Stereotactic Body Radiotherapy for Lung Lesions using the CyberKnife
State-of-the-art and New Innovations

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Outline

- Basic overview of CyberKnife
- Synchrony with fiducials: How does it work?
- Imaging, contouring & dose prescriptions
- Monte Carlo dose calculation
- Xsight Lung: How does it work?

CyberKnife system approach to SBRT

- Robot with 6 degrees of freedom coupled to an X-band linac
- Integrated with an orthogonal pair of X-ray images acquired repeatedly throughout treatment
- DRRs from planning CT compared with live orthogonal images to determine translational and rotational offsets

CyberKnife system approach to SBRT (cont.)

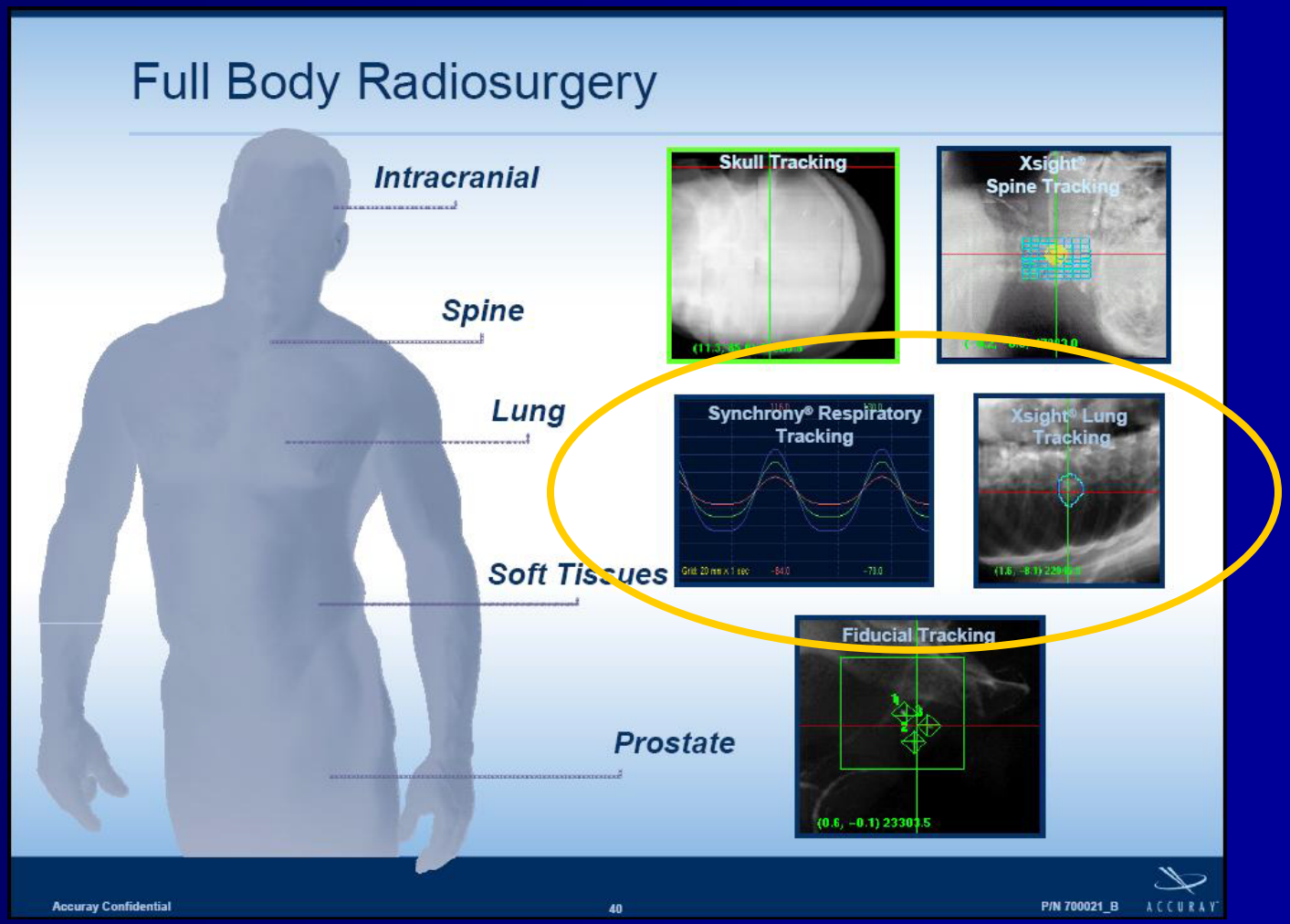
CyberKnife system approach to SBRT (cont.)

- CyberKnife's robotic arm makes treatment non-isocentric
- Radiation beams re-targeted as needed throughout treatment based on DRR/live image comparison
  - Submillimeter targeting accuracy maintained with limited immobilization (thermoplastic mask for skull, vacuum bags for extracranial locations)

CyberKnife system approach to SBRT (cont.)

- Radiation is 6 MV
  - Dmax = 1.5cm
  - No flattening filter
- Output 600-800 MU/min
- 12 fixed collimators (5mm to 60mm)
- Newest addition: IRIS variable aperture collimator

CyberKnife system approach to SBRT (cont.)



Question 1: Which aspect of the CyberKnife system allows continuous adjustment of the radiation beam during treatment?

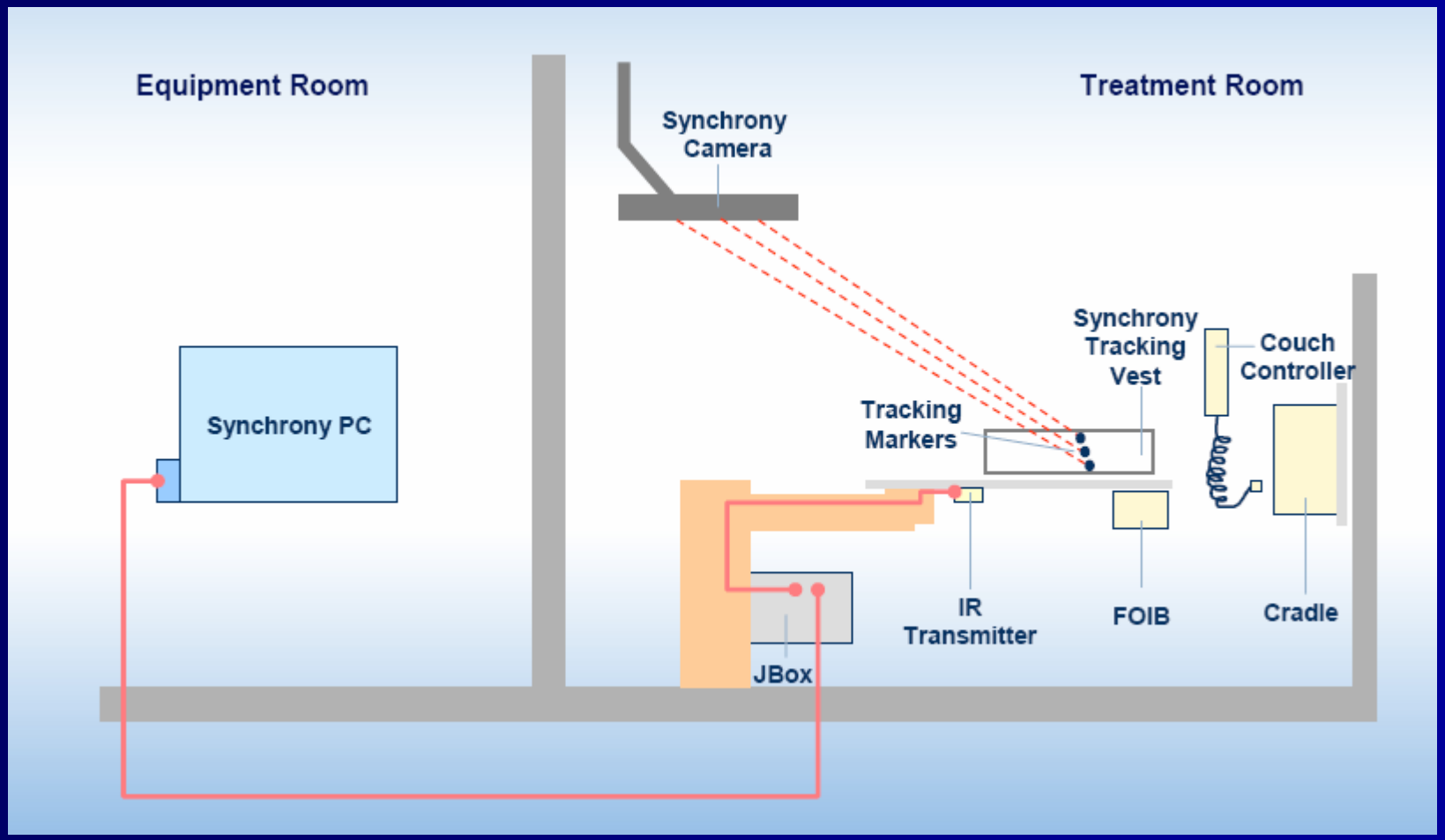
3%	1. Dynamic MLC
83%	2. Non-isocentric beam targeting
7%	3. Variable monitor unit output
0%	4. Innovative flattening filter design
7%	5. Continuous adjustment is not possible

Question 1: Which aspect of the CyberKnife system allows continuous adjustment of the radiation beam during treatment?

