.00</td>
<td>11.7</td>
<td>12.4</td>
<td>11.4 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>HP</td>
<td></td>
<td></td>
<td>95.8</td>
<td>0.99</td>
<td>11.7</td>
<td>12.4</td>
<td>11.4 ± 0.0</td>
</tr>
<tr>
<td>2</td>
<td>FBP</td>
<td>10.4</td>
<td>1.5</td>
<td>97.3</td>
<td>1.07</td>
<td>11.9</td>
<td>13.5</td>
<td>11.9 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>AVGP</td>
<td></td>
<td></td>
<td>97.3</td>
<td>1.06</td>
<td>11.9</td>
<td>13.2</td>
<td>12.0 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>PTVP</td>
<td></td>
<td></td>
<td>97.6</td>
<td>1.07</td>
<td>12.1</td>
<td>13.9</td>
<td>11.7 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>HP</td>
<td></td>
<td></td>
<td>97.3</td>
<td>1.06</td>
<td>11.9</td>
<td>13.1</td>
<td>11.6 ± 0.1</td>
</tr>
<tr>
<td>3</td>
<td>FBP</td>
<td>57.9</td>
<td>3.4</td>
<td>95.7</td>
<td>0.97</td>
<td>11.6</td>
<td>12.5</td>
<td>11.5 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>AVGP</td>
<td></td>
<td></td>
<td>95.0</td>
<td>0.97</td>
<td>11.3</td>
<td>12.1</td>
<td>11.3 ± 0.1</td>
</tr>
<tr>
<td></td>
<td>PTVP</td>
<td></td>
<td></td>
<td>95.6</td>
<td>0.97</td>
<td>11.7</td>
<td>12.5</td>
<td>11.4 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>HP</td>
<td></td>
<td></td>
<td>96.2</td>
<td>0.98</td>
<td>11.7</td>
<td>12.8</td>
<td>11.5 ± 0.2</td>
</tr>
</tbody>
</table>

Wiant...and Sintay: Med Phys: 41:081707 (2014)
Density overrides: 20 SBRT lung patients:
PTV density override (1.0 g/cc) vs no override (AveCT)

PTV mean dose difference
Rx dose = 50.5 Gy

(~3%)

Courtesy: Cindy Qin (Henry Ford Hospital)
To Gate or Not to Gate?

Decisions should be made based on clinically relevant dosimetric endpoints

- N=150 lung SBRT patients
- 18 Gy x 3; 12 Gy x 4; 10 Gy x 5
- Plans optimized for same target coverage
- PTV (ITV) margin = ITV + 5 mm
- Gated margin = GTV + 5 mm
- MLD, V20, V5 converted to EQ2Gy

Courtesy: J. Kim et al submitted to PRO
(Henry Ford Hospital)
### Mean Lung Dose _EQD2 (Gy); (18 Gy x 3)

<table>
<thead>
<tr>
<th></th>
<th>Gated (Gy)</th>
<th>ITV (Gy)</th>
<th>Diff. (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral (Lung Wall)</td>
<td>6.3 ± 3.2</td>
<td>7.2 ± 3.8</td>
<td>0.9 ± 1.1</td>
</tr>
<tr>
<td>(N=57)</td>
<td>(13.4)</td>
<td>(15.7)</td>
<td>(max=5.4; ITV=14.9)</td>
</tr>
<tr>
<td>Peripheral (Island)</td>
<td>6.5 ± 2.8</td>
<td>7.9 ± 3.3</td>
<td>1.4 ± 1.2</td>
</tr>
<tr>
<td>(N=57)</td>
<td>(13.6)</td>
<td>(15.5)</td>
<td>(max=4.8; ITV=8.9)</td>
</tr>
<tr>
<td>Central</td>
<td>8.5 ± 4.0</td>
<td>9.5 ± 4.6</td>
<td>1.0 ± 1.2</td>
</tr>
<tr>
<td>(N=36)</td>
<td>(20.4)</td>
<td>(24.4; 4.0)</td>
<td>(max=5.4; ITV=15.4)</td>
</tr>
</tbody>
</table>

V20 % differences less than 1.5% on average with a maximum V20 of 26.1% (ITV plan)

12 Gy x 4 and 10 Gy x 5 dosing schemes showed smaller MLD and V20 differences

Low dose comparison, V5 values were within 1-2% for ITV and Gated plans
Difference between ITV and Gating (V20) for different motion amplitudes

![Graph showing the difference in V20 of ESD2 for different motion amplitudes. The graph plots the absolute difference in V20 of ESD2 against the percentage of plans with tumor motion in interval X. The intervals X = [5-10 mm], X = [10-15 mm], and X = >15 mm are represented by solid, dashed, and dotted lines, respectively.](image-url)
The Interplay Effect

Describes the interaction between organ motion and MLC leaf motion.

