Management of Moving Targets in Radiotherapy

Steve B. Jiang, Ph.D.

Department of Radiation Oncology

jiang.steve@mgh.harvard.edu http://gray.mgh.harvard.edu/

MASSACHUSETTS GENERAL HOSPITAL

HARVARD MEDICAL SCHOOL

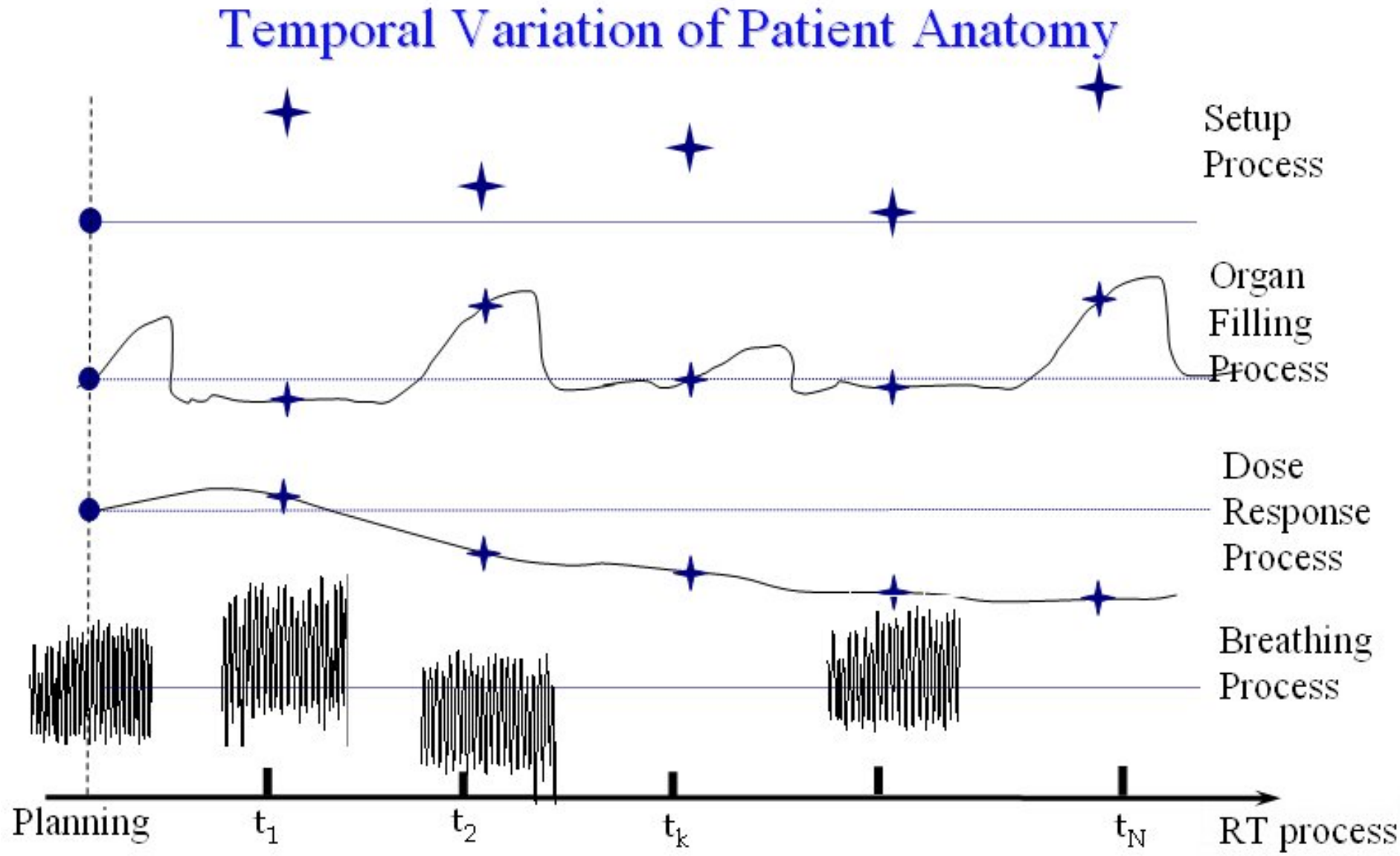
A Simplified View of the RT Process

- **Treatment preparation**
  - **Treatment simulation**
    - ❑ **Build a virtual patient model (reference geometry)**
  - **Treatment planning**
    - ❑ **Perform virtual treatment using virtual machine on virtual patient**
- **Treatment execution**
  - **Patient positioning**
    - ❑ **Reproduce the reference geometry acquired through treatment simulation and used for treatment planning**
  - **Treatment delivery**
    - ❑ **Maintain the reference geometry**

Image Guided Radiation Therapy

- **There should be a consistency in the patient geometry throughout the whole treatment course.**

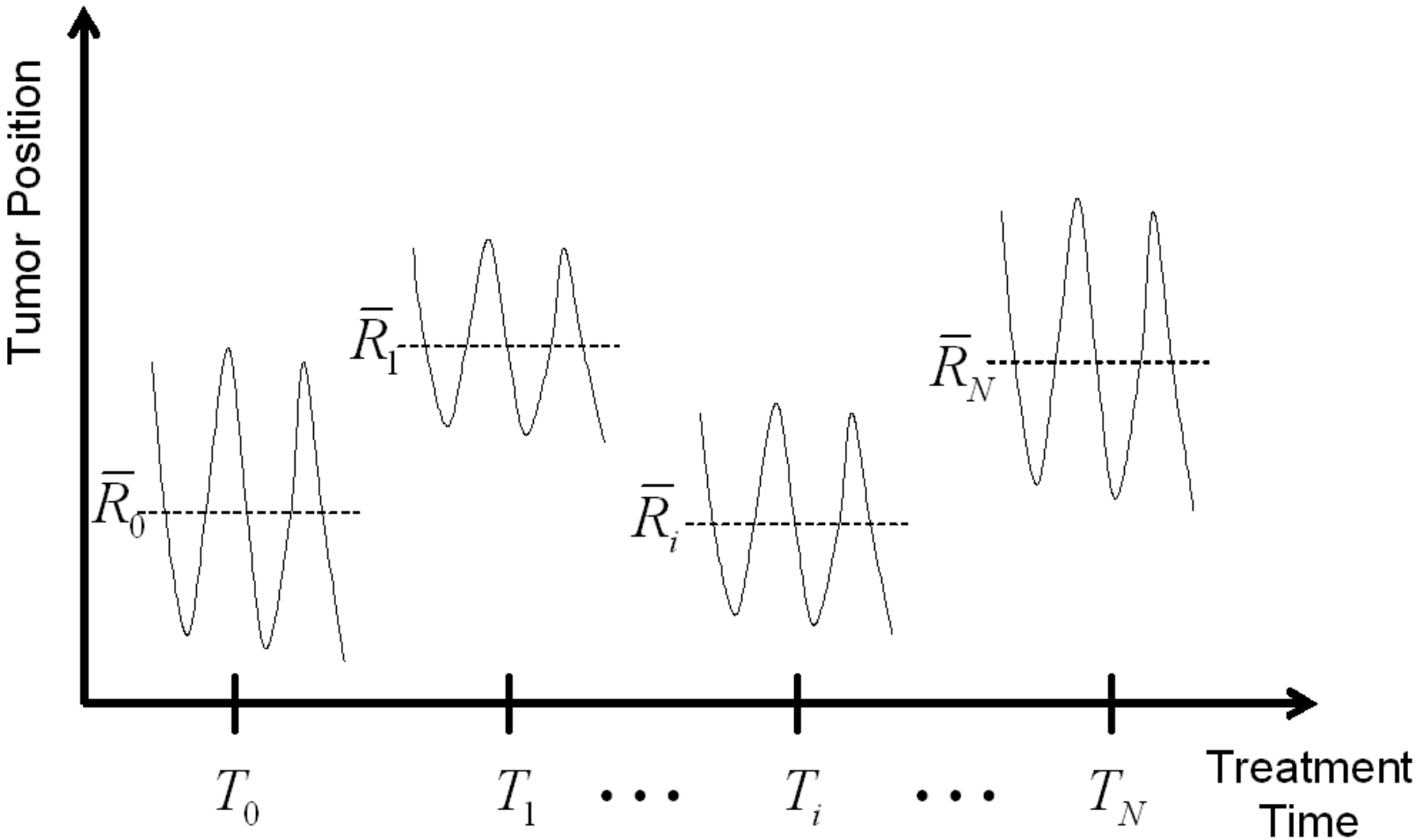
- **How to keep the patient geometry close to the reference model in the machine coordinate system, or how to update the model to accommodate the changing patient geometry, are exactly the research topics of IGRT.**



Two types of patient/organ motions: Inter- and intra-fractional motions

Figure Courtesy of Di Yan

Tumor Home Position and Instant Position



Respiratory motion is both intra- and inter-fraction motion

Treatment Simulation of Mobile Tumors

- To build the reference patient/tumor model at the <u>reference home position</u>

- Errors in treatment simulation will influence all treatment fractions and should be handled carefully

Three Types of Motion Artifacts

- If CT scanning speed << tumor motion speed, → smeared tumor image

- If CT scanning speed >> tumor motion speed, → tumor position and shape captured at an arbitrary breathing phase

- If CT scanning speed ~ tumor motion speed, → tumor position and shape heavily distorted

Move Objects during CT

Courtesy of George T.Y. Chen

Motion Artifacts

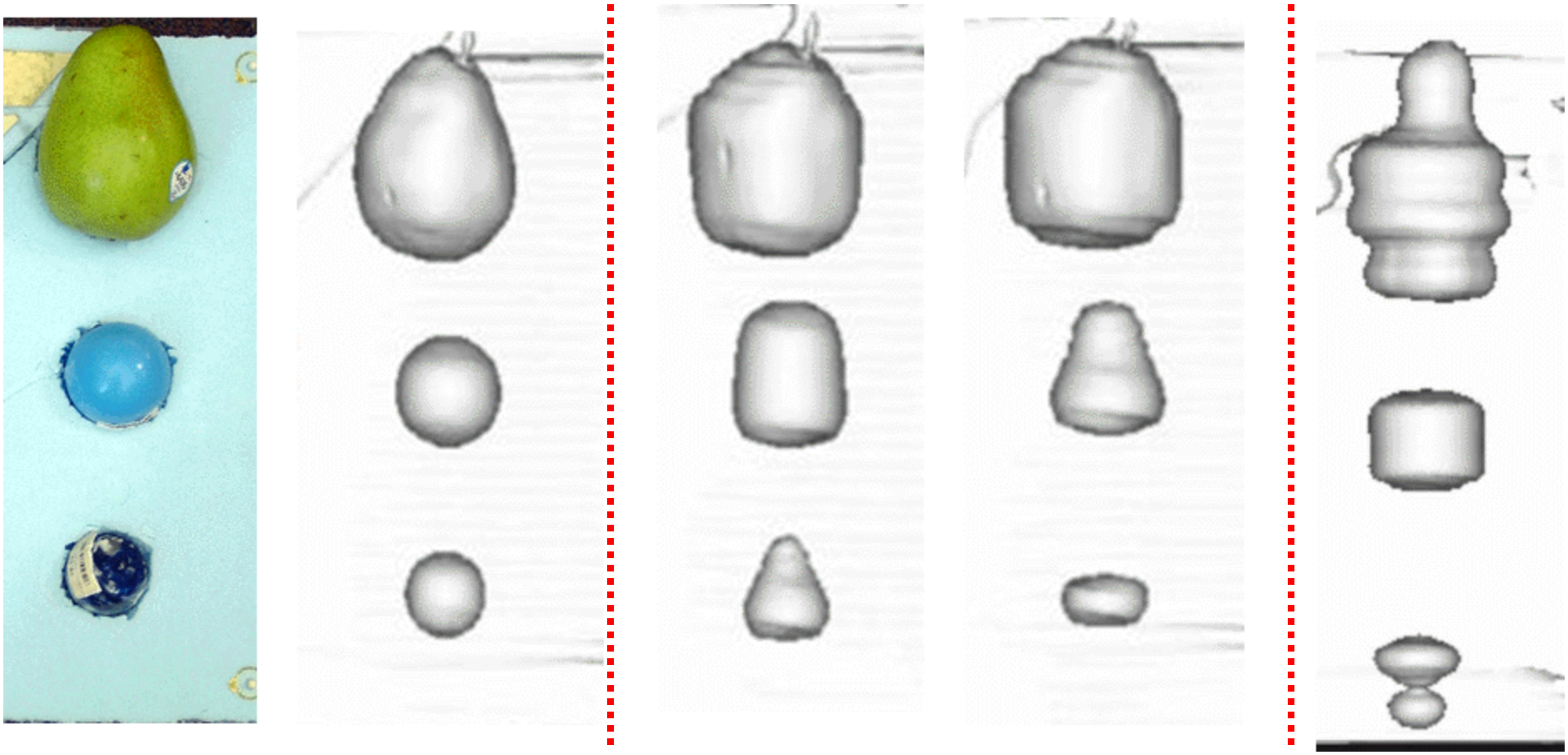
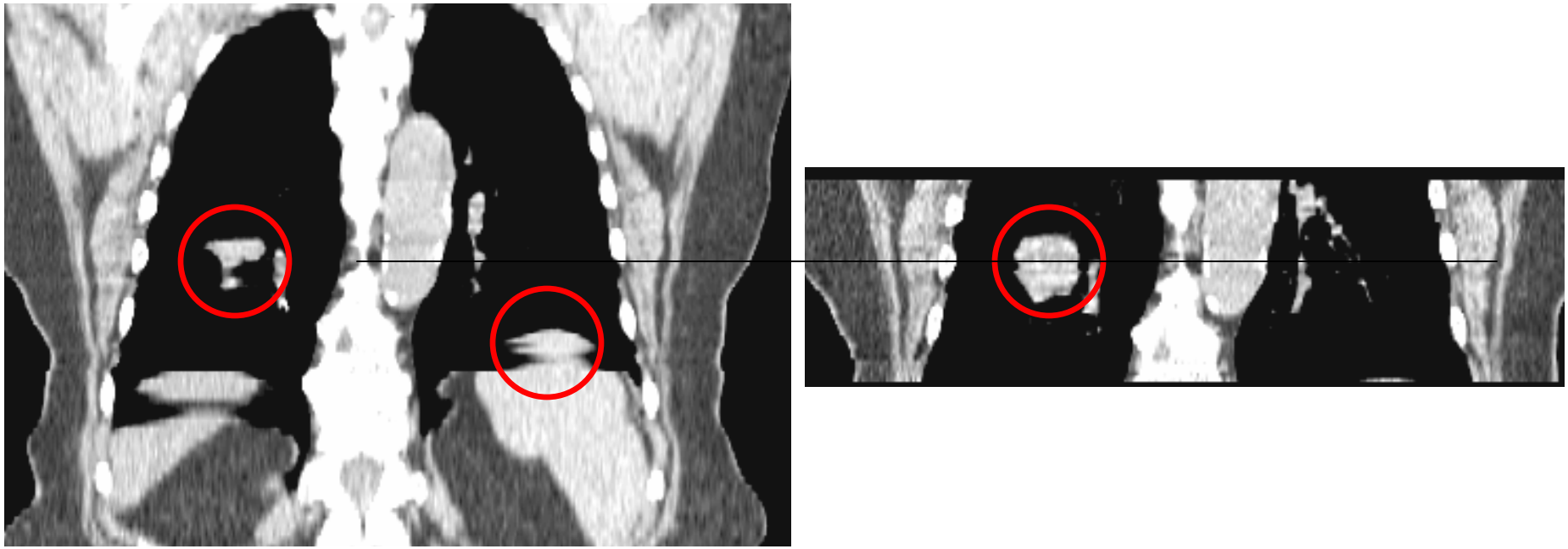