1. Dynamic MLC
2. **Non-isocentric beam targeting**
3. Variable monitor unit output
4. Innovative flattening filter design
5. Continuous adjustment is not possible

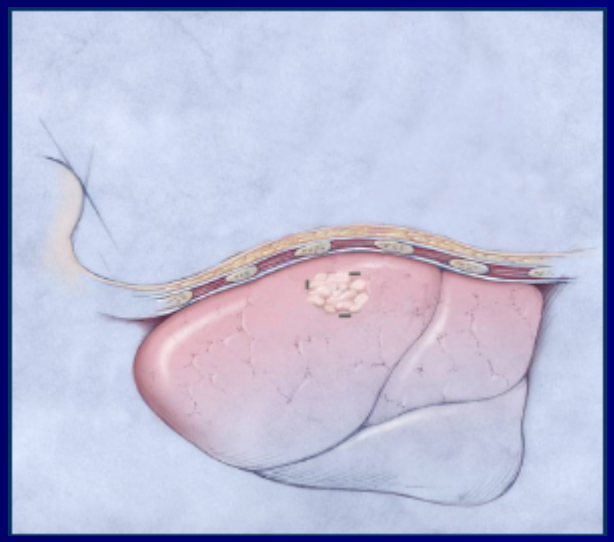
Correct answer: 2.

Synchrony with fiducials: How does it work?

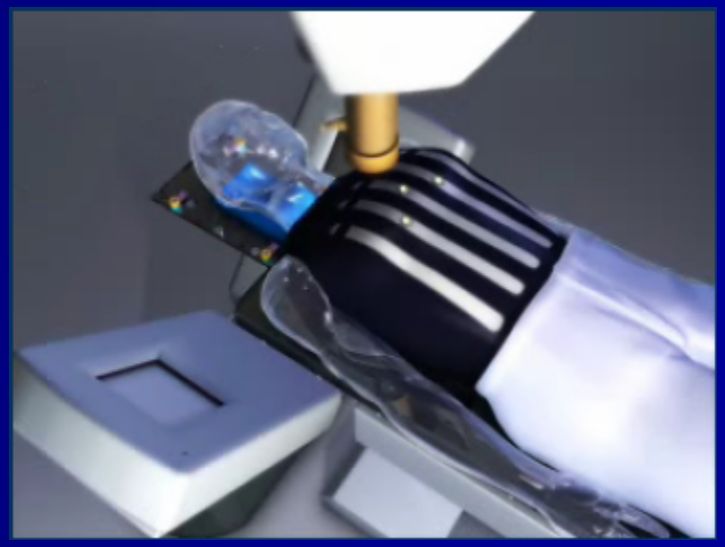


Synchrony with fiducials: How does it work? (continued)

Synchronization of two trackable signals:

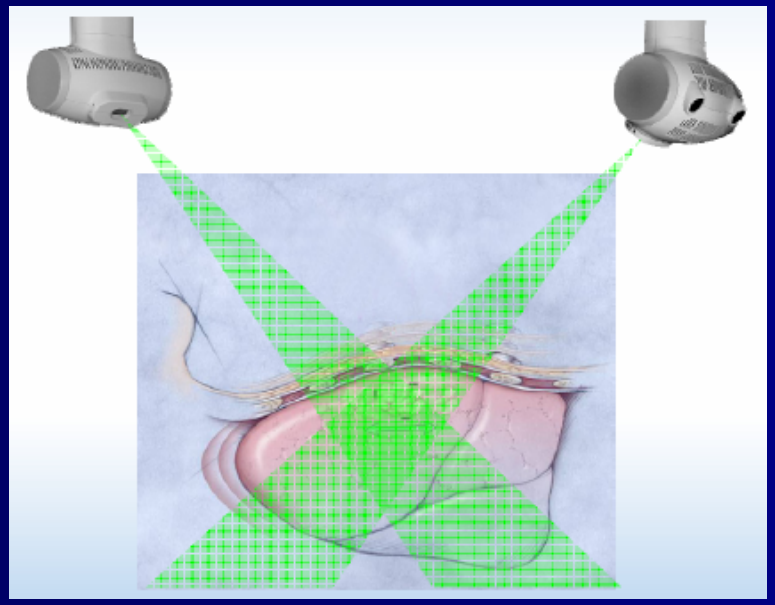


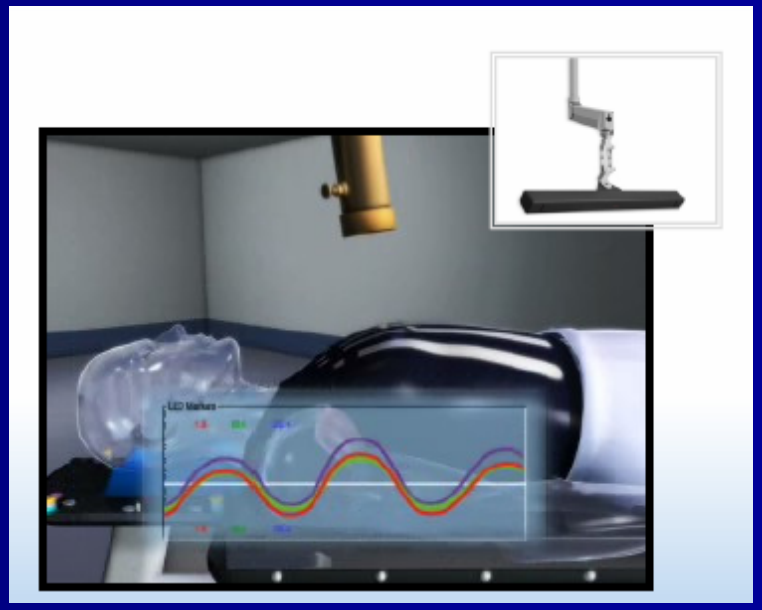
Implanted fiducials



Light-emitting diodes (LEDs) on the chest

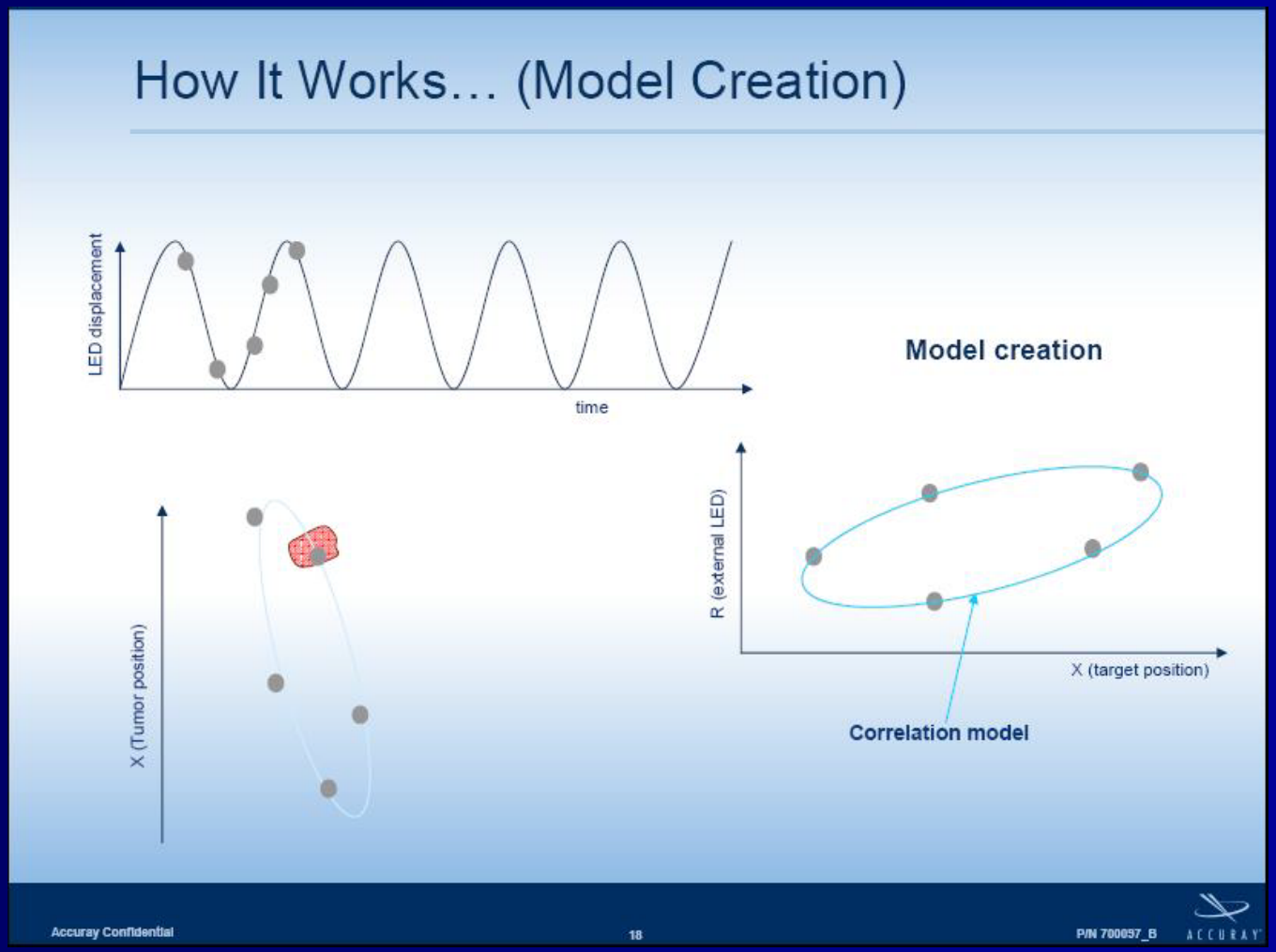
Synchrony with fiducials: How does it work? (continued)





