Respiratory Motion Management Systems

Christopher Peeler, Ph.D.
Assistant Professor, Thoracic Service
Department of Radiation Physics
The University of Texas M.D. Anderson Cancer Center

AAPM Annual Meeting

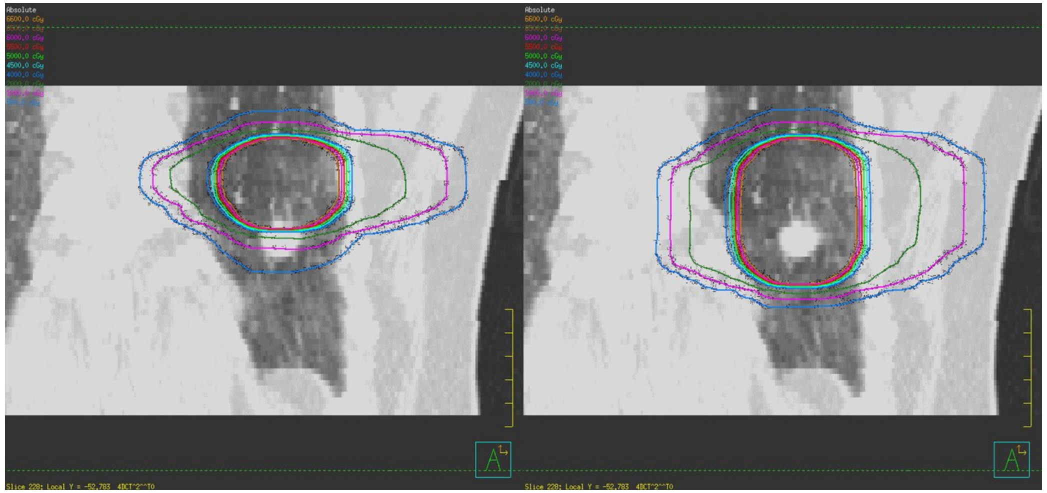
July 11, 2022

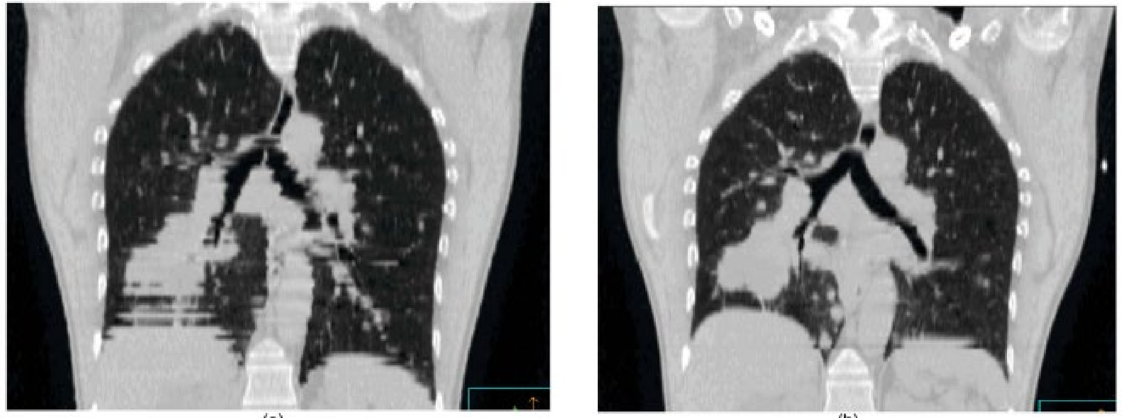
Disclosures

- Nothing to disclose

Why do we care about respiratory motion?

- Target miss
  - Underdose target
  - Overdose normal tissues
- Image artifacts
  - Uncertainty in target/organ at risk (OAR) delineation and dose calculation
- Difficulty in daily target alignment
  - Differences between reference and daily imaging
- More conformal treatments will be more greatly impacted





