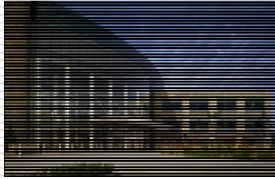


Gated Radiotherapy for Lung Cancer



Steve B. Jiang, Ph.D.

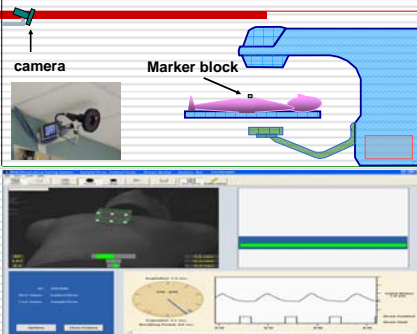
Department of Radiation Oncology
University of California San Diego

shjiang@ucsd.edu
radonc.ucsd.edu/Research/CART

Two Types of Gating

- **Internal gating (fluoroscopic gating)**
 - Use internal tumor motion surrogates such as implanted fiducial markers to indicate tumor position
 - Mitsubishi/Hokkaido RTRT system
- **External gating (optical gating)**
 - Use external respiratory surrogates such as abdominal surface to derive tumor position
 - Varian RPM system

Varian RPM System



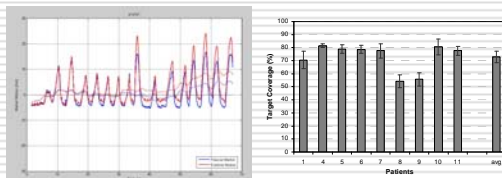
Shooting A Target by Looking in The Mirror



Image in the mirror
→ Target

External surrogates
→ Tumor

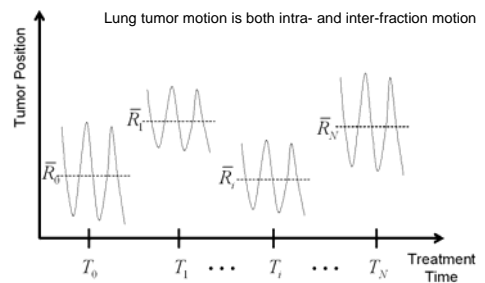
Gating based on External Surrogates



Kanoulas, Aslam, Sharp, Berbeco, Nishioka, Shirato, and Jiang
Phys Med Biol 52(17):5443-55456, 2007

Wu, Zhao, Berbeco, Nishioka, Shirato, Jiang
Phys Med Biol. 53(24):7137-7150, 2008

Tumor Home Position and Instant Position



Accurate External Gating

- During **treatment simulation**, the reference home position should be accurately measured, using techniques such as 4D CT.
- During **treatment planning**, the patient and tumor geometry at the reference home position should be used.
- During **patient setup**, the tumor daily home position should be matched to the reference home position.
- During the **treatment delivery**, the tumor home position should be maintained the same.

Jiang, Technical aspects of image-guided respiration-gated radiation therapy, *Med Dosim*, 31(2):141-51, 2006.



UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

7



Patient Breath Coaching

- To achieve regular and stable breathing pattern
- Audio instruction
- Visual feedback

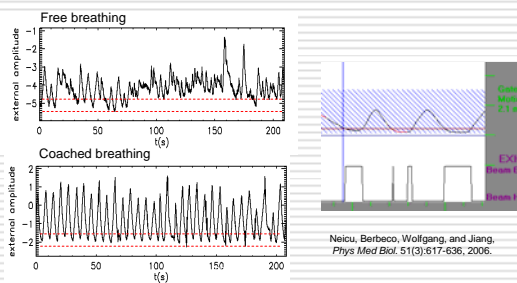


UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

8



A Breath Coaching Protocol



UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

9



CT Simulation for Gated Lung Cancer RT

- Free breathing CT scan
- Breath-hold CT scan
 - ☐ Voluntary breath hold
 - ☐ Active breathing control
- Slow CT scan
 - ☐ 4 seconds per slice in axial mode
- 4D CT scan
 - ☐ 3D scans at multiple phases