Static diagnostic images are acquired at discrete time points identified on the real-time 3-D chest movement cycle

Synchrony with fiducials: How does it work? (continued)



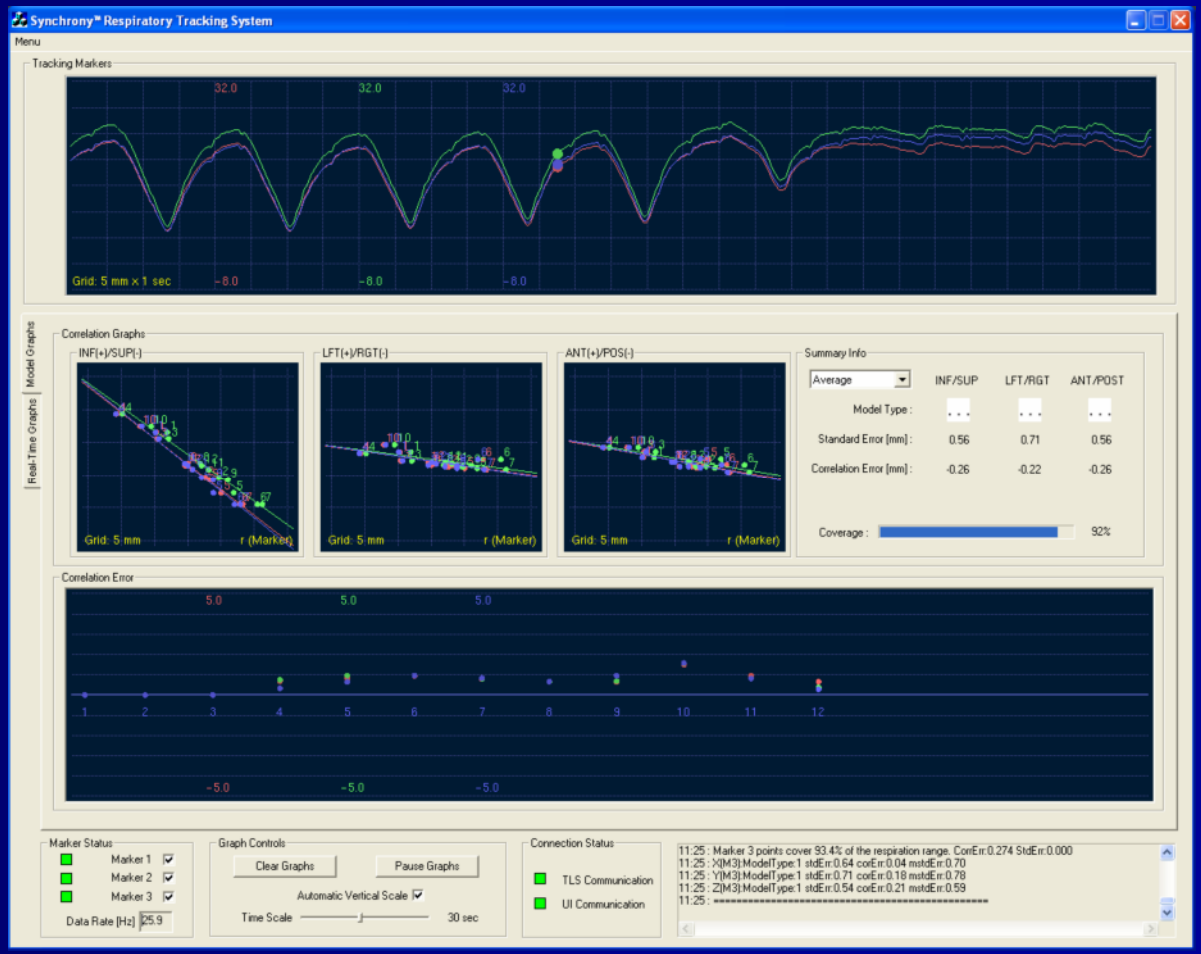
Synchrony with fiducials: How does it work? (continued)

- Top row:

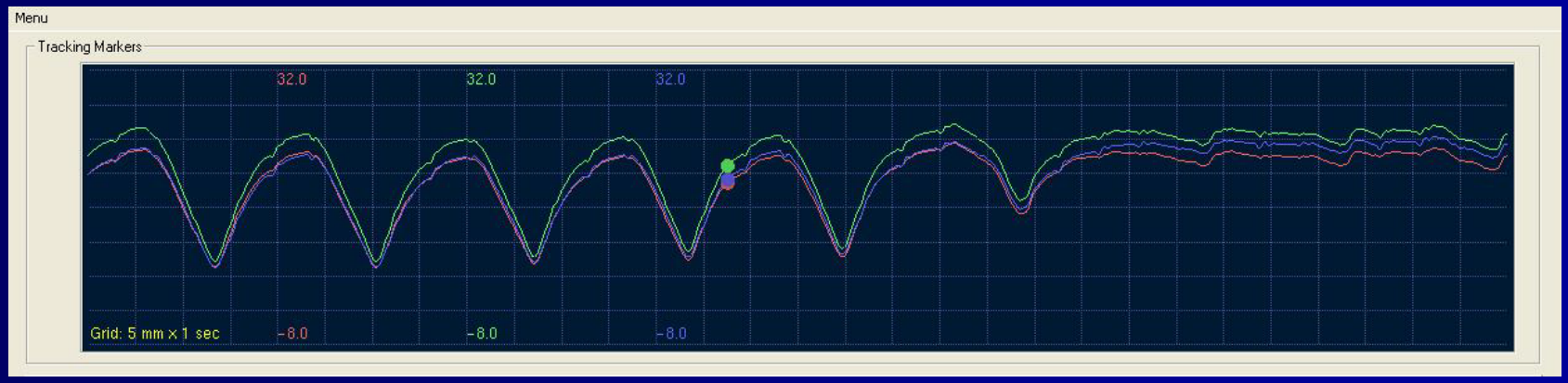
  Real-time LED traces
- Middle row:

  LED position (x axis) vs. fiducial position (y axis)
- Bottom row:

  Last 15 correlation errors (3-D difference between new fiducial position and prediction of the model)



Synchrony with fiducials: How does it work? (continued)