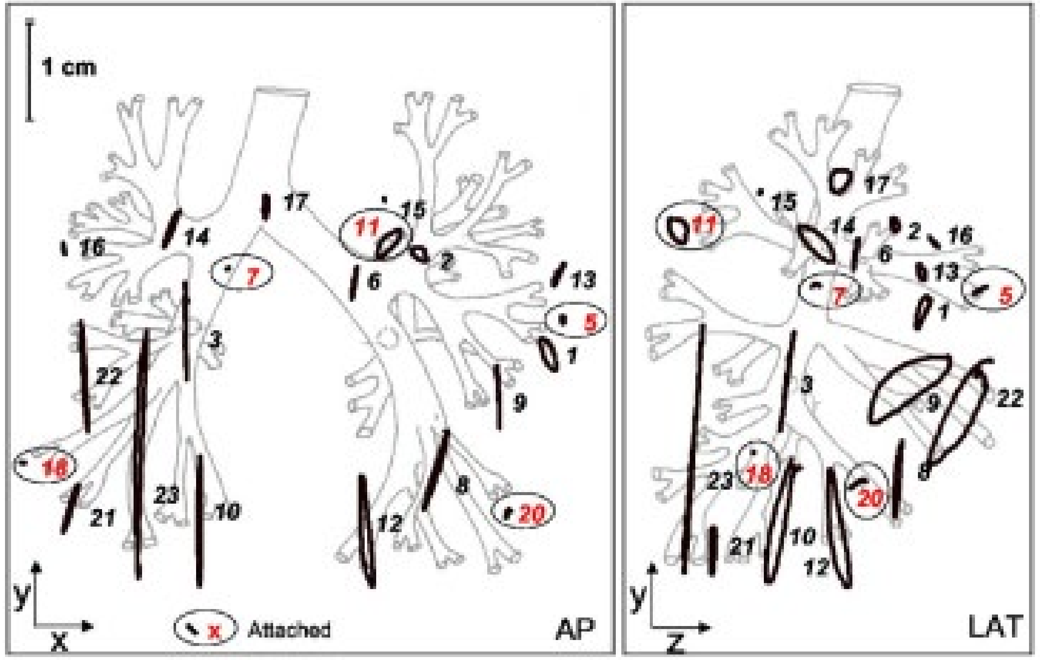
(a) (b)

Keall P et al. 2006. *Med. Phys.*

Impact of respiratory motion

- Primary sites affected are in thorax and abdomen

- Magnitude of respiratory motion can be substantial
  - Motion is primarily in the SI direction but can occur in any direction depending on location of target/OAR
  - Motion is patient specific



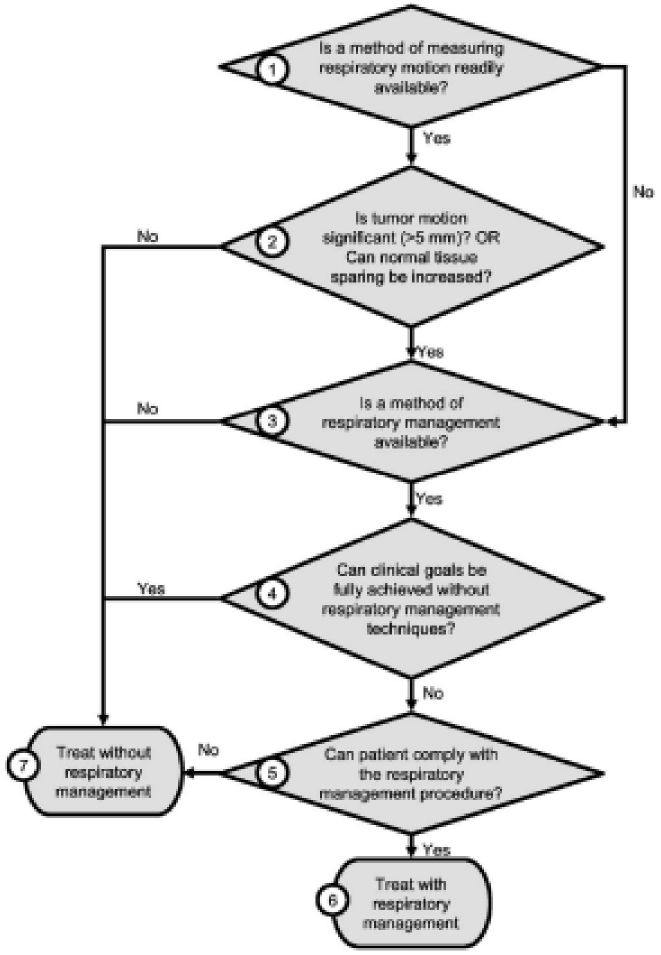
Keall P et al. 2006. *Med. Phys.*

Purpose of respiratory motion management

- Accurate delivery of radiation to moving targets
  - Ability to reduce margins
- Sparing of normal tissue through reduced margins
- Improvement in DVH characteristics through changes in organ volume/location
  - Increase in lung volume
  - Separation of target and normal tissue
    - Lung/breast targets near heart and chest wall
    - Abdominal targets near stomach and bowel

When do we need respiratory motion management?