Photo **Static** **Moving / HS mode** **HQ**

Courtesy of George T.Y. Chen

CT Artifacts in Patients



Helical light breathing scan **4DCT – 1 phase**

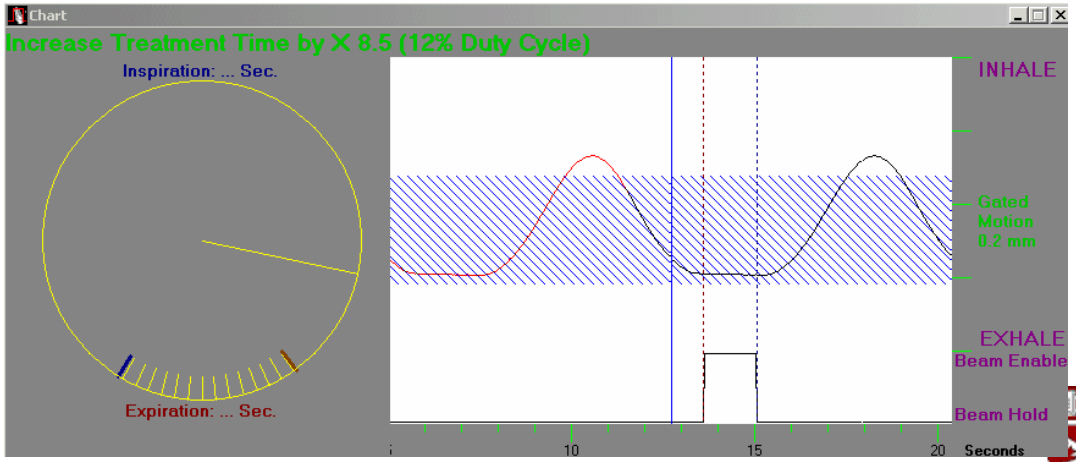
Courtesy of Eike Rietzel and George T.Y. Chen

4D CT Scan

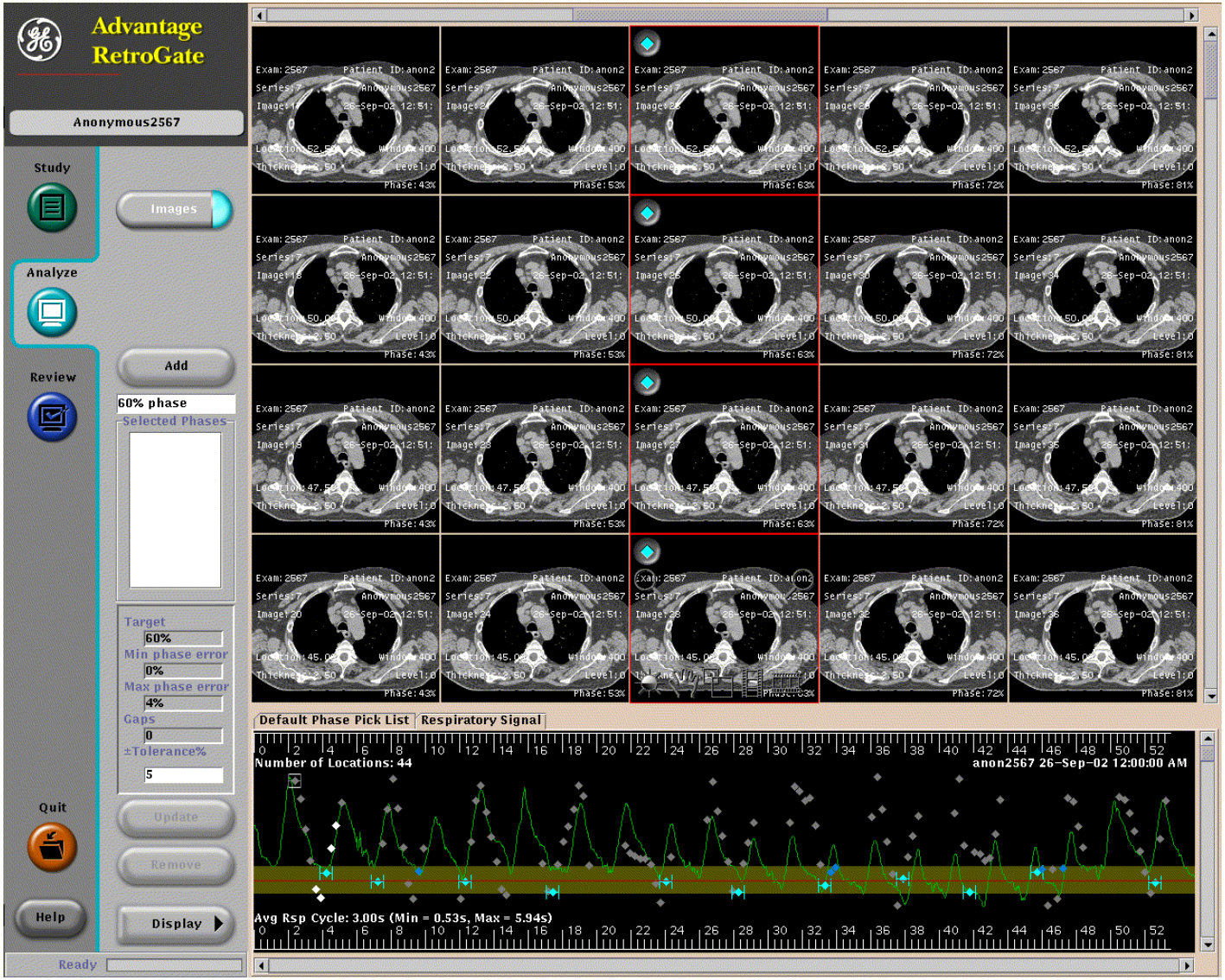
GE Lightspeed Scanner

Varian RPM system

Record amplitude and breathing phase for each slice

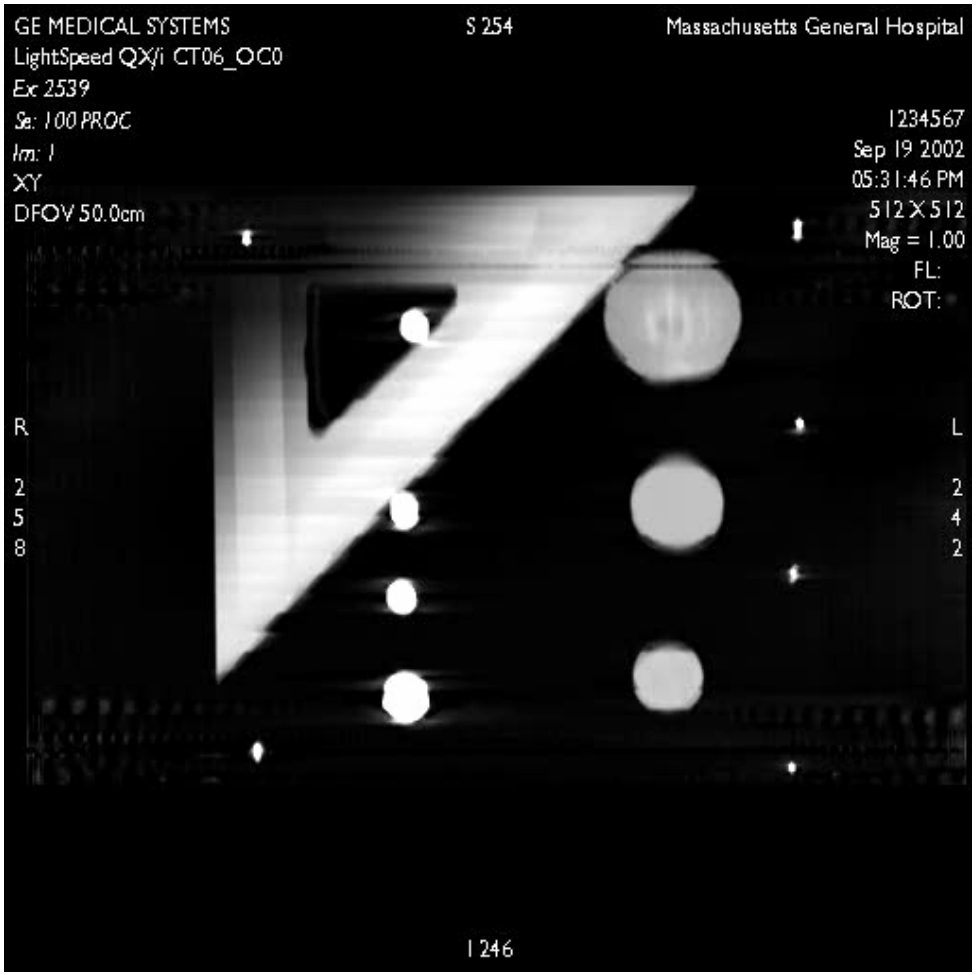


Resorting 500-1500 CT Slices



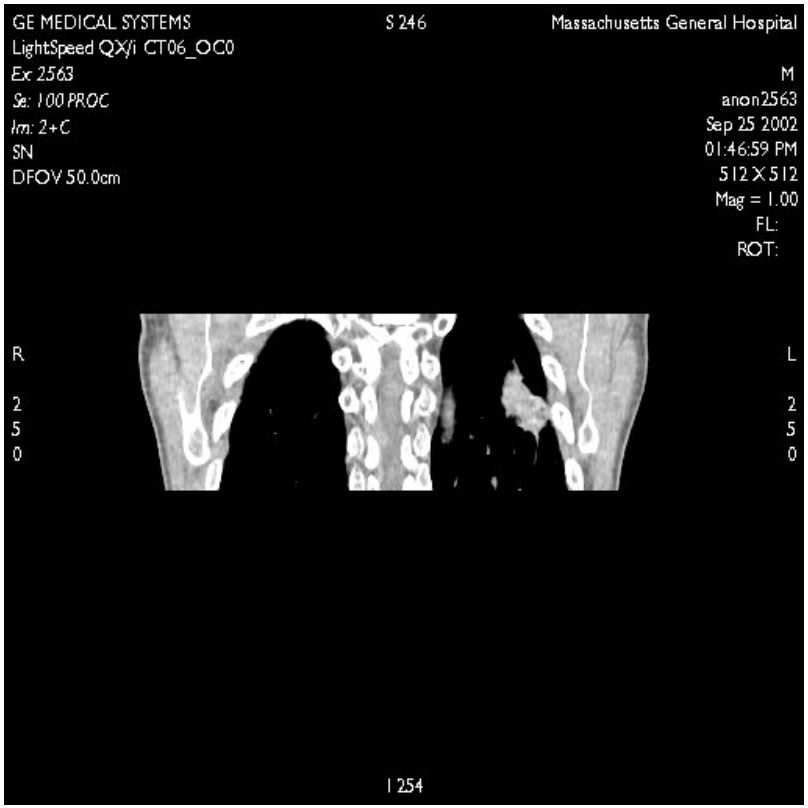
Courtesy of Eike Rietzel and George T.Y. Chen