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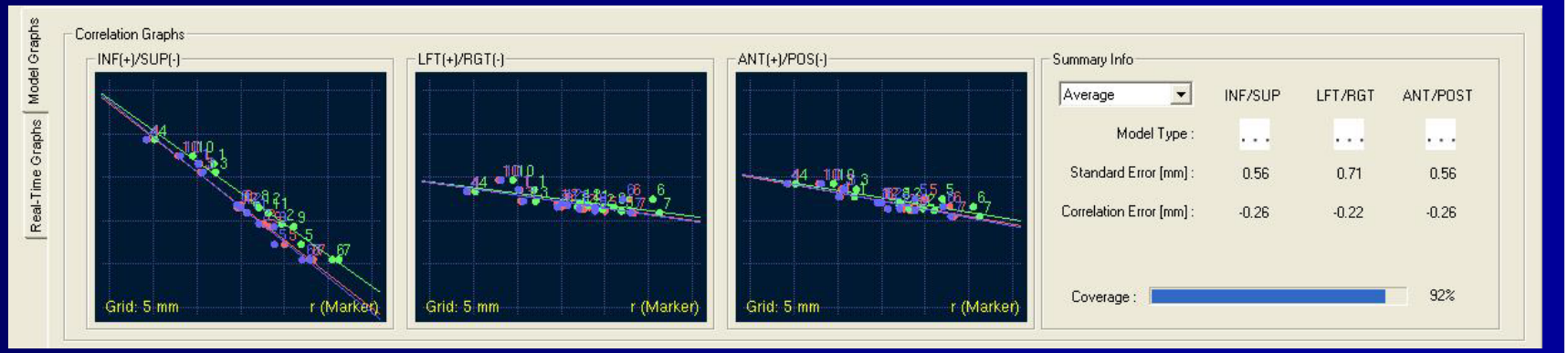
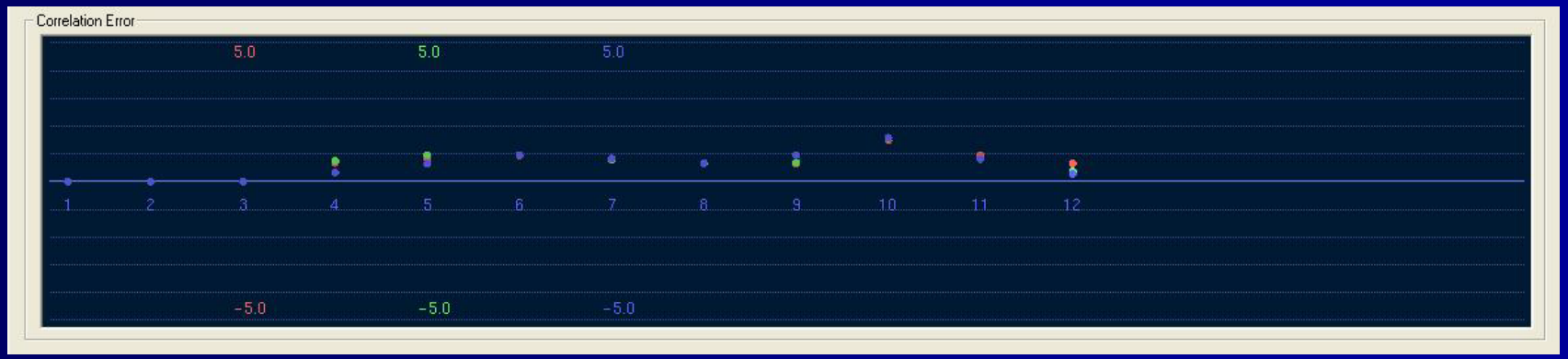
Synchrony with fiducials: How does it work? (continued)



- Middle row:
  LED position (x axis) vs. fiducial position (y axis)
- Model types: linear, arc, double-arcs (hysteresis)

Synchrony with fiducials: How does it work? (continued)

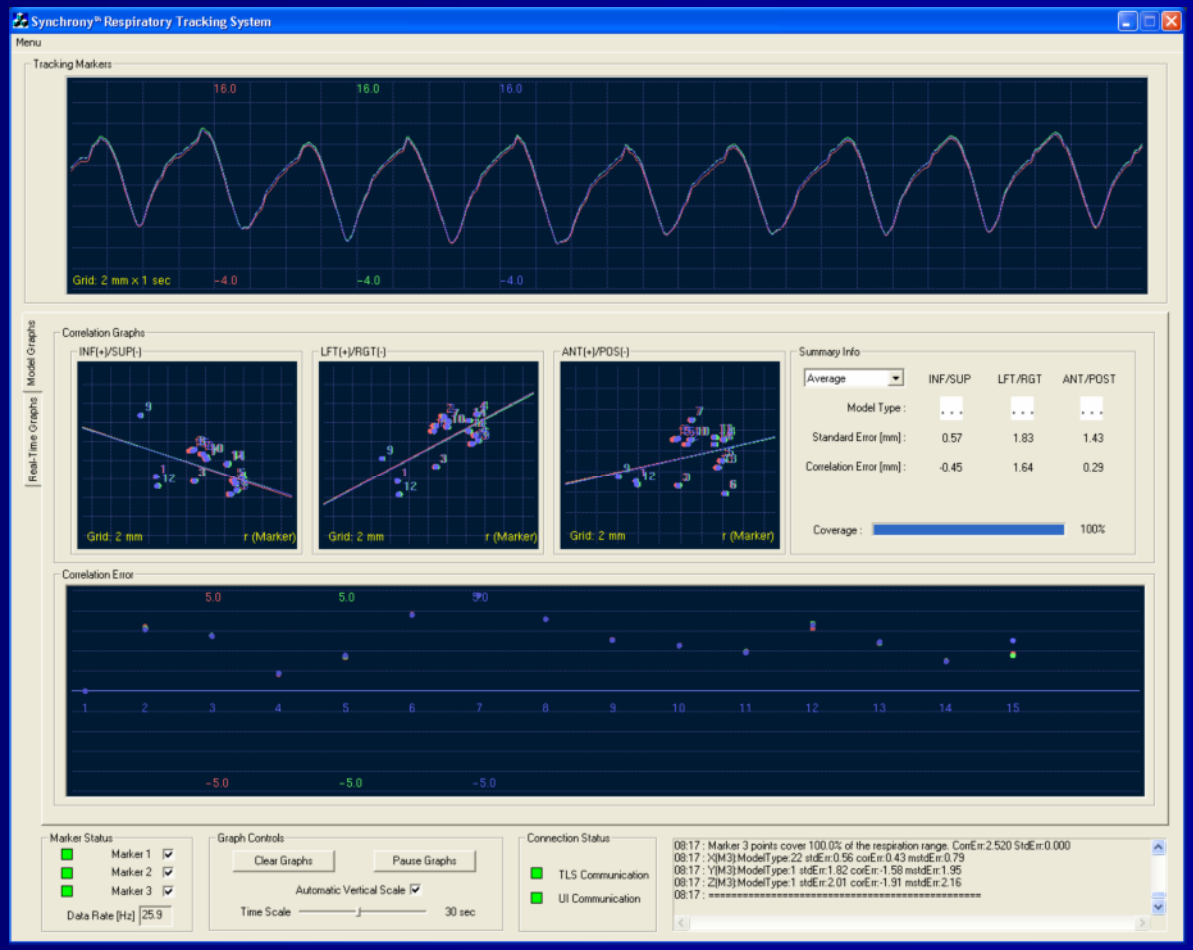


- Bottom row:

  Last 15 correlation errors (3-D difference between new fiducial position and prediction of the model)