- If a target is expected to move, then some form of management should be done to evaluate the motion
  - Driven by clinical goals
  - May not be deemed necessary in some cases, i.e. palliative treatments
- AAPM TG-76 Report recommends that respiratory motion management be performed when a target moves >5mm
  - Management at treatment can ultimately be active or passive



Keall P et al. 2006. *Med. Phys.*

Categories of motion management systems

- Motion-encompassing methods
- Respiratory gating and breath-hold techniques
- Forced shallow-breathing
- Respiration-synchronized techniques

Motion-encompassing methods

Accounting for motion at simulation

- Motion encompassing methods can be used to generate simulation images which account for target and OAR motion

- Include several different computed tomography (CT) methods
  - Slow CT
  - Inhalation and exhalation breath-hold CT
  - 4DCT

- Latter two methods require some method of tracking respiratory phase

Slow CT

- Scanning slowly will effectively create an average image of the target and other moving OARs
- Will deliver more imaging dose than a standard free-breathing scan
- Does not require any tracking of respiratory motion
- Will likely produce an image with motion artifacts particularly if the scan speed and patient breathing rate are not well-matched and if target motion is large

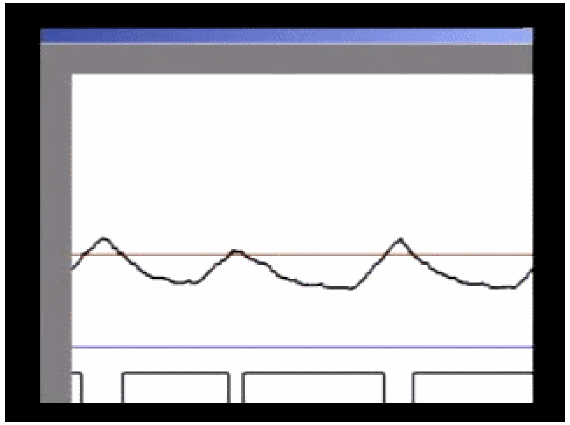
Tracking respiratory phase

Pneumatic bellows

Surface tracking

Infrared reflectors Infrared camera

Respiratory trace

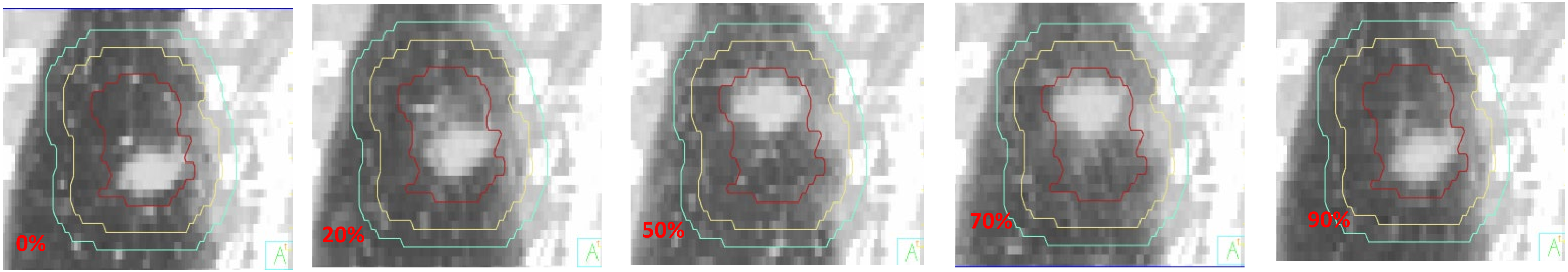


Inhalation and exhalation breath-hold CT

- CT scans acquired at max inhale and max exhale
- Allows for visualization of maximum motion of target
- Target can be contoured on both scans and then interpolation can be done between the two locations if no overlap
- Requires some method of ensuring a consistent breath-hold
- Preferable to use a free-breathing scan for actual treatment planning if no other motion management is to be done
    - More nominal representation of lung volume

4DCT

- Respiration-correlated CT allows for visualization of tumor motion
- Low pitch CT scan acquired while tracking respiratory phase
- Image data is associated with respiration based on phase or amplitude



4DCT

4DCT

- Maximum intensity projection (MIP) over all phases can be used for target contouring
  - Internal target volume (ITV) described by ICRU 62 can be developed based on the MIP
  - May elect to use an iGTV if a CTV is not used

- Average intensity projection (AIP) is typically used for treatment planning and dose calculation
  - Average representation of anatomy if patient is free-breathing at treatment
  - Daily CBCT imaging will more closely resemble the average