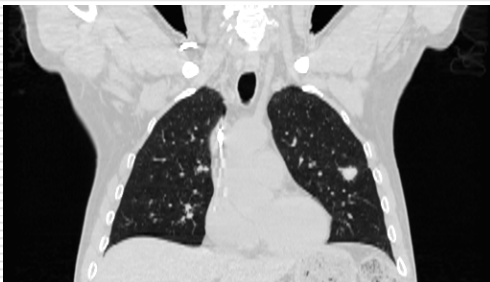


UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

10



4DCT Scan



UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

11



Patient Setup for Gated Lung Cancer RT

- Room laser/skin tattoos
- X-ray image of bony structure
- 3D/4D cone beam CT



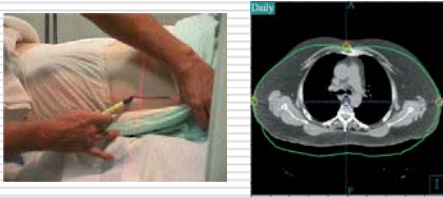
UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

12



Patient Setup For Gated Lung Cancer RT

- Room laser/skin tattoos



Nelson, Starkschall, Balter, Moric, Stevens, Chang, *Int J Radiat Oncol Biol Phys*, 67(3):915-23, 2007.



UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

13



Patient Setup For Gated Lung Cancer RT

- X-ray images of bony structure



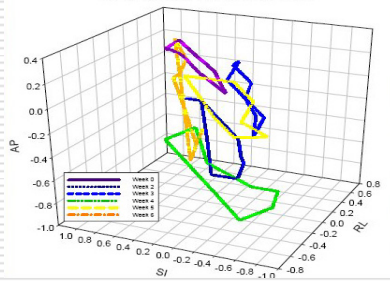
UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

14



Inter- and Intra-fraction Motion of Lung Tumor

3D tumor traces on different weeks



Courtesy of Lei Dong

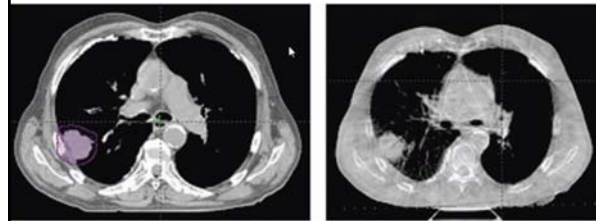


UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

15



Patient Setup For Gated Lung Cancer RT

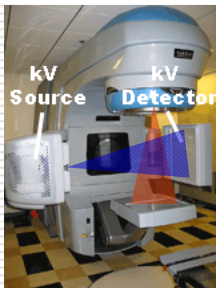


UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

16



On-line Treatment Verification



- Based on MV imager

- Based on kV imager



UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

17



Cine EPID for Lung Tx Verification using ANN

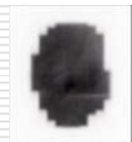
- Before treatment

- ❑ Generate simulated EPID images using CT data for each beam and with various possible positional errors
- ❑ Train ANN using the simulated EPID images to recognize two classes: tumor within/without the beam aperture



- During treatment

- ❑ Apply the trained network to cine EPID images to see if the tumor is inside the beam



- Preliminary results

- ❑ 6 patients, 4-5 fractions each
- ❑ 95% accuracy

Tang, Lin, and Jiang, *Phys Med Biol* 2009 (in press)