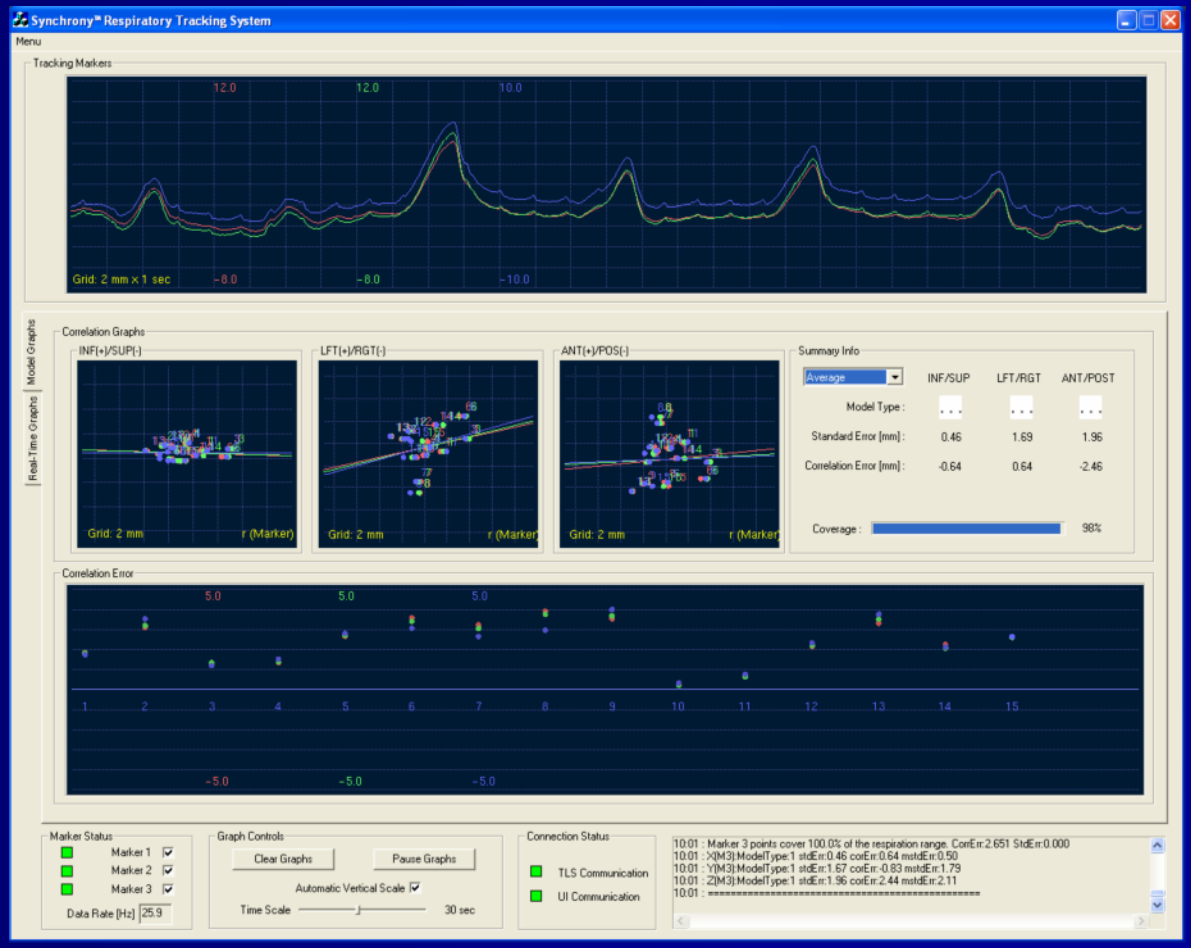
Synchrony with fiducials: How does it work? (continued)

- Models are not always clean
- System interrupts treatment for correlation errors > 5mm
- Automatic interruption in real time for sneezes, coughs, apnia, etc.



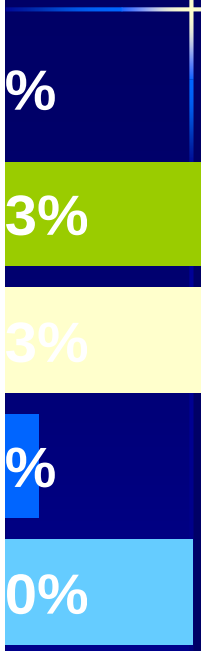
Synchrony with fiducials: How does it work? (continued)

- Synchrony does not replace careful observation and decisions based on experience!
- PTV margins should reflect correlation model limits (and vice versa)



Synchrony with fiducials: How does it work? (continued)

Question 2:
Synchrony software is used by CyberKnife to correlate which two measured quantities?



1. Fiducial ant/post translations and fiducials sup/inf translations
2. Fiducial 3-D translations and light-emitting diode (LED) 3-D translations
3. Fiducial 3-D translations and LED rotations
4. Fiducial rotations and LED 3-D translations
5. Fiducial rotations and fiducial 3-D translations

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4. Fiducial rotations and LED 3-D translations
5. Fiducial rotations and fiducial 3-D translations

Correct answer: 2.

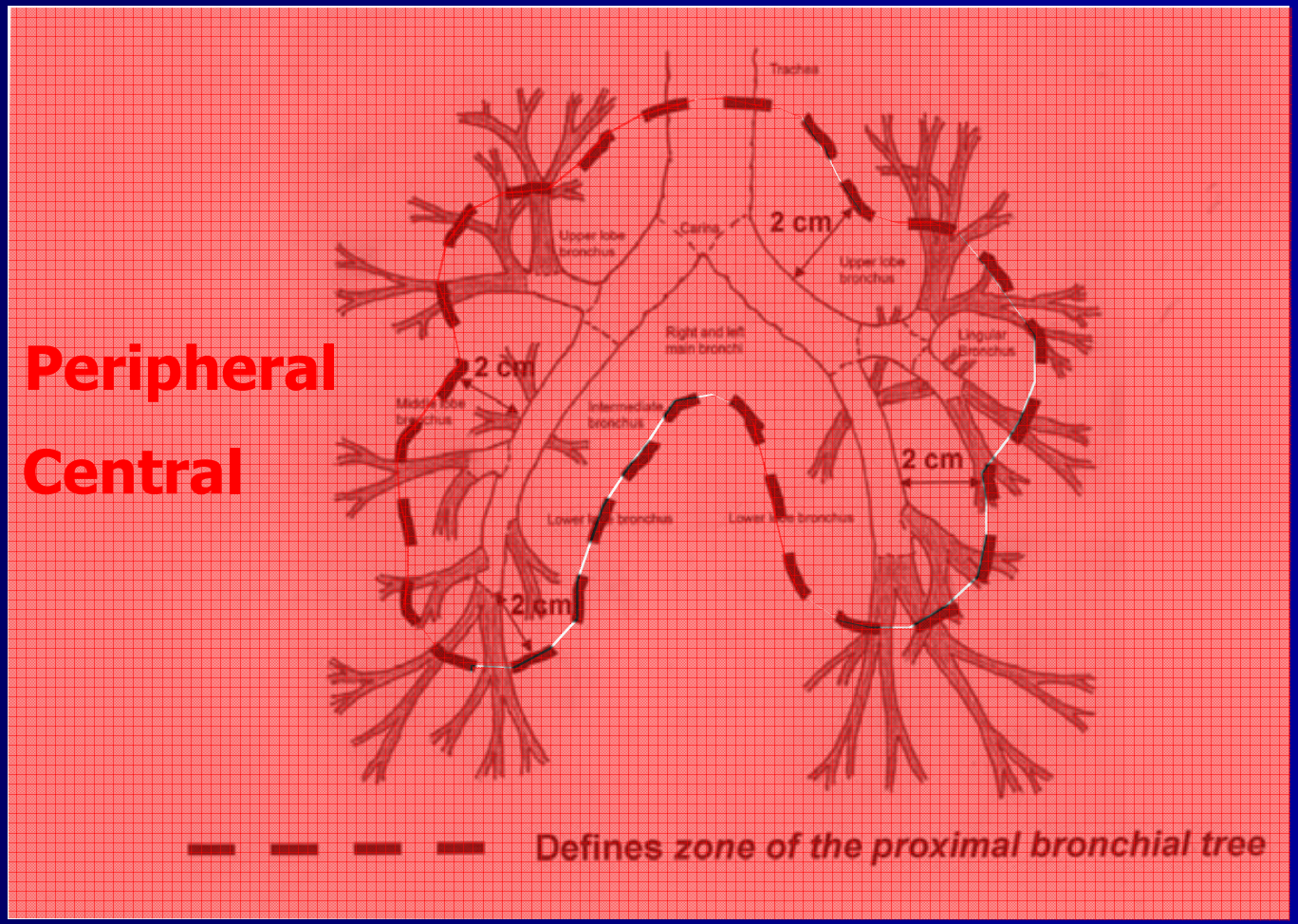
Imaging, contouring & dose prescriptions

- CT always required (for DRR creation)
- CT with breath-hold is used (generally at full exhalation) without contrast
- Fusion of PET scans is common for lung and pancreatic lesions
- Fusion of breath-hold MR images often used for liver, pancreatic lesions

Imaging, contouring & dose prescriptions (continued)

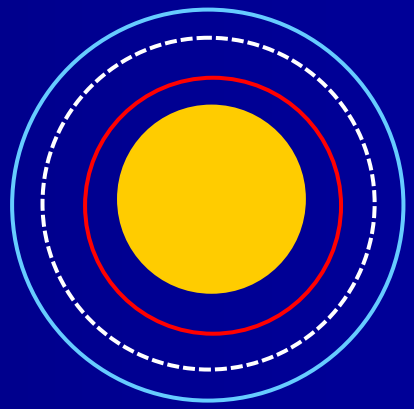
- Common dose schema:
  - Peripheral lesions:
    - 20 Gy x 3 (Timmerman RTOG0236, homogeneous calculations)
    - 18 Gy x 3 (Timmerman RTOG0618, heterogeneous calculations)
  - Central lesions:
    - 12 Gy x 4 (Nagata et al 2005)
    - 12 Gy x 5 (Lagerwaard et al 2008)

Imaging, contouring & dose prescriptions (continued)