4DCT Scan of A Phantom



Courtesy of Eike Rietzel and George T.Y. Chen

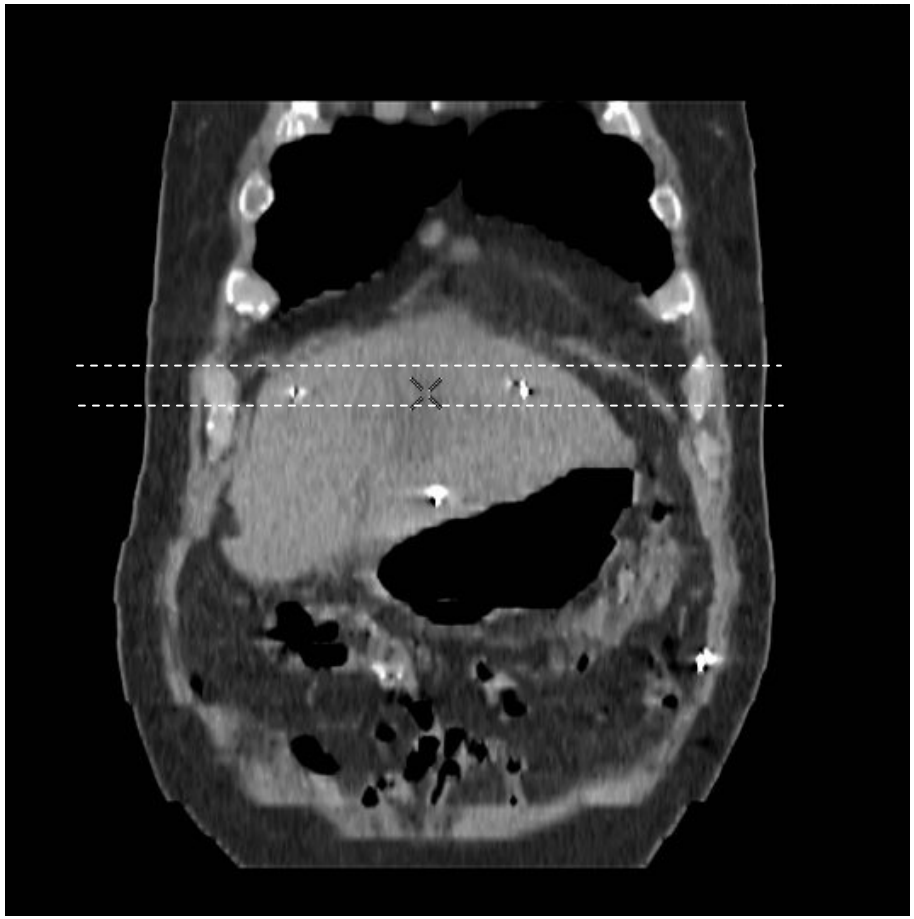
4DCT Scan of A Lung Tumor



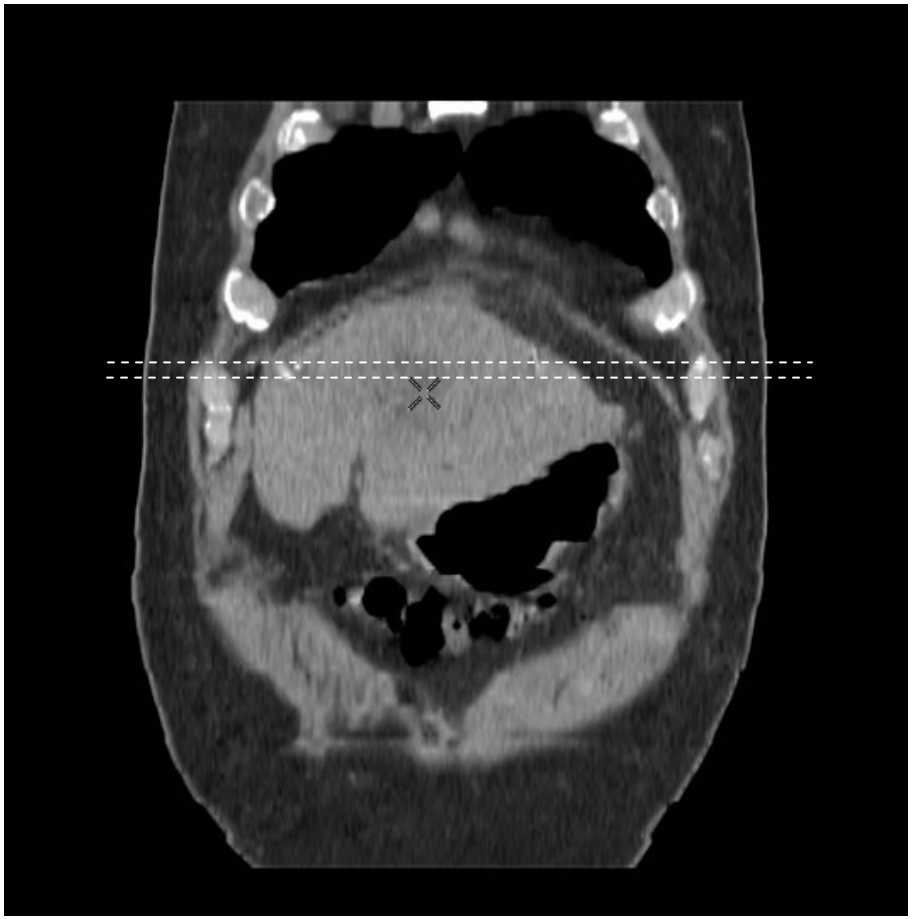
Courtesy of Eike Rietzel and George T.Y. Chen

Defining the gating window

ungated



gated



5 mm residual clip motion in SI direction

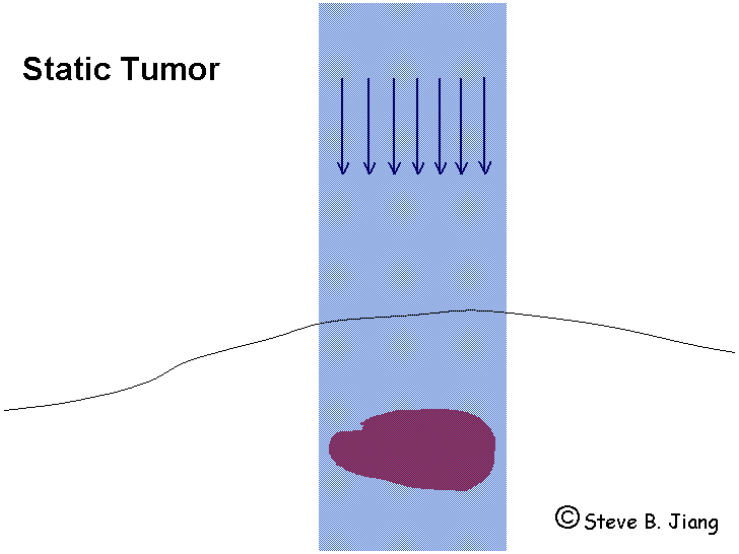
Chen et al., MGH 2004

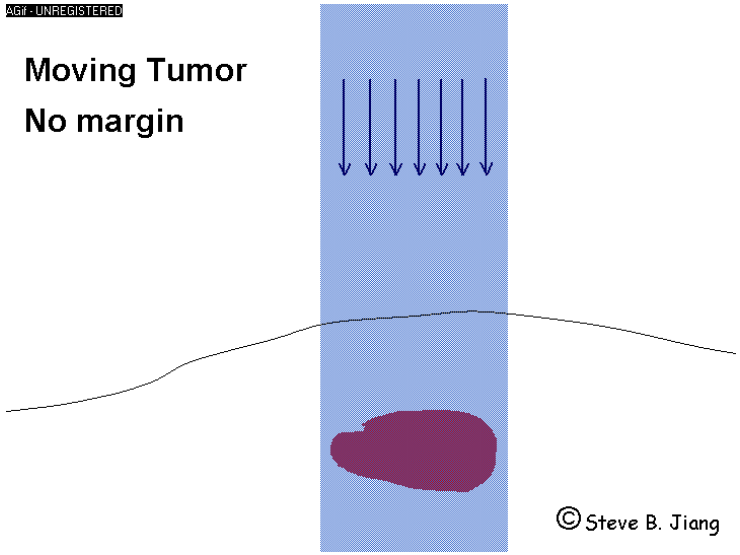
Some Notes on 4D CT

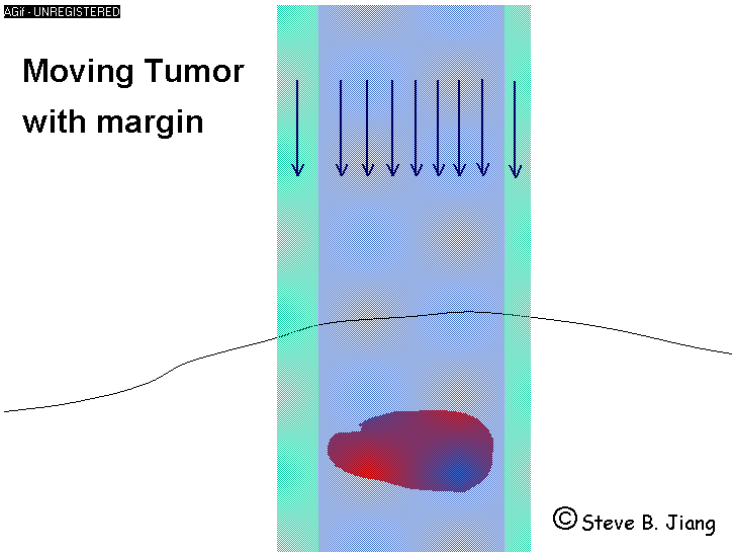
- 4D CT scan not only reduces motion artifacts, but also gives the tumor/organ motion information.

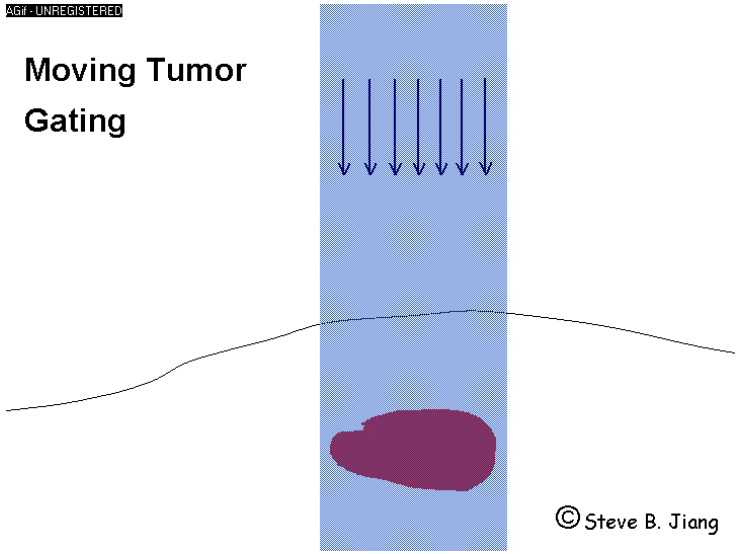
- 4D CT scan is NOT really 4D.
  - Temporal information is mapped into one breathing cycle.
  - Irregular respiration will cause artifacts in 4D CT images.
  - Breath coaching is always needed.