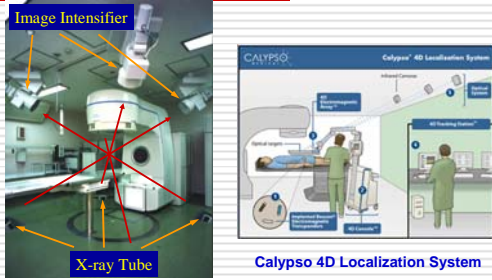


UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

18

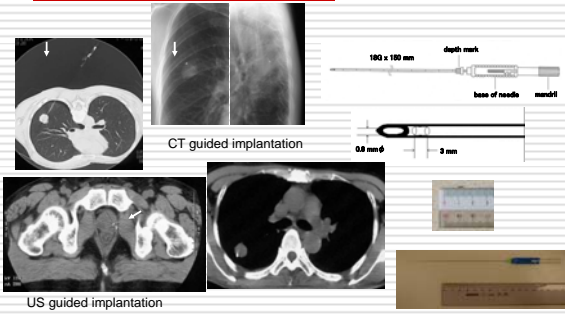


Gating based on Implanted Fiducial Markers



Mitsubishi/Hokkaido RTRT System

Implantation of Fiducial Markers

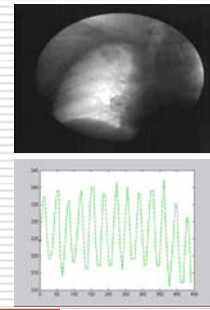


How to Track a Moving Tumor?



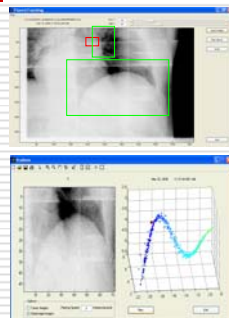
Direct Lung Tumor Tracking w/o Markers

- **Multiple Template Tracking**
 - Cui, Dy, Sharp, Alexander, and Jiang, *Phys Med Biol*, 52(20):6229-6242, 2007.
- **Active Shape Model Tracking**
 - Xu, Hamilton, Schowengerdt, and Jiang, *Phys Med Biol*, 52(17):5277-5293, 2007.
- **Optical Flow Tracking**
 - Xu, Hamilton, Schowengerdt, Alexander, and Jiang, *Med Phys*, 35(12):5351-9, 2008.



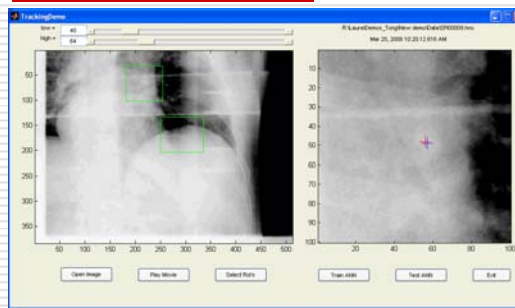
Indirect Fluoroscopic Tracking

- **Issues with direct tracking**
 - Directly tracking of the tumor sometimes is impossible due to poor image quality and low target contrast
 - Common tracking methods used in computer vision often fails since tumor has no color, no texture, and often no clear shape
- **We proposed an indirect tracking approach**
 - Tracking invisible tumor by tracking visible surrogate features



Lin, Cervino, Tang, Vasconcelos, and Jiang, *Phys Med Biol* 54(4): 981-992, 2009.

Indirect Fluoroscopic Tracking



Diaphragm as an Internal Surrogate

$$y_0 = a + \sum_i b_i s_i$$

Mean error ~ 1 mm
Maximum error (e95) ~ 2 mm

Cervino, Chao, Sandhu, and Jiang
Phys Med Biol 54(11): 3529-3541, 2009

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

25 UCSD

Diaphragm Does Not Always Work

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

26 UCSD

Gating Is A Two-Class Classification Problem

Template matching

Gating problem

Linear classifier

Classification problem

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

27 UCSD

Gating as A Classification Problem

Training: Training Fluoroscopic Images → Preprocessing (PCA, etc) → Labeling → Trained Classifier

Treatment: Incoming Fluoroscopic Images → Preprocessing (PCA, etc) → Classification → Gating Signal

- Template Matching Methods
 - Berbeco, Mostafavi, Sharp, and Jiang, *Phys Med Biol* 50(19): 4481-4490, 2005.
 - Cui, Dy, Sharp, Alexander, Jiang, *Phys Med Biol* 52(3):741-55, 2007.
- Support Vector Machines (SVM)
 - Cui, Dy, Alexander, and Jiang, *Phys Med Biol* 53(16):N315-27, 2008.
- Artificial Neural Network (ANN)
 - Lin, Tang, Dy, and Jiang, *Phys Med Biol* 54(6): 1555-1563, 2009.