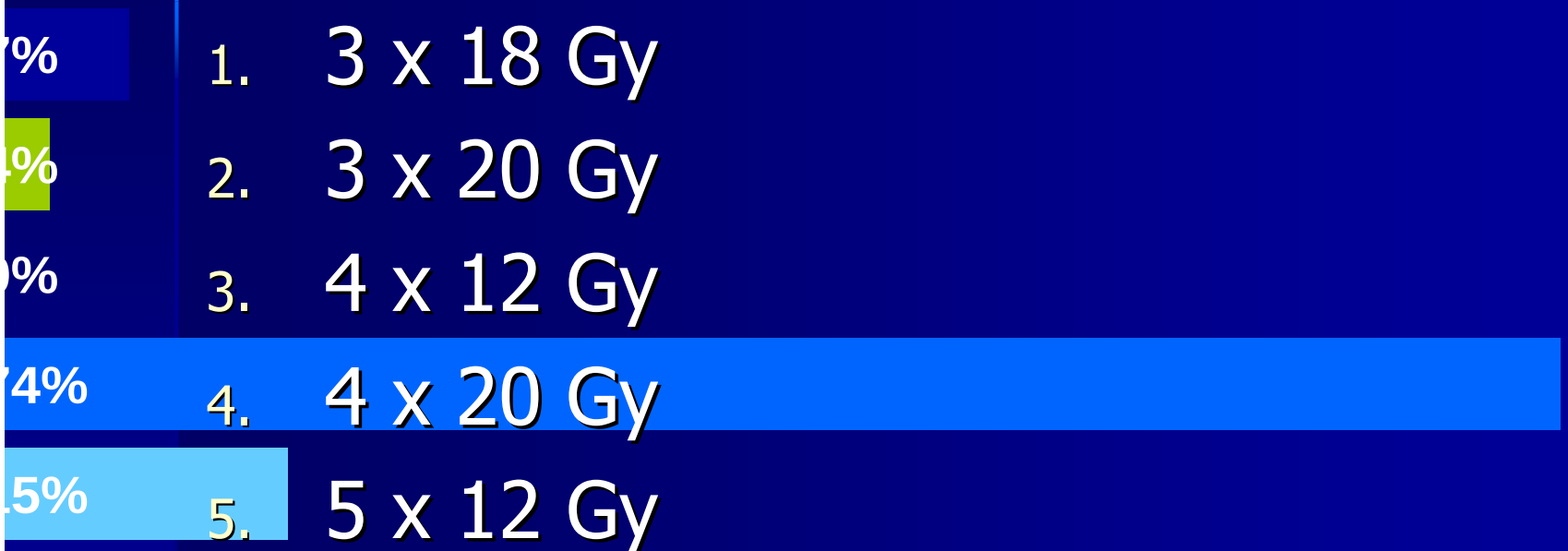
Imaging, contouring & dose prescriptions (continued)

- New trial (CyberKnife only): STARS
  - MD Anderson; central AND peripheral
- STARS trial definitions (Stage I NSCLC):
  - GTV
  - PTV1 (GTV + margin)
  - CTV (PTV1 + margin)
  - PTV2 (CTV + margin)



- PTV1 and PTV2 both have minimum dose and coverage requirements

Question 3:
Which of the following dose fractionation schemes is <u>not</u> typical for SBRT of early stage lung cancer?



Question 3:
Which of the following dose fractionation schemes is <u>not</u> typical for SBRT of early stage lung cancer?

1. 3 x 18 Gy (RTOG 0618)
2. 3 x 20 Gy (RTOG 0236)
3. 4 x 12 Gy (Nagata 2005)
4. **4 x 20 Gy**
5. 5 x 12 Gy (Lagerwaard 2008)

Correct answer: 4.

Monte Carlo dose calculations

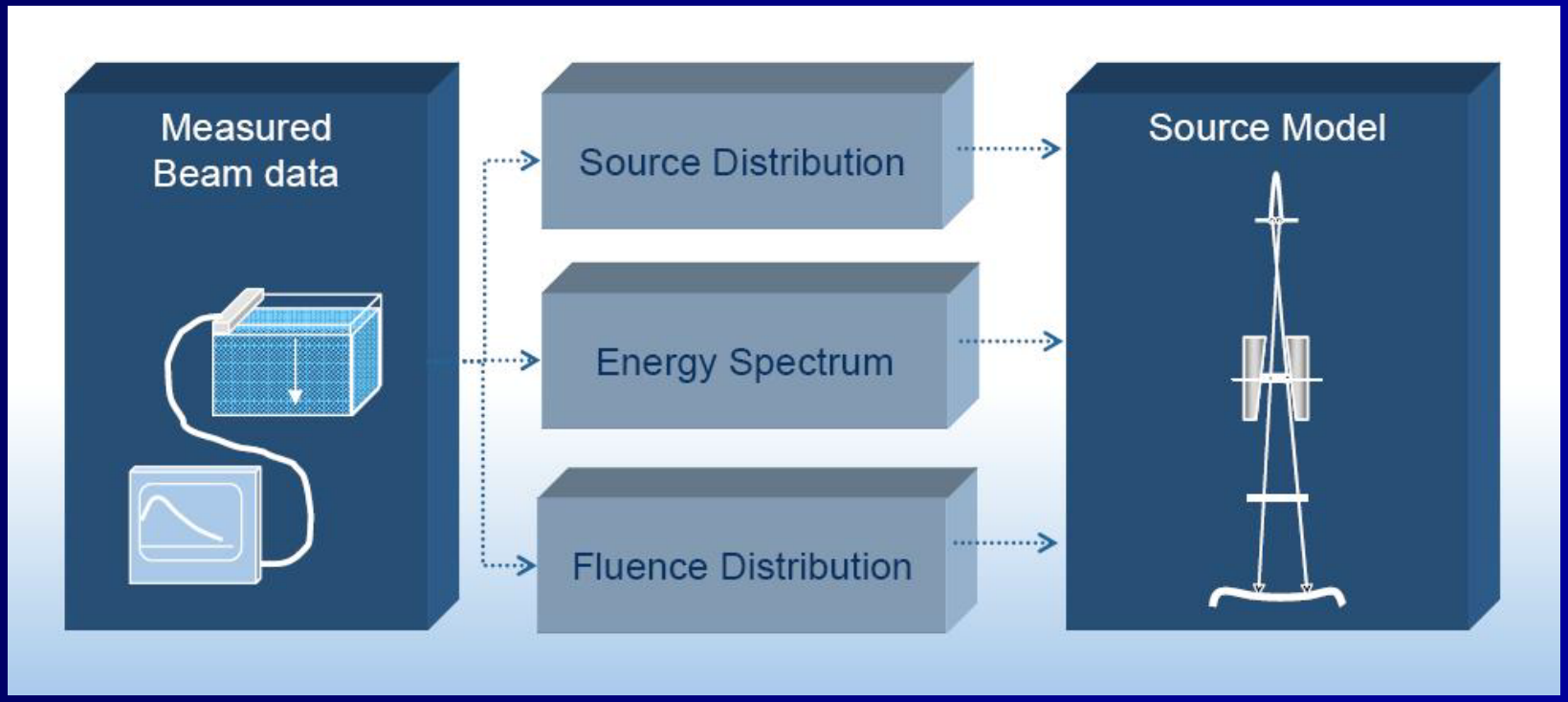
- The MultiPlan dose calculation algorithm is inaccurate near interfaces between different types of materials (tissue-air) and different densities (lung tissue-tumor tissue)
- Accurate calculation of doses to the edge of the planning target volume (PTV) requires another physical model
- The Monte Carlo method is the gold standard – it models individual photons

Monte Carlo dose calculations (continued)

- Monte Carlo is stochastic, so smaller uncertainty requires more photon histories (calculations can be lengthy)
- Clever techniques reduce uncertainty without too much time increase
  - Pre-computed phase space calculation
  - Single source model
  - Sampling of electron tracks already computed
  - Russian roulette
  - More!