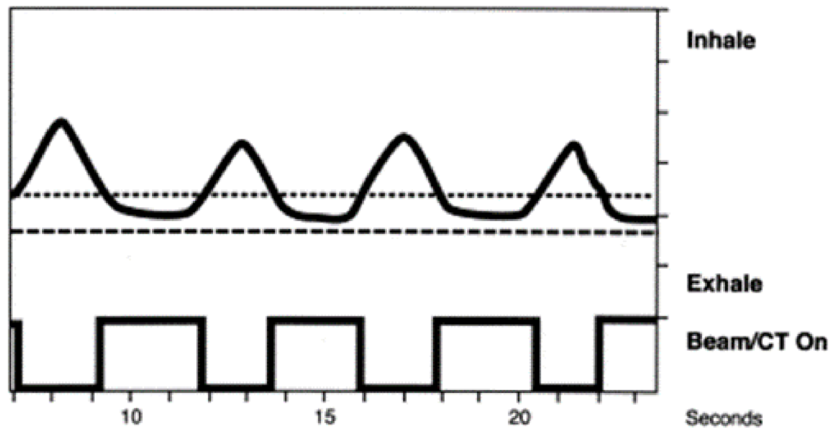
Respiratory gating and breath-hold techniques

Respiratory gating

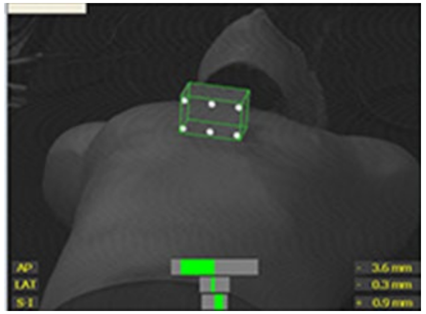
- Different considerations for gating techniques
  - Breath-hold vs. Free-breathing
  - Inhale vs. Exhale

- Surrogate is generally required for determining what respiratory phase the patient is in

- Gating method is generally linked to the treatment machine so that the beam is stopped when patient is outside gating window

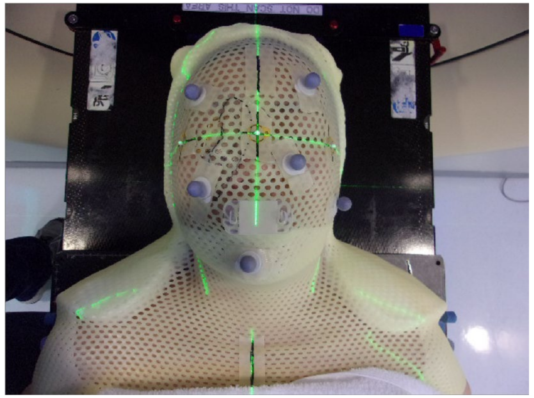


External surrogates – reflective markers



Varian RPM box

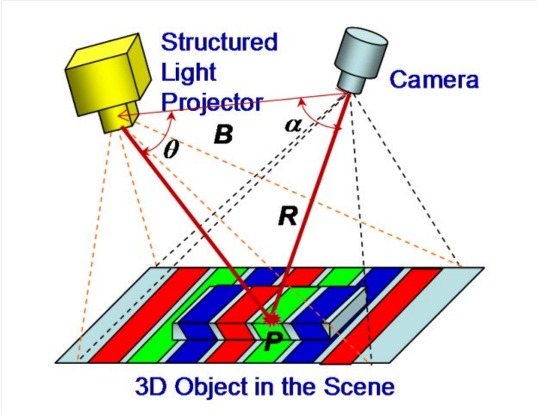
Cyberknife



ExacTrac

External surrogates - surface imaging

- Systems may be stereoscopic or monoscopic
- Structured light
  - Light of a known pattern projected onto patient
  - Camera(s) monitor surface
  - Deformation of pattern used to determine 3D surface
  - Compare 3D surface to expected 3D surface
  - Ex. Speckle pattern in VisionRT
- LED/laser scanning
  - Surface is scanned with laser or LED light
  - Reflection is detected by camera
  - Triangulation and deformable registration used to calculate surface
  - 3D surface compared to planned 3D surface
  - Ex. C-RAD Catalyst uses visible range LEDs to scan surface



Geng. 2011. Advances in Optics and Photonics.