From Bortfeld et al. Physics in Medicine and Biology: 47, 2002

Interplay effect in IMRT is generally small (~1%) especially for highly fractionated treatments
The percentage of pixels for which the daily dose error could be larger than 5% increased with increasing plan complexity field MU, but was less than 15% for all plans if the motion was 1 cm or less. For 2 cm motion, the dose error could be larger than 5% for 40% of pixels, but was less than 5% for more than 80% of pixels for MU550, and was less than 10% for 99% of all pixels.

The interplay effect increases with plan complexity, and with target magnitude and period. It may average out after many fractions.
Dosimetric Impact of the Interplay Effect on VMAT/RapidArc Lung Cancer Treatment Using SABR

Courtesy: Haisen Li et al. (Henry Ford Hospital)
### Dosimetric Impact of the Interplay Effect on VMAT and IMRT

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tumor location and motion amplitude in SI, AP, RL (cm)</td>
<td>RLL</td>
<td>LLL</td>
<td>RLL</td>
</tr>
<tr>
<td></td>
<td>1.3, 0.4, 0.2</td>
<td>1.0, 0.5, 0.7</td>
<td>0.7, 0.5, 0.3</td>
</tr>
<tr>
<td>RA</td>
<td>-0.1</td>
<td>0.0</td>
<td>1.9</td>
</tr>
<tr>
<td>IMRT</td>
<td>-0.5</td>
<td>-0.2</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tumor location and motion amplitude in SI, AP, RL (cm)</td>
<td>RLL</td>
<td>LLL</td>
<td>RML</td>
</tr>
<tr>
<td></td>
<td>1.0, 0.0, 0.0</td>
<td>1.2, 0.4, 0.1</td>
<td>0.8, 0.7, 0.5</td>
</tr>
<tr>
<td>RA</td>
<td>-0.8</td>
<td>0.6</td>
<td>-0.2</td>
</tr>
<tr>
<td>IMRT</td>
<td>0.8</td>
<td>0.6</td>
<td>-0.2</td>
</tr>
</tbody>
</table>
Considerations: VMAT/RapidArc Interplay

Is dependent on:

Direction of major tumor motion relative to that of MLC motion

Amplitude of motion

Complexity of intensity modulation

Tends to average out over multiple fractions

Is similar for IMRT and VMAT – tradeoff between number of beam angles and level of modulation
Which of the following statements regarding the interplay effect is True?

A. It is independent of the modulation complexity.
B. It is independent of the direction of major tumor motion in relation to the MLC motion.
C. It is independent of the amplitude of motion.
D. It is much larger for VMAT than for IMRT.
E. It tends to average out over many fractions.
Which of the following statements regarding the interplay effect is True?

20%  1. It is independent of the modulation complexity.
20%  2. It is independent of the direction of major tumor motion in relation to the MLC motion.
20%  3. It is independent of the amplitude of motion.
20%  4. It is much larger for VMAT than for IMRT
20%  5. It tends to average out over many fractions.
Answer: It tends to average out over many fractions.

Ref: Court, et al. "Evaluation of the interplay effect when using RapidArc to treat targets moving in the craniocaudal or right-left direction", Med Phys 37, 4-11 (2010).
Summary

4D simulation helps create appropriate planning margins for motion – care must be taken in defining the target; no. of datasets, and the phase used for planning are important factors.

Daily volumetric imaging (CBCT) helps reduce margins and provides institutional experience on tailoring of margins.

Convolution/superposition or MC-based methods should be used for lung cancer treatment planning – avoid pencil beam algorithms.

Pay attention to interplay effects for IMRT and VMAT motion when amplitude is large (> 1.5 cm) and modulation is high.
Acknowledgements

Henry Ford Health System
Cindy Qin, MS
Josh Kim, PhD
Ning (Winston) Wen, PhD
Haisen Li, PhD
Karen Chin-Snyder, MS
Salim Siddiqui, MD
Benjamin Movsas, MD
Munther Ajlouni, MD

Brian Kavanagh, MD, Univ. of Colorado

AAPM Spring Clinical Program Committee
Thank You