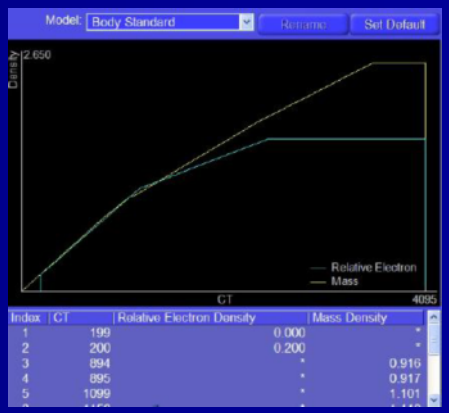
Monte Carlo dose calculations (continued)

- Additional beam data used to construct source model

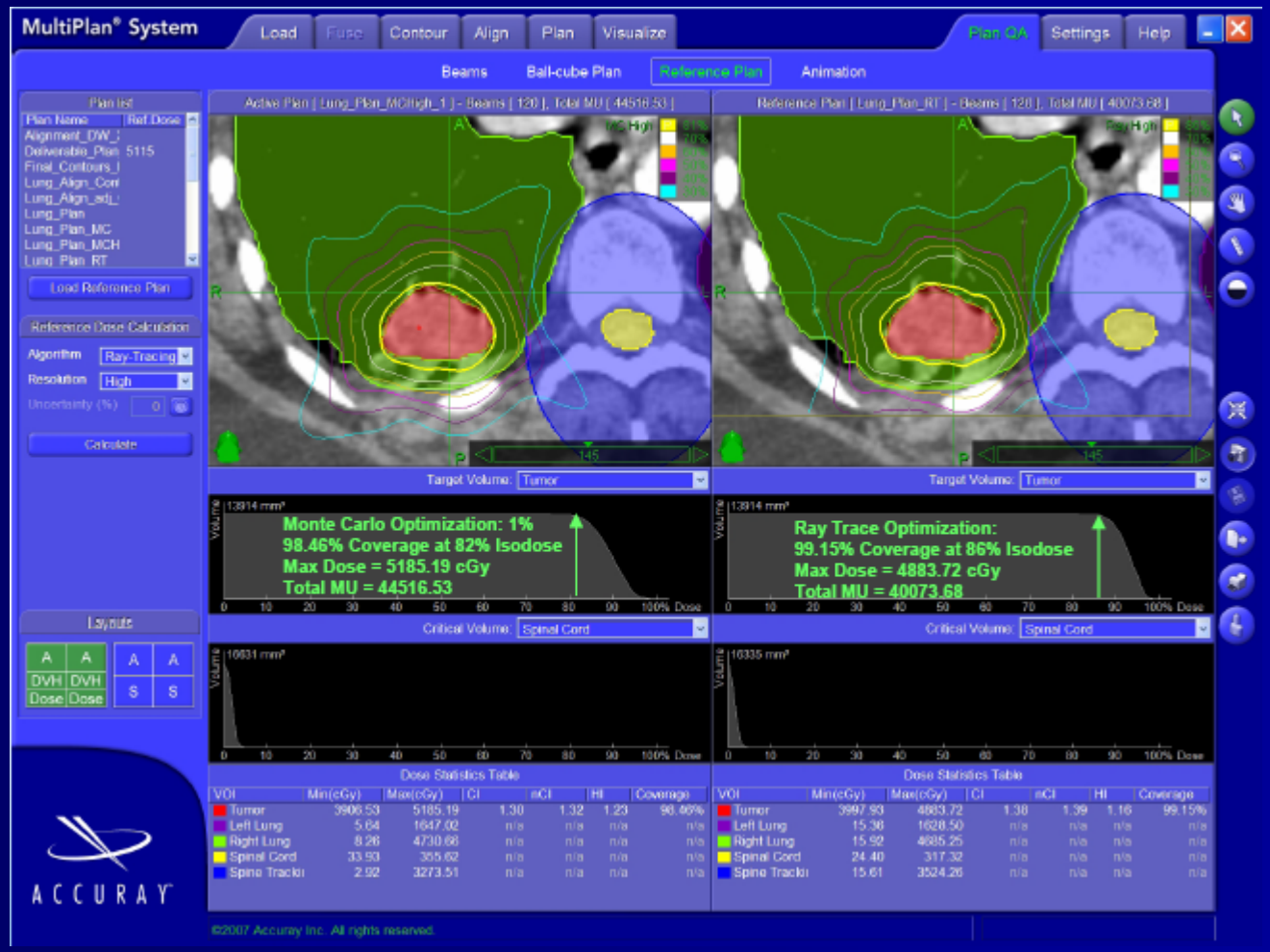


Monte Carlo dose calculations (continued)

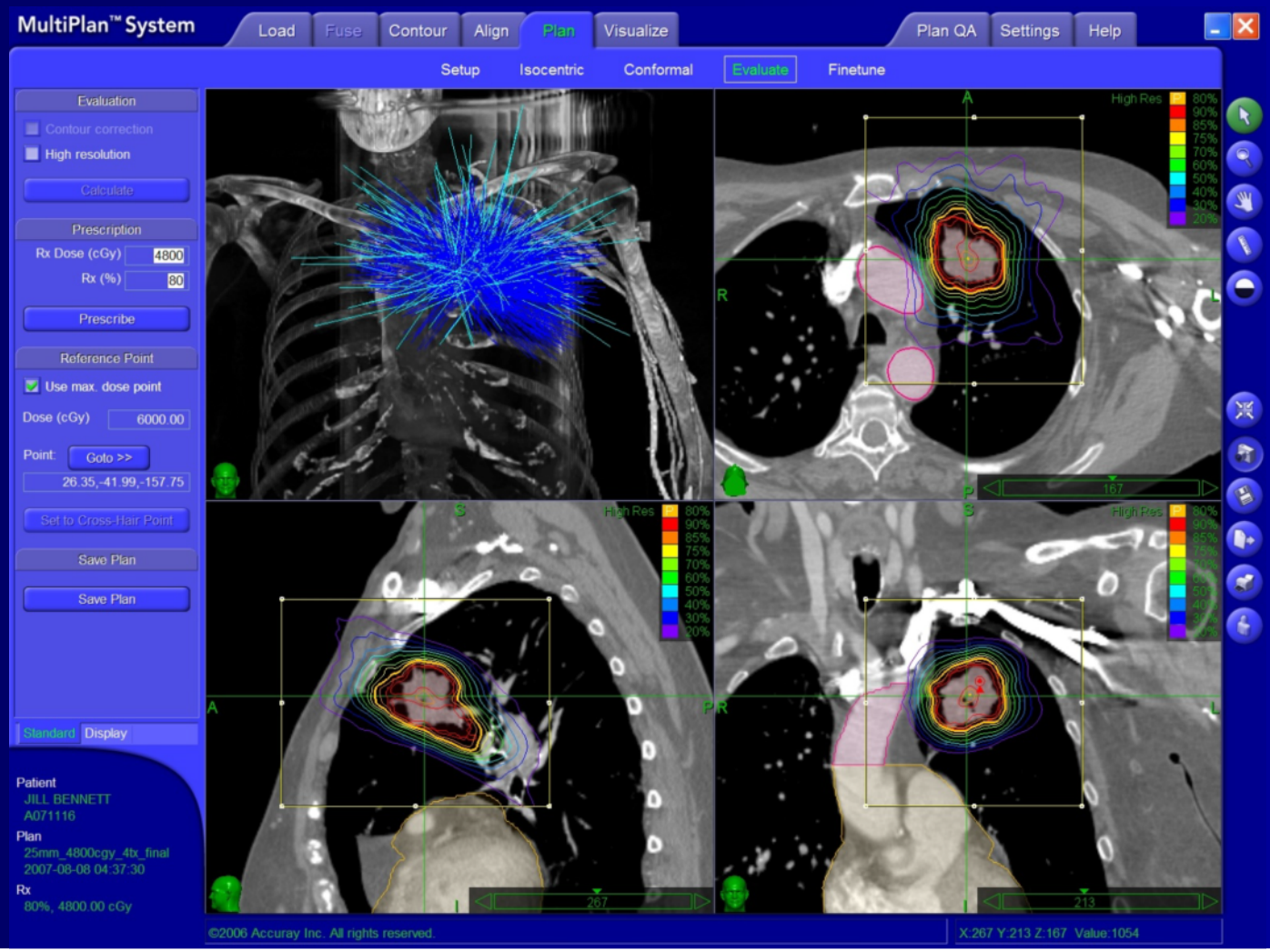
- Patient model based on CT image set
- Both electron and mass densities employed
- Divides patient into material types
  - Air
  - Soft tissue
  - Bone