Techniques for Treating Moving Tumor

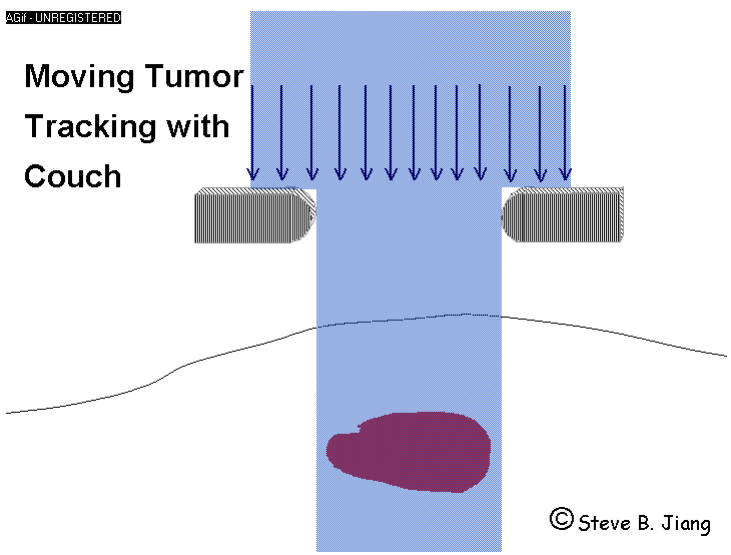


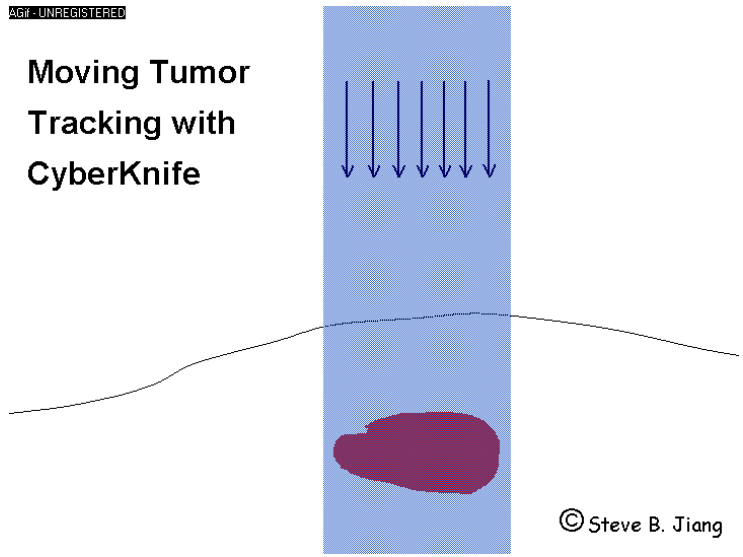


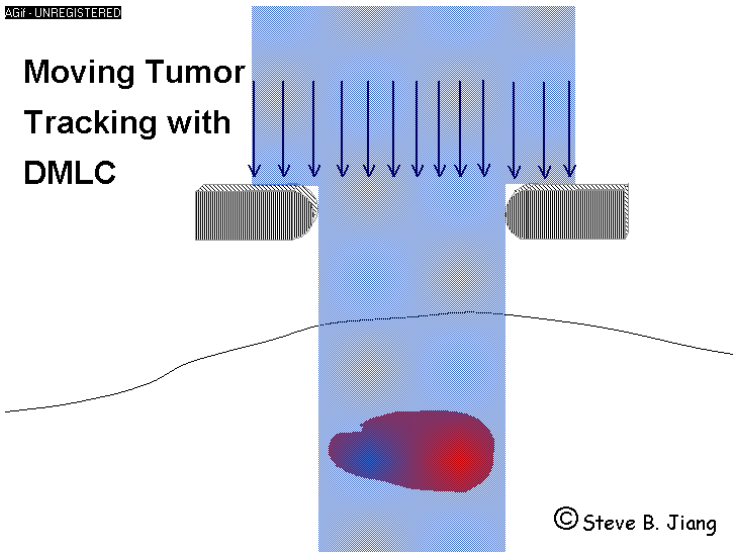


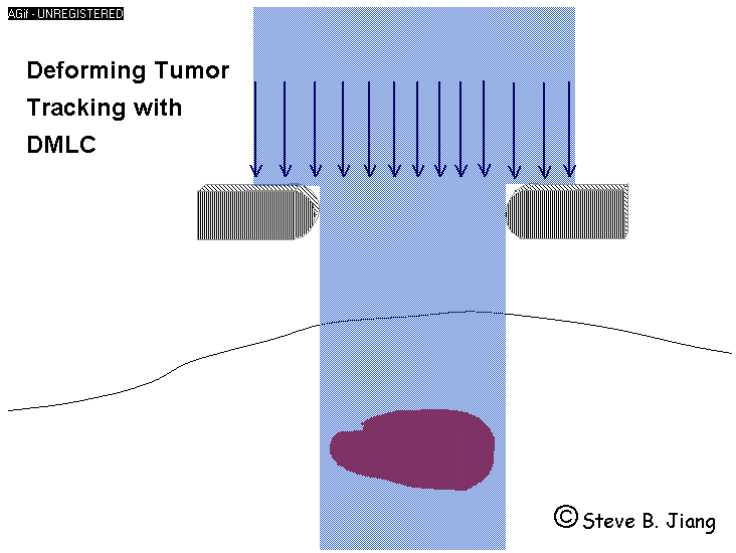


Techniques for Treating Moving Tumor









"Margin" Techniques for Mobile Tumors

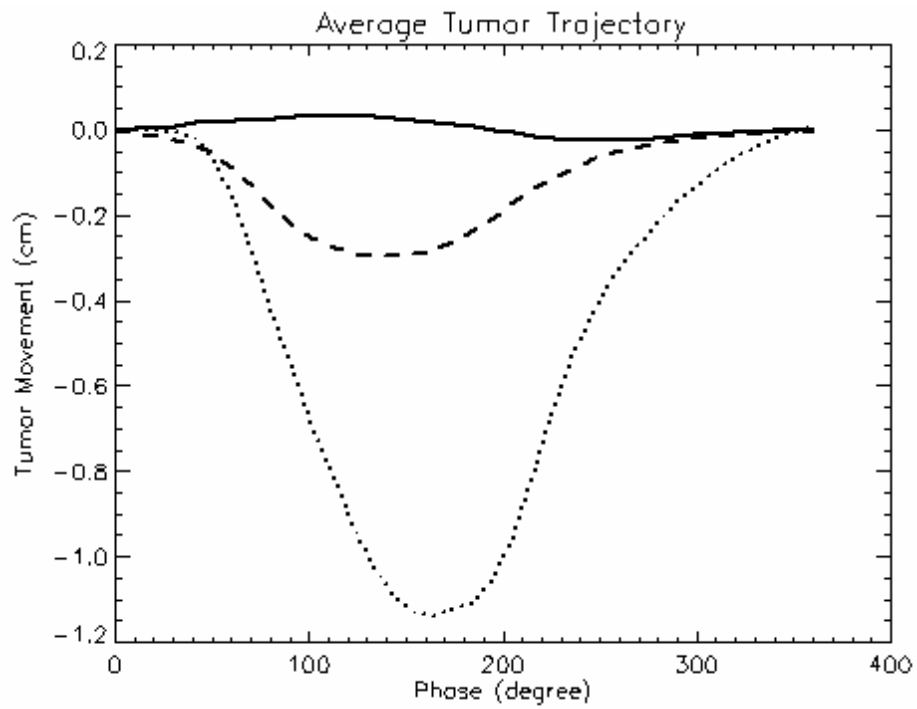
- Patient population-based CTV-PTV margin
- Patient specific CTV-PTV margin
  - measured for a specific patient through fluoroscopy or 4D CT scan
- ITV based on 4D CT or slow CT scan
- IMRT optimization using motion PDF
  - The more patient specific motion information is used, the more accurate motion "margin" results. However such info can vary during the treatment course.

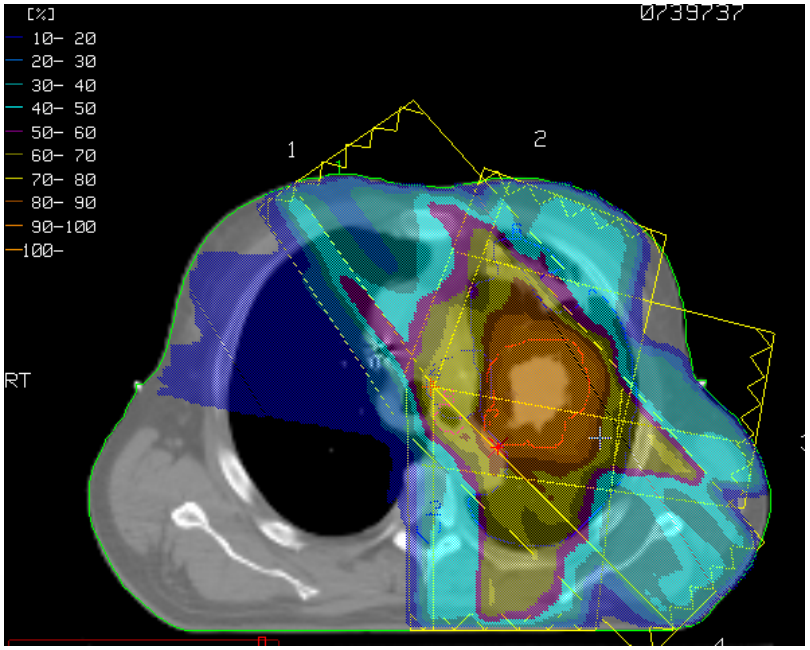
Current Status of MLC Tracking

- Various algorithm development work
  - MCV, MGH, Indiana Univ, Steve Webb, etc
- MCV implementation
  - Leaf motion based on real time tumor position
- MGH implementation
  - Synchronized Moving Aperture Radiation Therapy (SMART)
- May have a role in SBRT (efficiency)
- Precise localization of tumor position in real time is required

SMART: Planning/Simulation

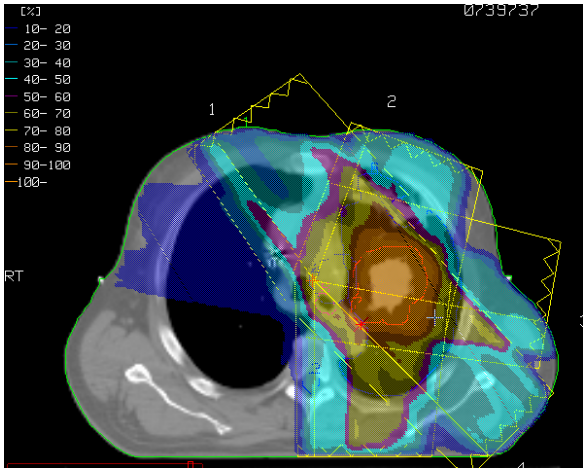
Measure average tumor trajectory (ATT)