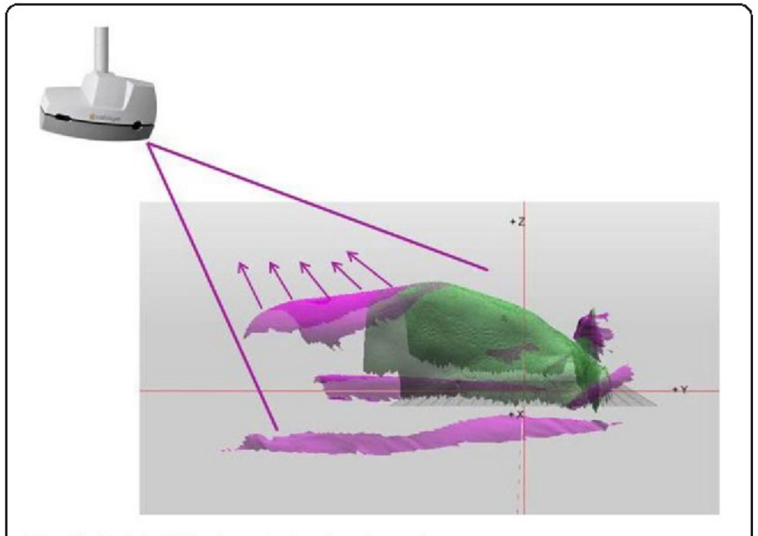
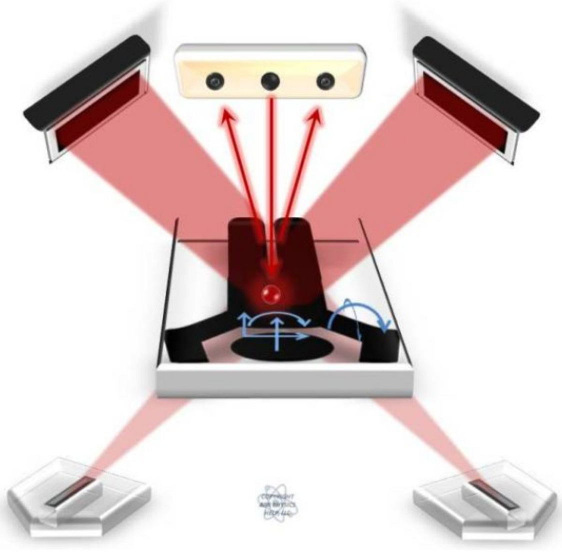


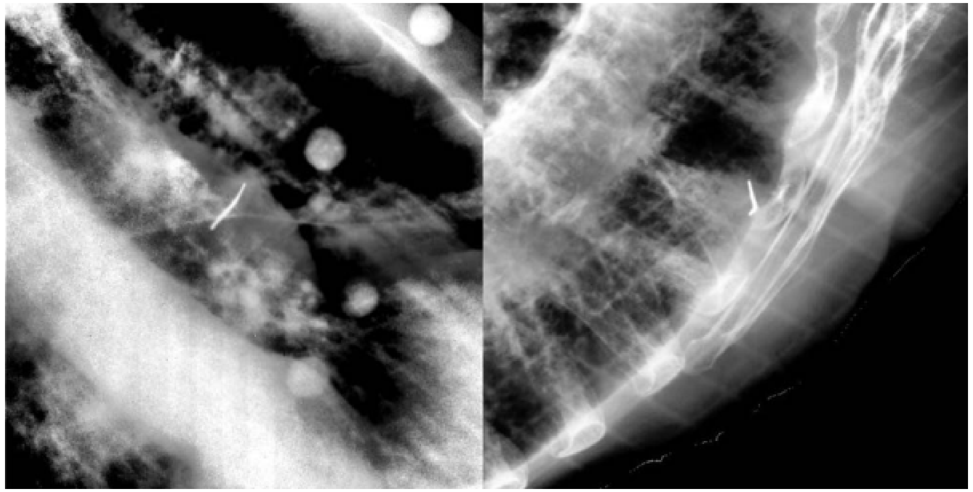
Fig. 1 Catalyst™ setup in the treatment room

Walter et al. 2016. Radiation Oncology.

Internal surrogates – implanted devices

- Implanted fiducial markers
  - Can be localized with static x-ray imaging or fluoroscopy
  - Example: Exactrac
    - KV imaging from oblique angles
    - Imaging can be performed during treatment
    - Combines external infrared markers