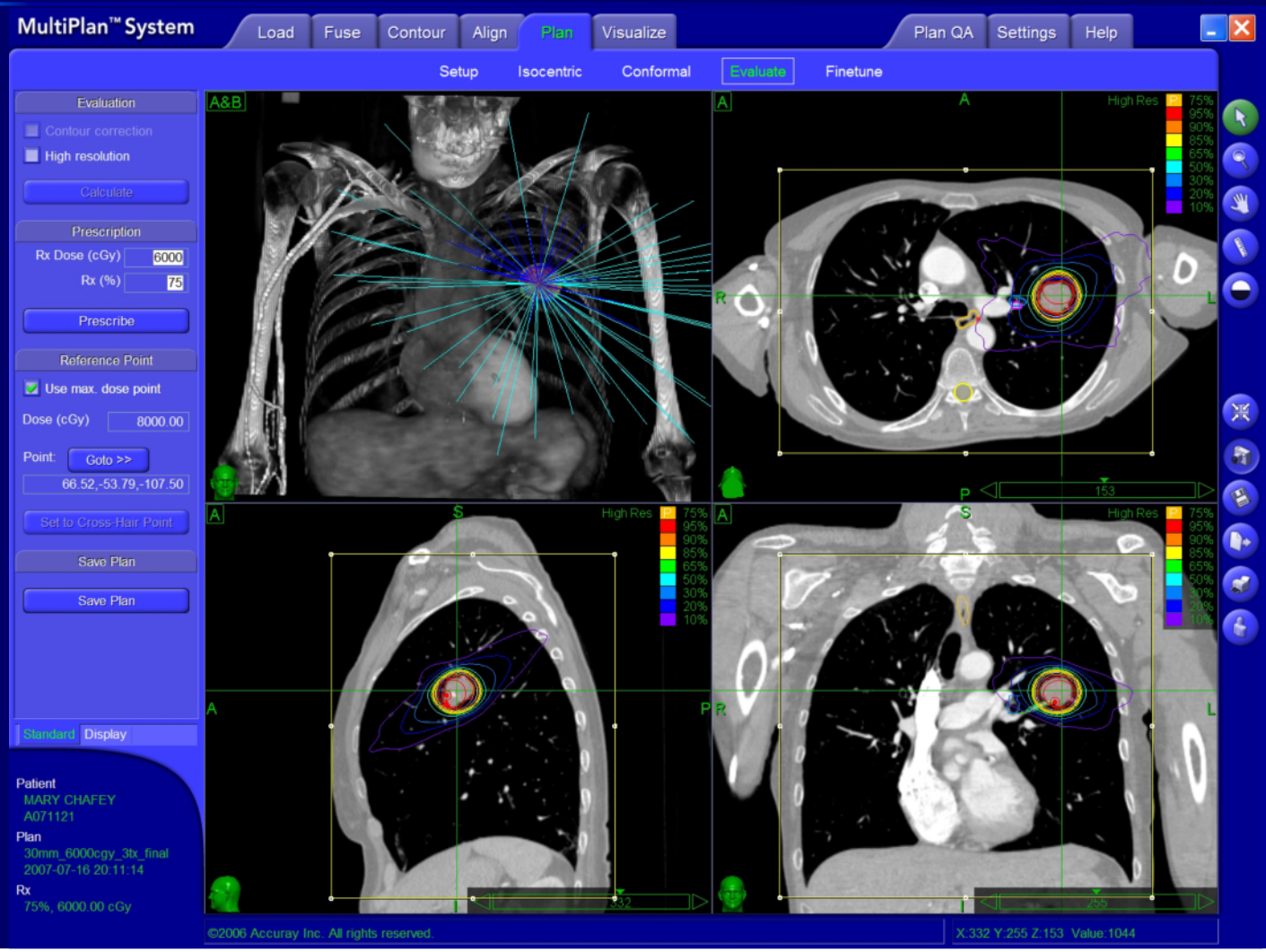
Monte Carlo dose calculations (continued)



Monte Carlo dose calculations (continued)



Monte Carlo dose calculations (continued)



Question 4:
Which of the following is <u>not</u> included in the Monte Carlo calculation software for CyberKnife?

3%	1. Pre-computed phase space calculation
17%	2. Single source model
62%	3. Dose enhancement effects in metal
10%	4. Angle- and energy-dependent photon source distributions
7%	5. Pre-computed electron tracks

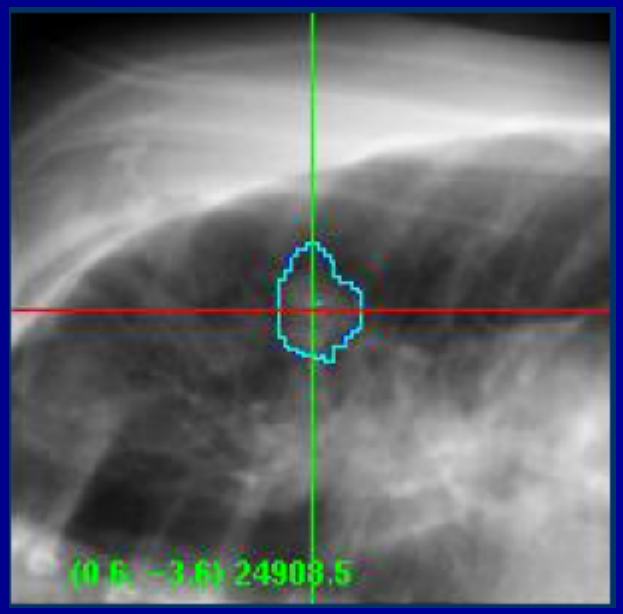
Question 4:
Which of the following is <u>not</u> included in the Monte Carlo calculation software for CyberKnife?

1. Pre-computed phase space calculation
2. Single source model
3. **Dose enhancement effects in metal (air, soft tissue, bone)**
4. Angle- and energy-dependent photon source distributions
5. Pre-computed electron tracks

Correct answer: 3.

Xsight Lung: How does it work?

- In certain cases, the density difference between lung and solid tumor can be used for tracking <u>without</u> need for fiducials
- No pneumothorax risk
- No delay for fiducial implant and 7-day recovery period before imaging



Xsight Lung: How does it work? (continued)

- Centroids of target on DRR and live diagnostic images are compared to determine 3-D translation
- Rotation determined using spine tracking, then shifting from spine- to tumor-center
- Synchrony still used to track breathing motions
- XST has been available for about one year (still fairly new)

Xsight Lung: How does it work? (continued)

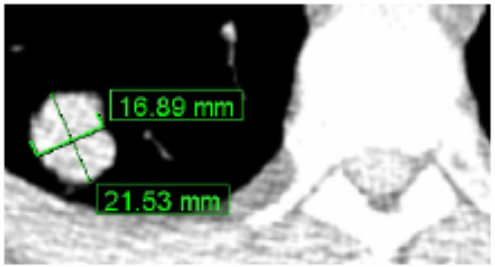
- First, use spine grid to fix body rotations…

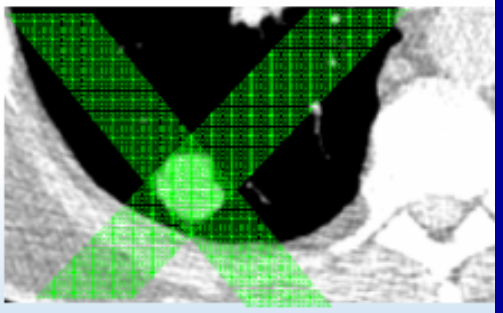
  then shift to tumor centroid to create Synchrony model

Xsight Lung: How does it work? (continued)

- Tracking requirements:

Target Dimensions:	Tumor must measure greater than 15 mm on all axis
Target Location:	Peripheral region of the lung
Target Visualization:	Tumor not completely obstructed by spine structures in the live X-ray projection and DRR images





Xsight Lung summary

- In my limited experience (about 25 cases since June 2007), Accuray's acceptance criteria are correct
- A local search algorithm is employed to determine a confidence level
- 100% confidence has been observed without perfect overlay of contour with dense "blob" on Live Image
- About 30-50% of lung cases are XLT candidates

Question 5:
Which of the following criteria would <u>not</u> preclude a patient from receiving CyberKnife treatment using Xsight Lung tracking?

1% 1. Tumor dimension greater than 15mm

% 2. Tumor at 45º to spine

% 3. Tumor at 45º to heart

4. Tumor at 45º to greater vessels

2% 5. Tumor located within dense lung parenchyma

6%

Question 5:
Which of the following criteria would <u>not</u> preclude a patient from receiving CyberKnife treatment using Xsight Lung tracking?

1. **Tumor dimension greater than 15mm (less than 15mm precludes)**
2. Tumor at 45º to spine
3. Tumor at 45º to heart
4. Tumor at 45º to greater vessels
5. Tumor located within dense lung parenchyma

Correct answer: 1.

References

- *Physics Essentials Guide*. (Accuray Incorporated, 2006).
- Lagerwaard F, Haasbeek C, Smit E et al. *IJROBP*. 2008; 70(3): 685-692.
- Deng J, Guerrero T, Ma C-M, Nath R. *Phys. Med. Biol*. 2004; 49: 1689-1704.
- Fu D, Kahn R, Wang B et al. Urschel, Kresl, Luketich, Papiez & Timmerman, eds. *Treating Tumor that Move with Respiration*. (Springer, Berlin 2007).

Thank You