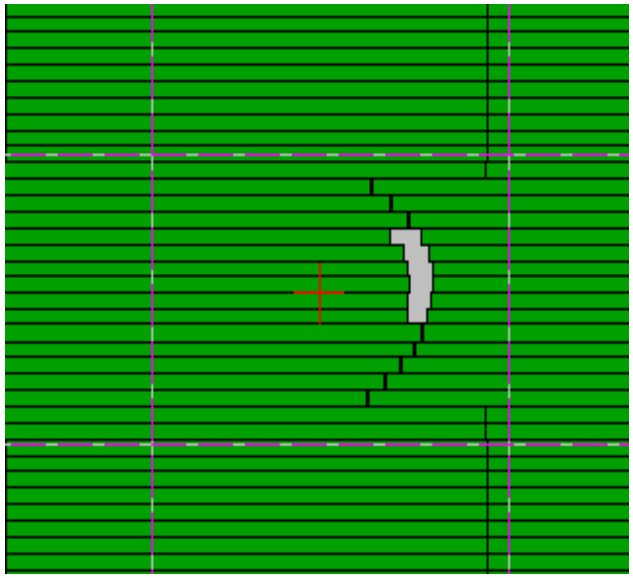


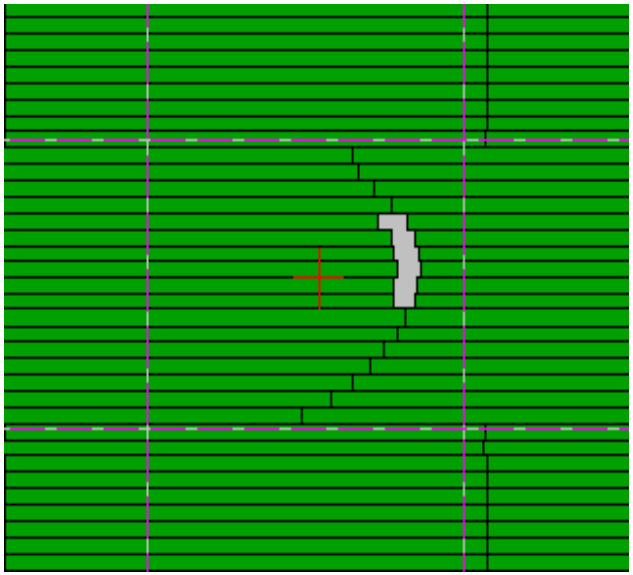


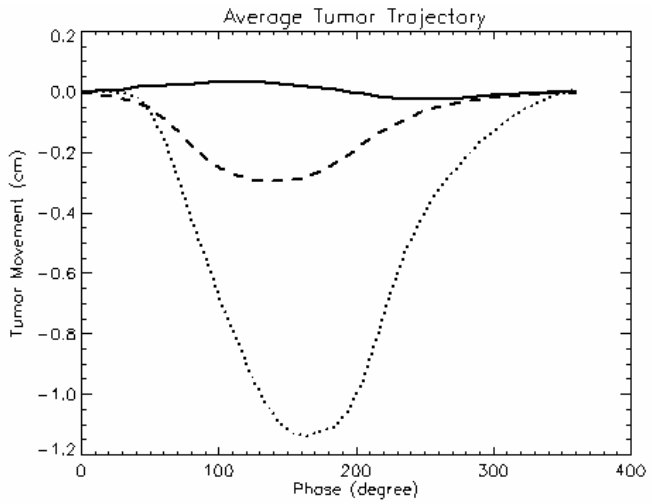
IMRT inverse planning using CT data at a particular breathing phase

SMART: Include tumor motion into IMRT MLC leaf sequence

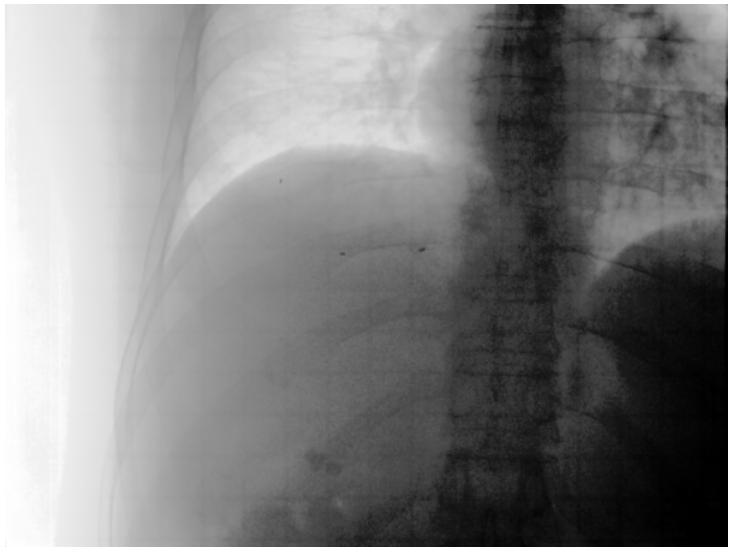








SMART: Treatment Delivery

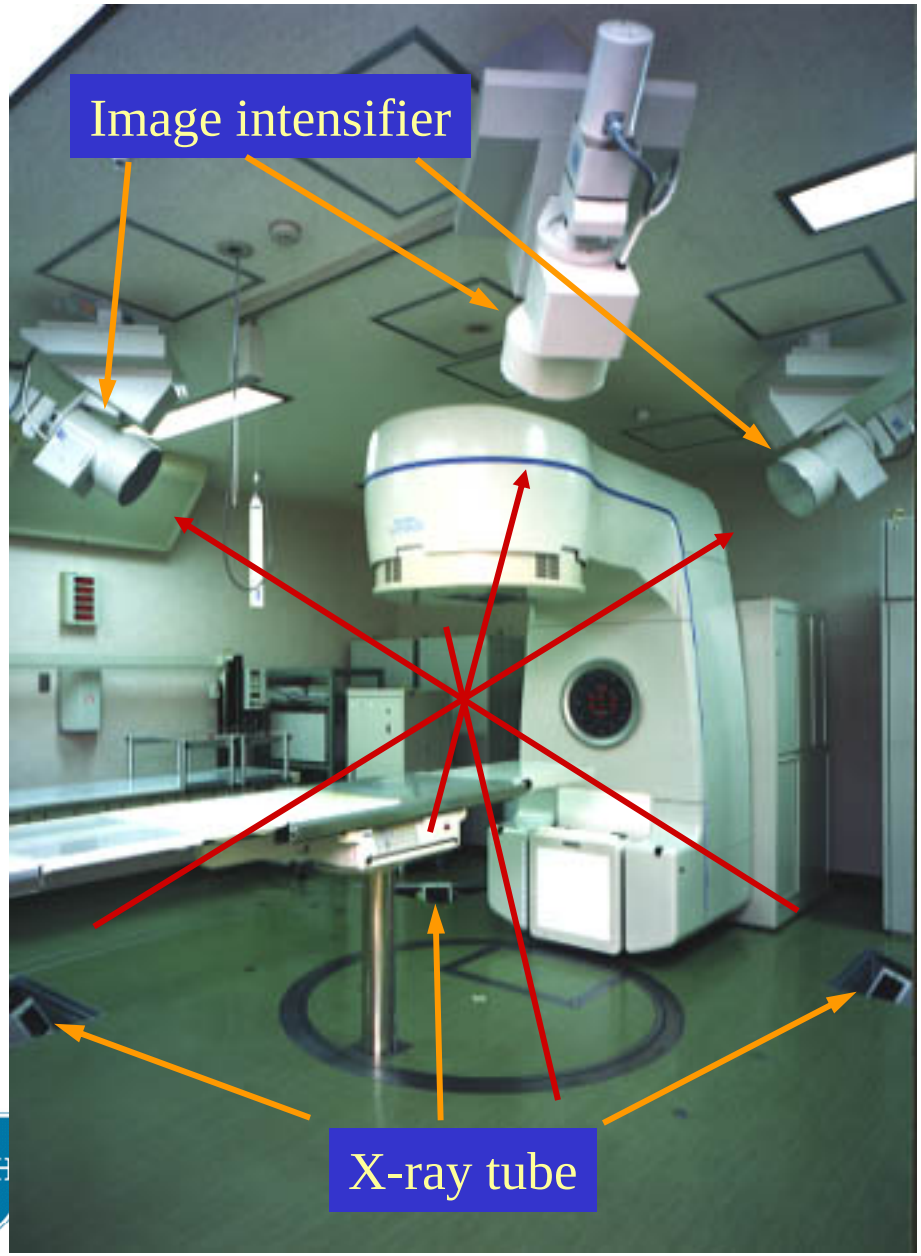


- ❑Monitor tumor motion
- ❑Synchronize the MLC motion with tumor motion
- ❑Interrupt and restart the treatment when target motion differs from the simulated pattern

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

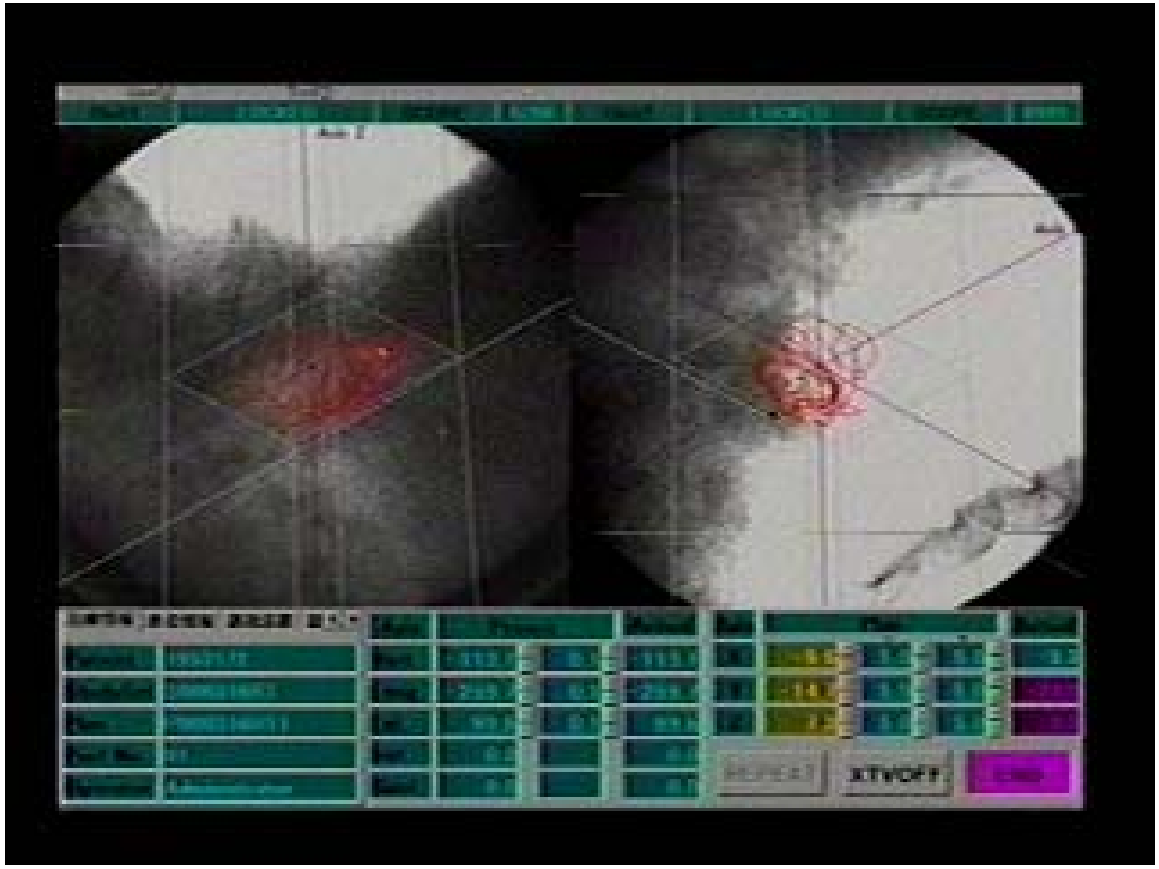
Real-Time Tumor Tracking System



- **4 sets diagnostic X-ray systems**
- **Motion tracking software**
- **Carbon fiber couch**
- **2 mm gold marker inside/near tumor**
- **1 mm detection accuracy**
- **0.033 s time delay**