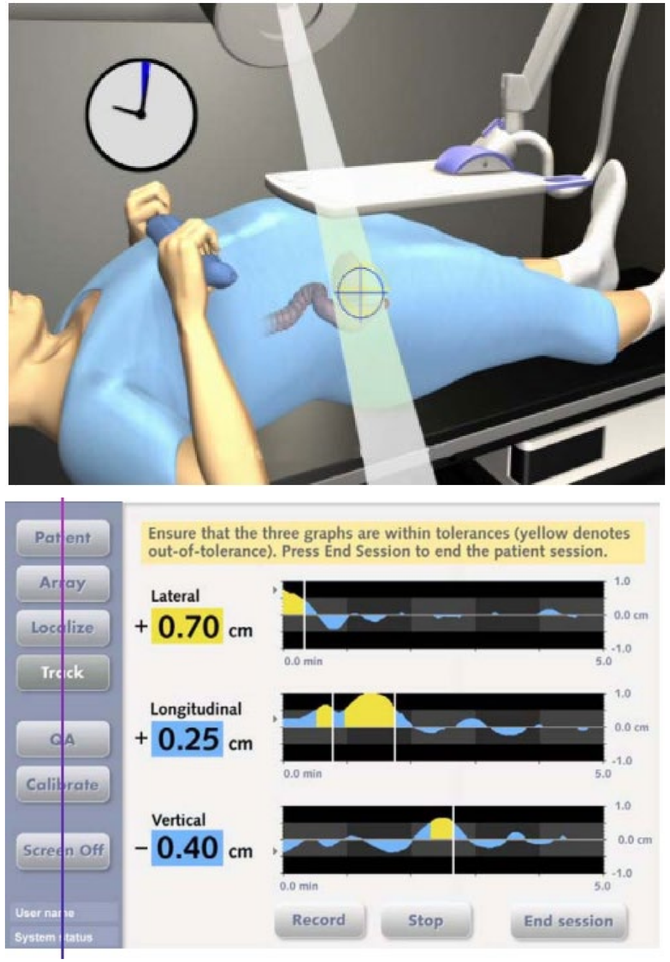




Willoughby T et al. 2006. IJROBP.

Internal surrogates – implanted devices

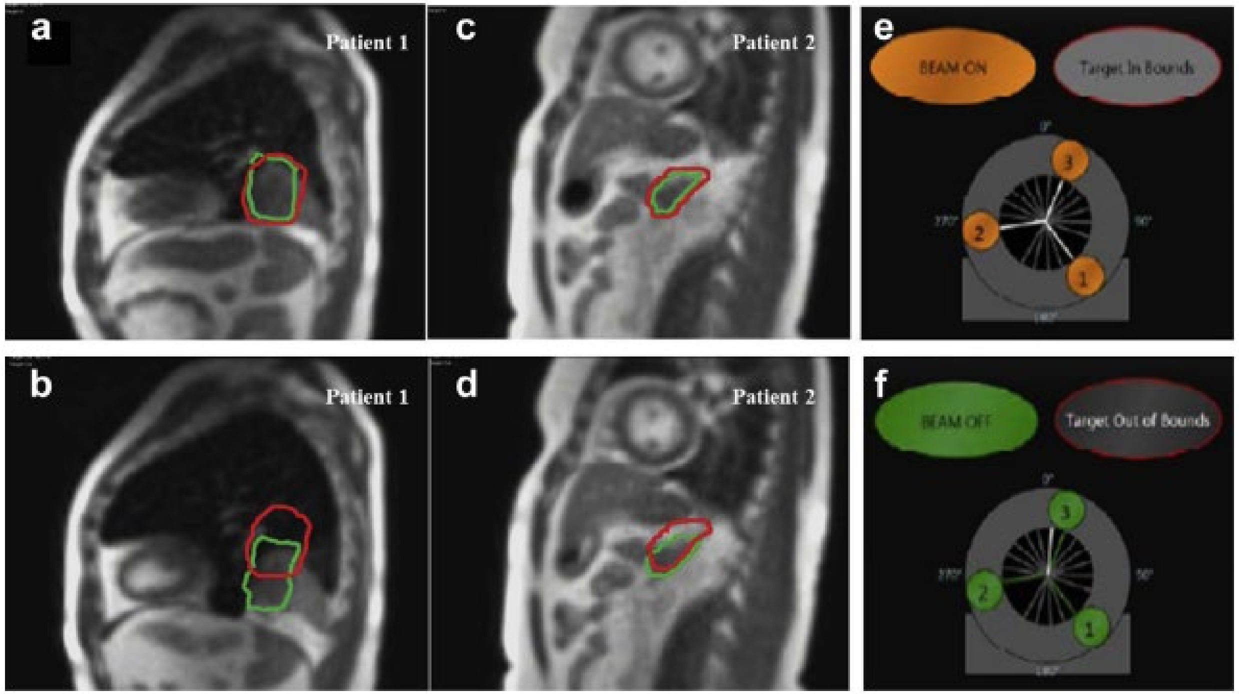
- Implanted electromagnetic beacons - Calypso
  - Implanted in or near the target
  - Multiple beacons may be placed
  - Source coils outside of patient produce electromagnetic signals which excite the transponders
  - Receiver coils localize the signal from the transponders
  - Allows real-time (10 Hz frequency) monitoring of transponder positions
  - Magnetic field is weak so working volume is small