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

28 UCSD

ANN based Gating

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

29 UCSD

Pros and Cons of Each Gating Method

- **Internal: accurate however expensive**
 - Carefully implanted multiple fiducial markers
 - High cost, invasive, imaging dose
- **External: less expensive however less accurate**
 - Low cost, noninvasive, radiation free, easy to implement
 - Uncertainties in external/internal correlation

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

30 UCSD

Hybrid Gating

X-ray
(Only when necessary)

Surface Tracking Camera
(Always on)

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

31

UCSD

Future Gated Lung Cancer RT

- **Respiratory surrogates → gating signals**
 - ❑ Better respiratory signals
 - ❑ Real-time 3D surface imaging
- **X-ray images → update internal/external correlation**
 - ❑ Only taken when necessary
 - ❑ Derive tumor positions using machine learning methods
 - ❑ Correlation based on sophisticated lung models
- **Breath coaching**
 - ❑ Required for some patients to ensure sufficient accuracy and efficiency
- **Cine EPID based on-line treatment verification**
- **Very high dose rate**
 - ❑ "Snapshot" therapy

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

32

UCSD

Future Gated Lung Cancer RT

- **Gating should be applied to every lung cancer RT**
- **Nothing to lose when motion is small**
 - ❑ ~ 100% duty cycle
- **Motion may change later in the treatment course**
- **Gating can be used to monitor patient motion**

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

33

UCSD

Which of the following CT simulation technique is best suited for gated treatment of lung cancer patients?

0% 1. 4D CT scan

0% 2. Breath hold CT scan

0% 3. Slow CT scan

0% 4. Free breathing CT scan

0% 5. None of the above

0%

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

34

UCSD

10

Answer: 1 – 4D CT scan

References

Jiang SB
Radiotherapy of mobile tumors
Semin Radiat Oncol, 2006. 16(4): p. 239-48.

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy
Med Dosim, 2006. 31(2): p. 141-51.

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

35

UCSD

Which of the following statement is NOT true for gating based on external surrogates (external gating)?

0% 1. External gating is non-invasive

0% 2. External gating is relatively easy to implement

0% 3. External gating does not require any radiation dose for imaging

0% 4. External gating rely on a good and stable correlation between tumor motion and surrogate signal

0% 5. The correlation between tumor motion and surrogate signal does not change intra- and inter-fractionally for any lung cancer patients

UNIVERSITY of CALIFORNIA, SAN DIEGO
MEDICAL CENTER MOORES CANCER CENTER

36

UCSD

10

Answer: 5 – The correlation between tumor motion and surrogate signal does not change intra- and inter-fractionally for any lung cancer patients

References

Jiang SB
Radiotherapy of mobile tumors
Semin Radiat Oncol, 2006. 16(4): p. 239-48.

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy
Med Dosim, 2006. 31(2): p. 141-51.

Which of the following statement is NOT true for gating based on implanted fiducial markers (internal gating)?

- 0% 1. Internal gating is less accurate than external gating
- 0% 2. Internal gating is more invasive than external gating
- 0% 3. Marker implantation in lung may cause pneumothorax
- 0% 4. High imaging dose may be required for the fluoroscopic tracking of the implanted fiducial markers
- 5. The combination of external and internal gating may reduce the imaging dose

Answer: 1 – Internal gating is less accurate than external gating

References

Jiang SB
Radiotherapy of mobile tumors
Semin Radiat Oncol, 2006. 16(4): p. 239-48.

Jiang SB
Technical aspects of image-guided respiration-gated radiation therapy
Med Dosim, 2006. 31(2): p. 141-51.