Shirato et al IJROBP 48:435-442, 2000

Tumor Tracking System at Hokkaido University

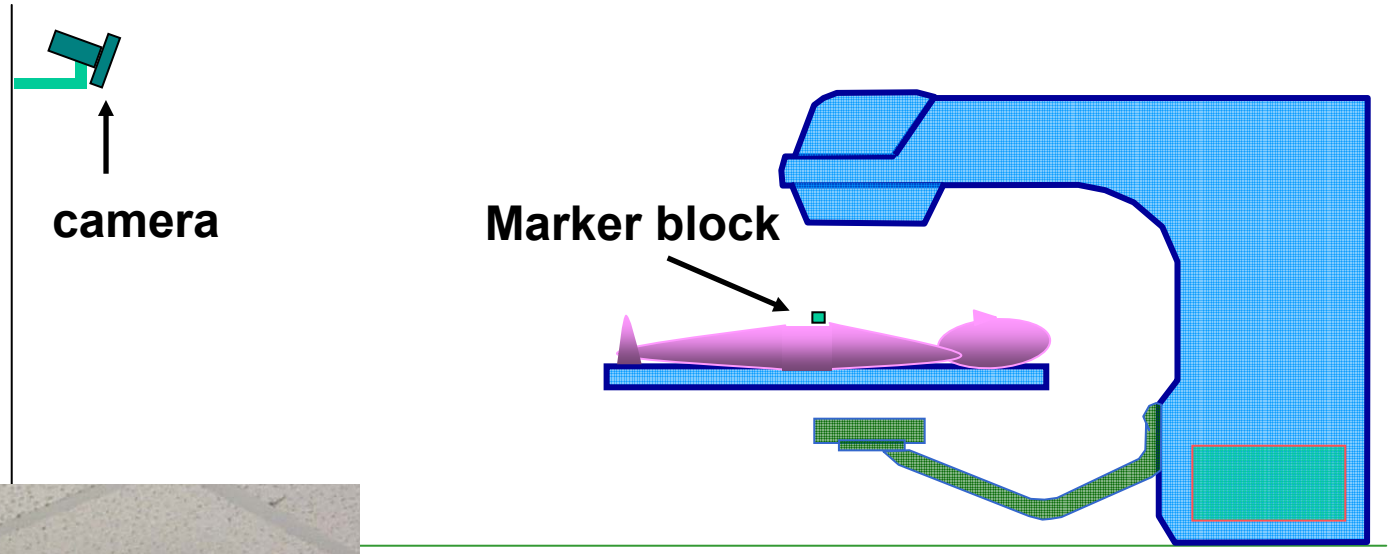


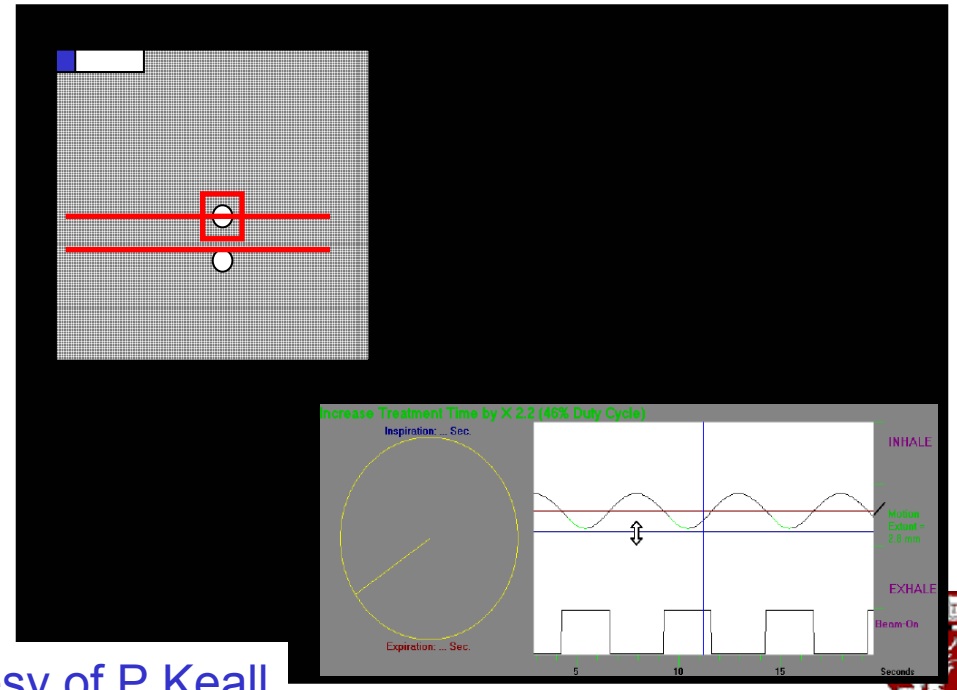
Courtesy of H Shirato

Problems with Internal Gating

- Invasiveness of the marker implantation procedure
  - Might be acceptable for liver and other abdominal sites
  - Not for lung due to the risk of pneumothorax
- Significant imaging dose may be required for fluoroscopic tracking

Varian RPM System





Photos courtesy of P Keall

Problems with External Gating

- **Uncertainties in deriving tumor position from external surrogates**
  - **The correlation between tumor position and external marker position can vary inter- and intra-fractionally.**

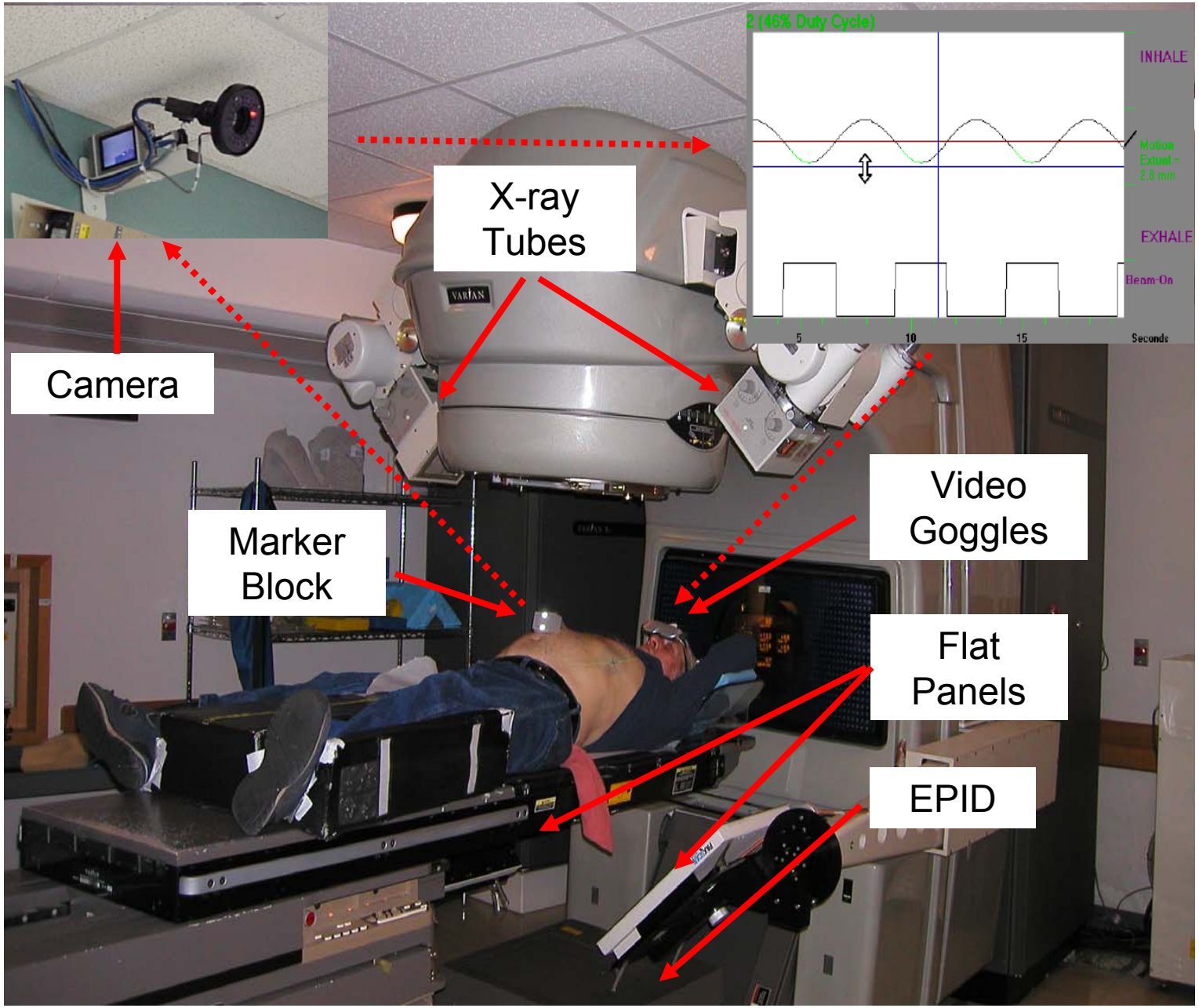
Accurate External Gating

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

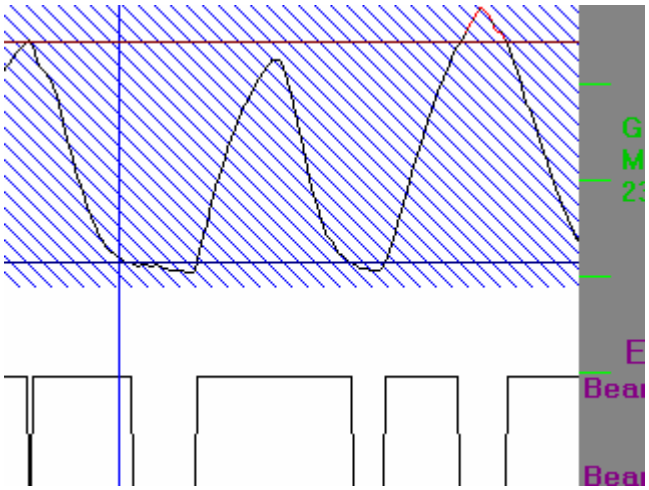
Key Components for Accurate External Gating

- Patient breath coaching
- 4D CT simulation
- Patient setup based on gated tumor image
- Treatment verification

Hardware Platform for MGH Gating Procedure



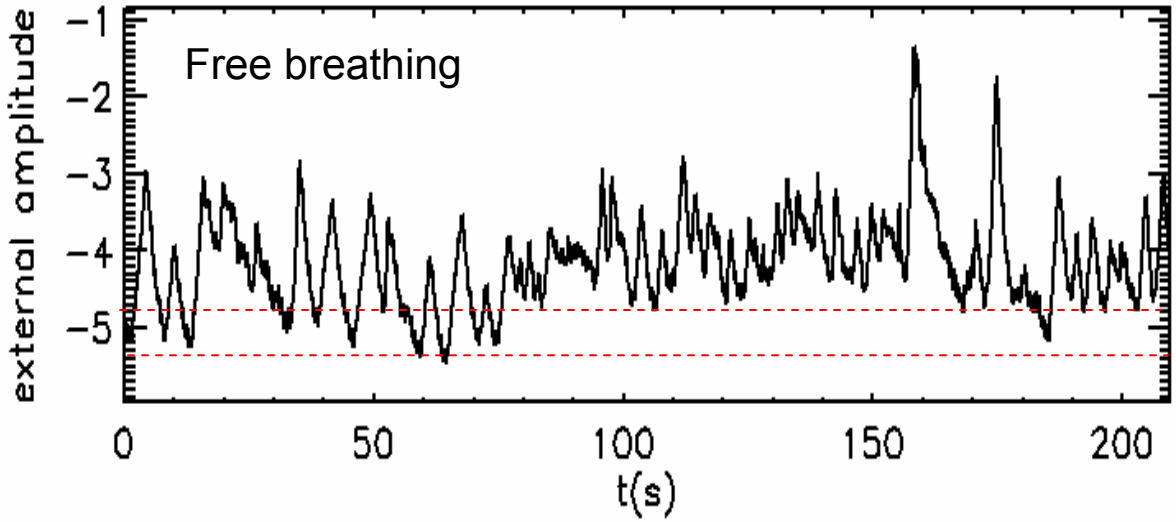
Breath Coaching Using RPM System

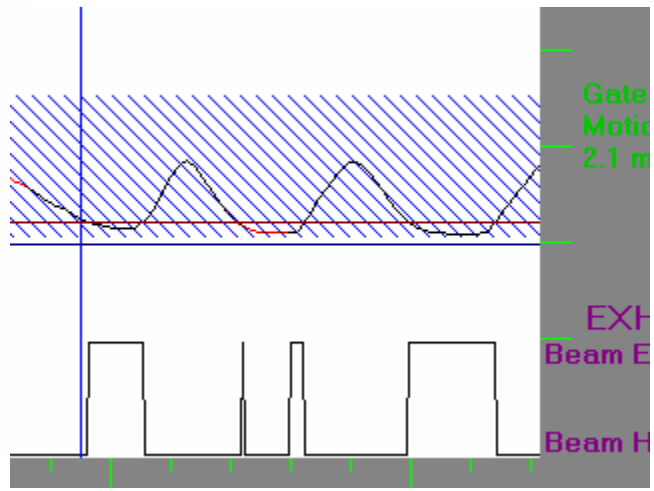


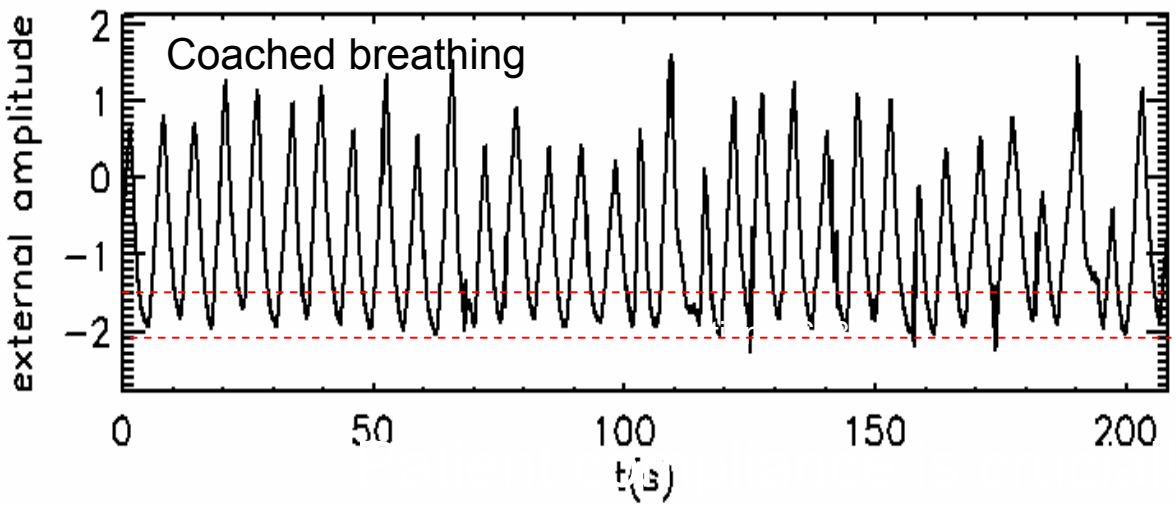
- Audio instruction
- Visual feedback
- 5 volunteers with 6 sessions (free breathing vs coached breathing)
- ~ 30 patients with one session (free breathing vs coached breathing)

T Neicu, R Berbeco, J Wolfgang, and SB Jiang, *Phys Med Biol*. 51(3):617-636.