Langen et al. 2008. IJROBP

Internal surrogates – MR imaging

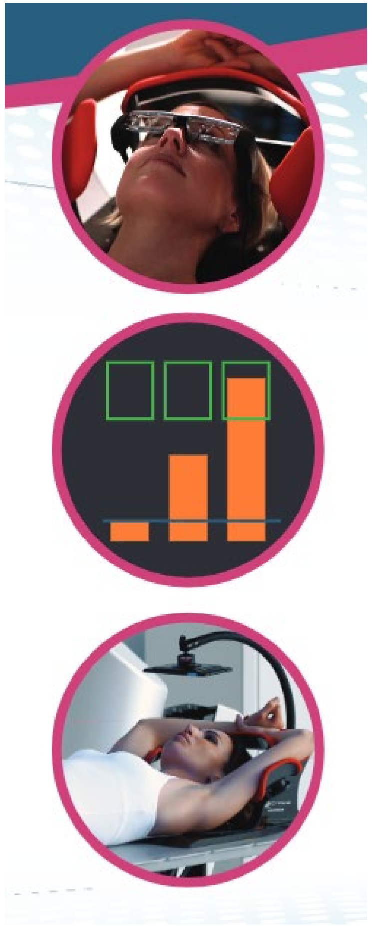
- MR-guided radiotherapy
  - MRI + linear accelerator
  - Allows for visualization of internal anatomy during treatment
  - Cine MR images allow for gating based on actual target location
  - Recent updates now allow for gating based on multiple viewing planes and targets or OARs
  - Solutions available from Elekta and ViewRay



Fischer-Valuck B et al. 2017. Adv in Radiat Oncol.

Breath-hold gating – patient feedback

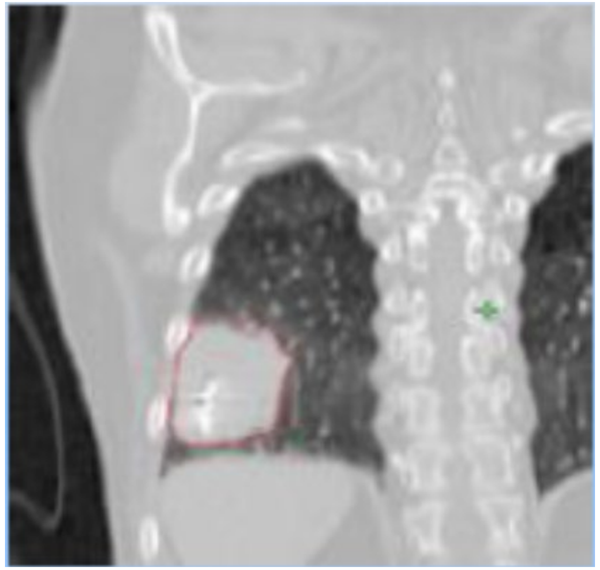
- Breath-hold freezes tumor motion
- Requires some feedback to patient to ensure breath-hold is reproducible
- Worn goggles or tablet devices can provide visual coaching



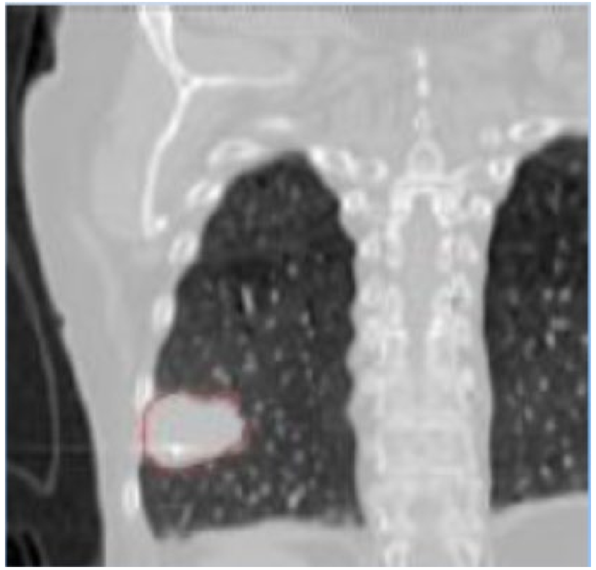
www.c-rad.com

Breath-hold gating

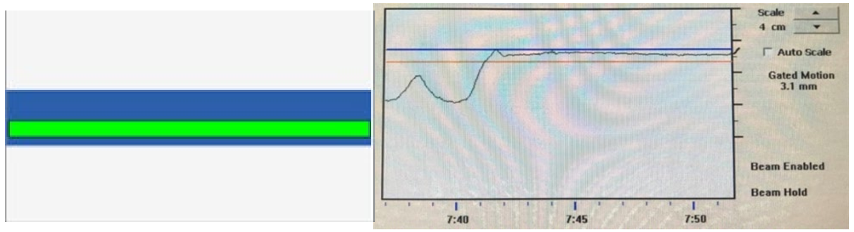
- Beam is only on while patient is within preselected gating window
- Limits tumor motion
- Reduces volume of treated tissue
- Improves DVH statistics
    - Increases lung volume
    - Can create separation between lung target and heart
- Exhale breath-hold useful for abdominal targets
- Reproducibility can be an issue – important to acquire multiple breath-hold scans at simulation