A New Breath Coaching Protocol

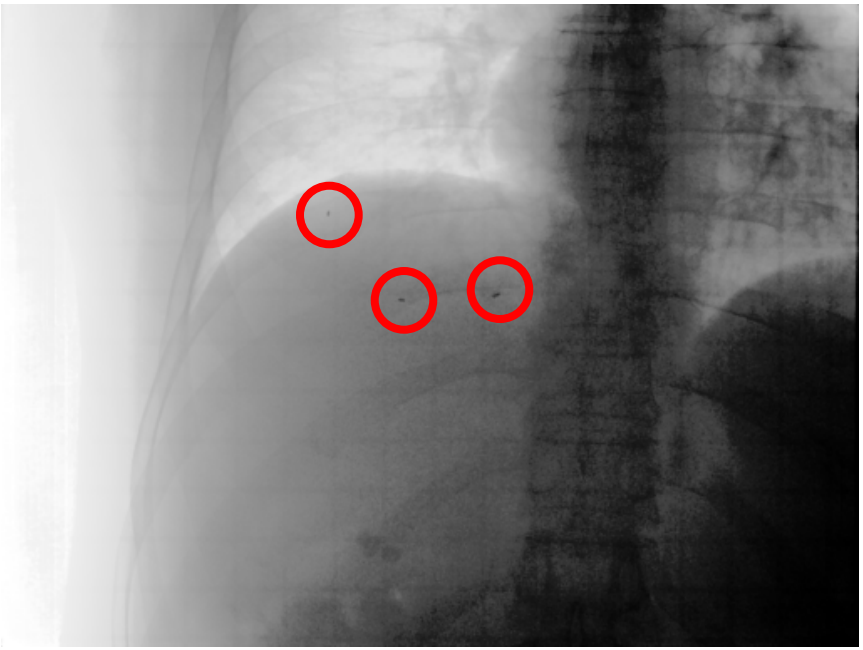


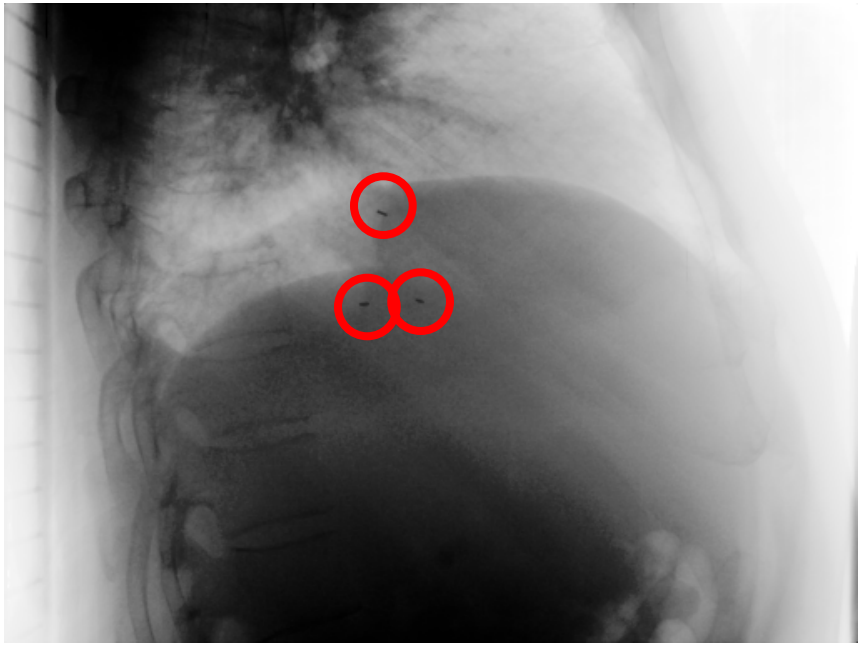




T Neicu, R Berbeco, J Wolfgang, and SB Jiang, *Phys Med Biol*. 51(3):617-636.

Gated Radiograph for Patient Setup

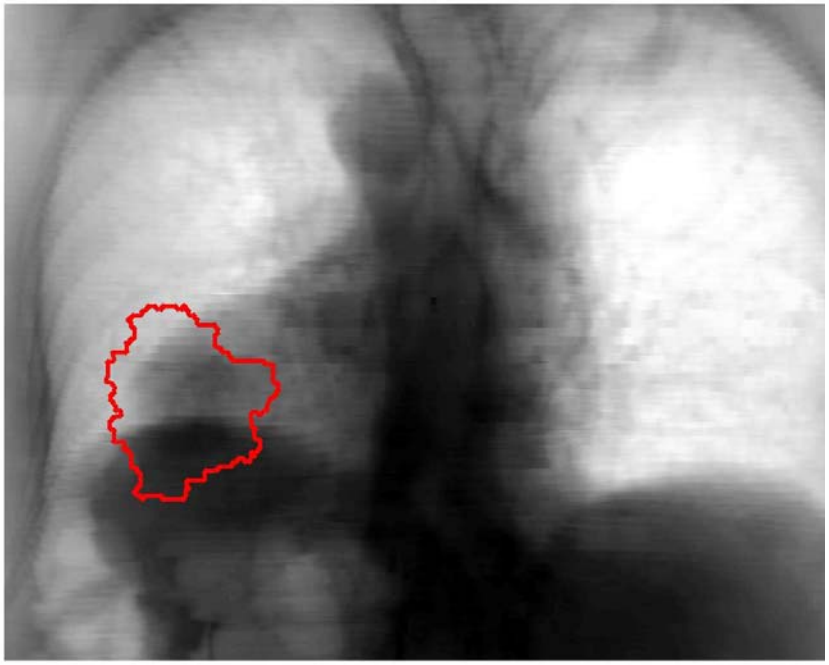




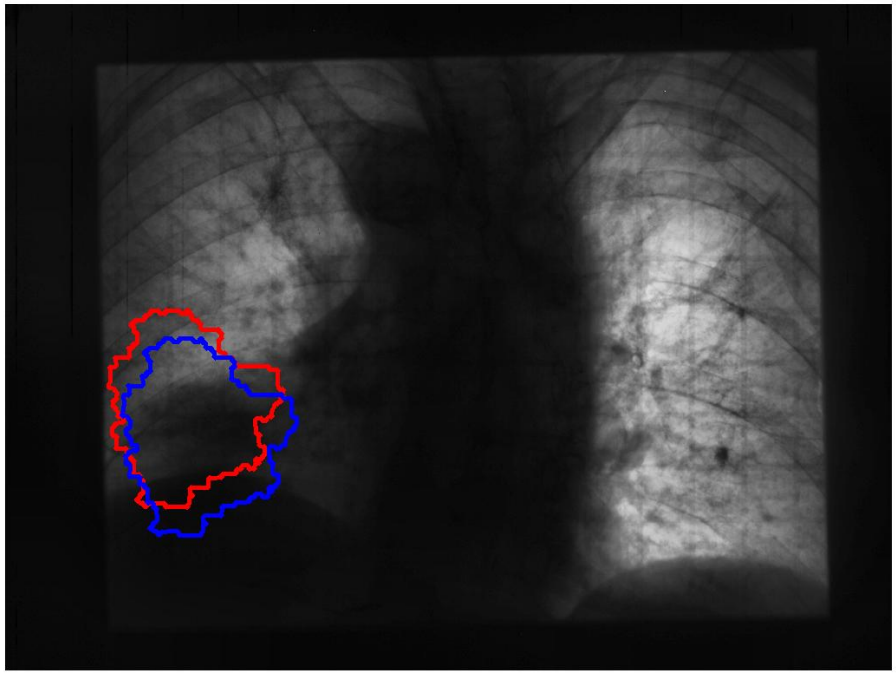
AP LAT

Each radiograph requires ~1/5 dose of film

Gated Radiograph for Patient Setup



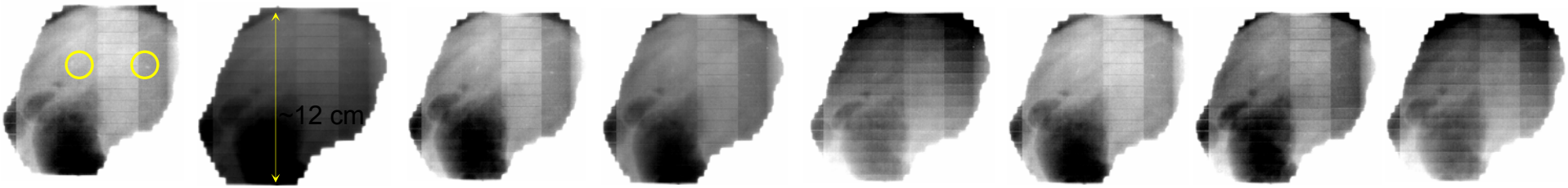
DRR

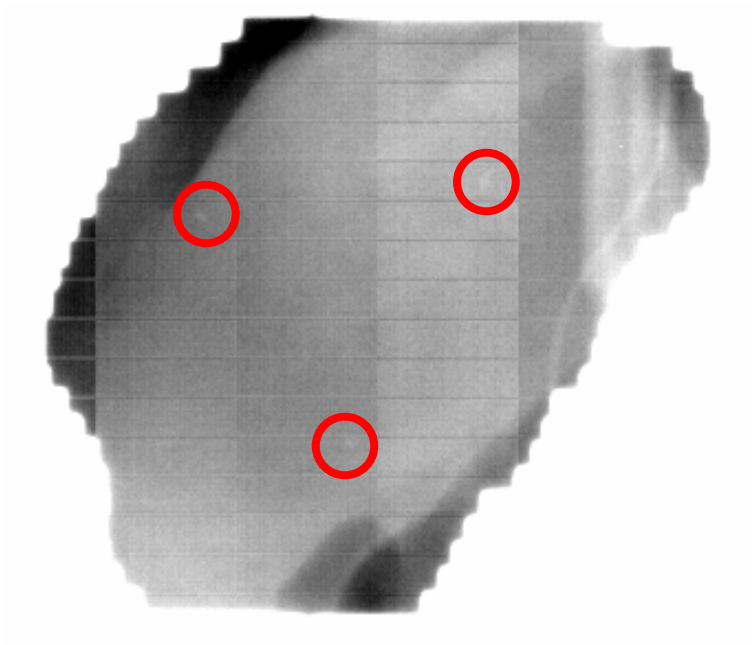


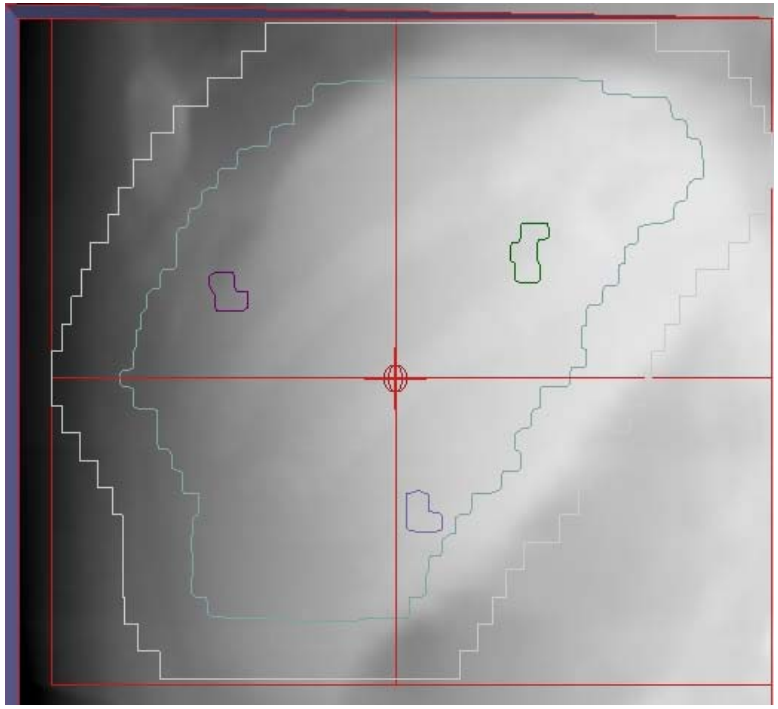
Radiograph

XL Tang, GC Sharp, and SB Jiang, 2006.

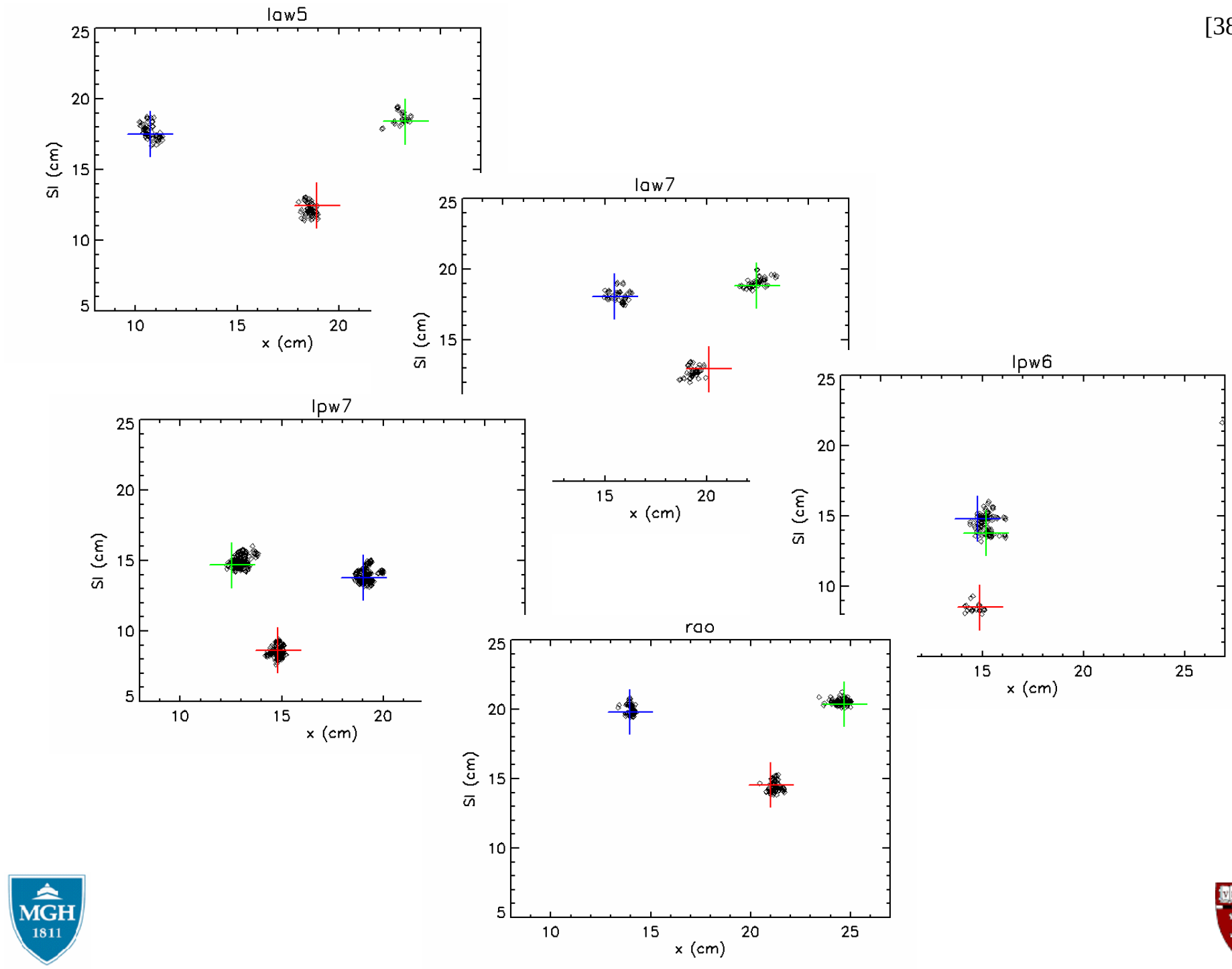
EPID Images versus DRRs







RI Berbeco, T Neicu, E Rietzel, GT Chen, and SB Jiang, *Phys Med Biol* 50(16):3669-3679, 2005.


law5
law7
lpw7
lpw6
rao
SI (cm)
x (cm)

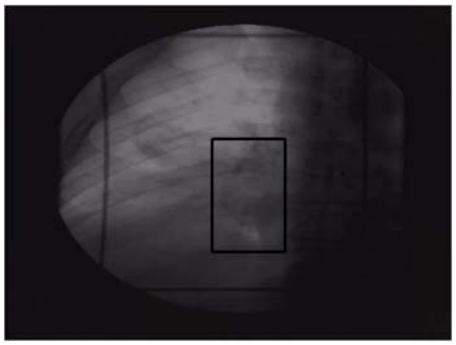
Future Development of Gated Radiotherapy

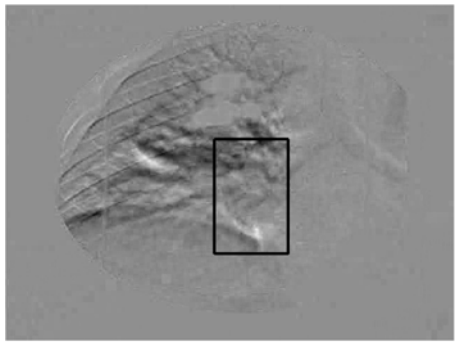
- Combine external and internal signals
  - More accurate than external gating
  - Less imaging dose than internal gating
- Lung treatment without implanted markers
- Issues with gated IMRT

Combine External/Internal Signals

- External gating, internal verification
  - Dynamically display tumor positions in the gating window, detected in x-ray images
- Double gating
  - External signal → imaging → tumor position → linac
- Hybrid gating
  - Drive tumor positions from external surrogates
  - Low frequency updating of external/internal correlation

Gating Directly Based on Tumor Mass



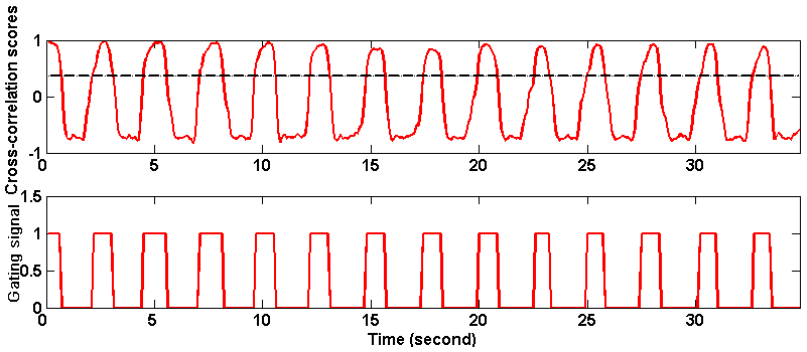


Patient Setup:

Training Fluoroscopic Images → Motion Enhanced Images → Reference Templates

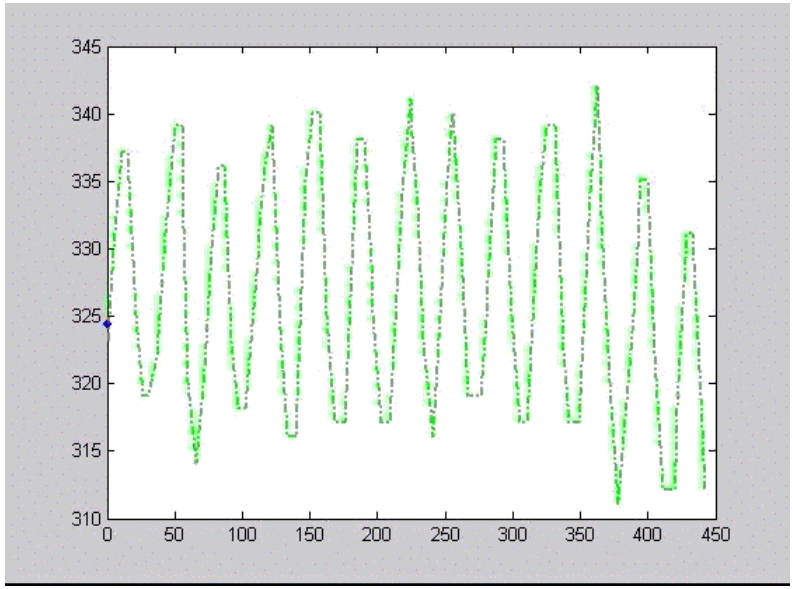
Treatment:

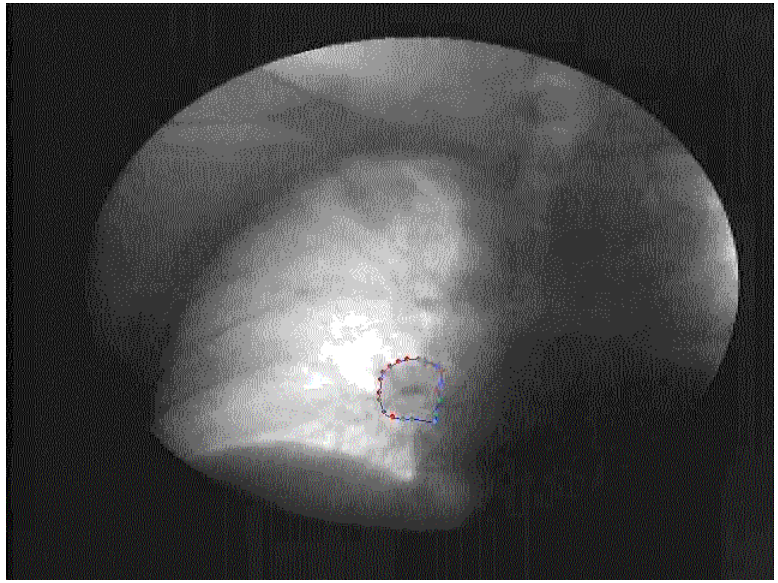
Incoming New Images → Motion Enhanced Images → Template Matching and Scoring → Gating Signal



RI Berbeco, H Mostafavi, GC Sharp, and SB Jiang, *Phys Med Biol.* 50(19): 4481-4490, 2005.

Multiple-Template Based Tracking





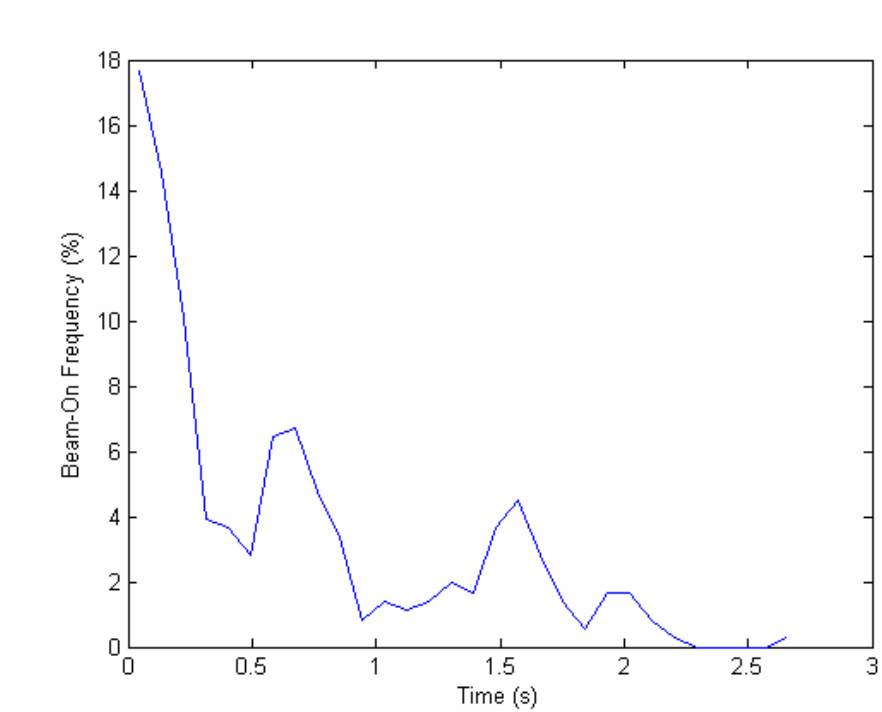
Y Cui, J Dy, GC Sharp, and SB Jiang, 2006.

Tracking with Deformation

QY Xu, RJ Hamilton, and SB Jiang, 2006.

Issues with Gated IMRT

- Treatment verification
- Treatment time
  - May not be a problem for Step and Shoot
- Biased beam-on time in the gating window



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