Target based on 4DCT MIP



Target under breath-hold



Active breathing control (ABC)

- Form of breath-hold management
- Spirometer tracks breathing and a valve is used to halt breathing at a particular lung volume/respiratory phase
- This creates a reproducible breath-hold level; however, it is often uncomfortable for patients
- Active Breathing Coordinator available from Elekta

www.elekta.com

Forced shallow-breathing

Abdominal compression

- Limits tumor and OAR motion through restriction of abdominal motion

- Typical implementations consist of a belt which wraps around the patient and an air bladder and/or hard plate
  - Adjustable hard plate only options also exist

- Amount of motion restriction is patient-specific and some studies have shown an increase in motion in some cases

Air bladder + hard plate

Hard plate only

Air bladder only

Respiration-synchronized techniques

Tumor tracking

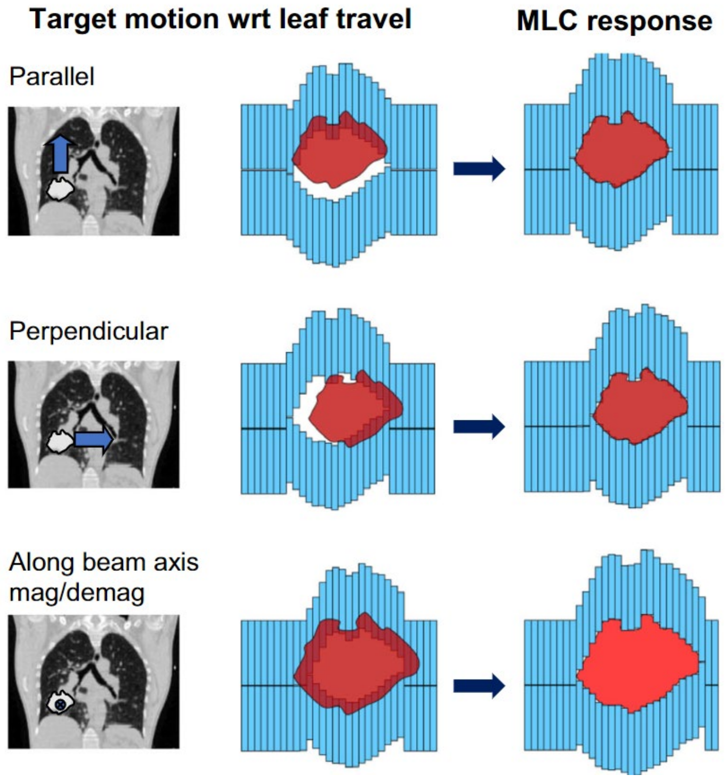
- Objective: follow tumor motion and adjust the machine to deliver dose to the target as it moves
- Method:
  - Track tumor motion through one or multiple methods that have been discussed (surface imaging, internal surrogates, external surrogates, anatomical imaging, etc.)
  - Develop a model of tumor motion in order to predict motion
  - Move the machine or MLCs to deliver dose to target

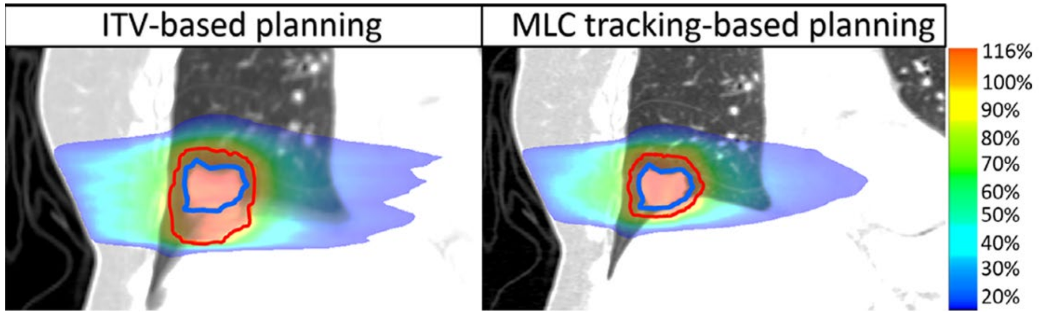
Considerations for tumor tracking

- Ideal characteristics
  - Eliminates the need for breath-hold
    - Some patients are not good candidates for breath hold but still have large tumor motion
  - Shortened treatment time
- Concerns
  - Accuracy of motion model is important
  - Update time for predicted tumor motion must be fast
  - How to handle dose calculation/summation and QA?

Linac-based MLC tracking

- Position monitoring system send target location information to MLC tracking algorithm
- Motion prediction model accounts for system latency
- Multiple targets with different motion could potentially be treated simultaneously
- Current implementations - position monitoring handled through implanted transponders or imaging of implanted fiducials

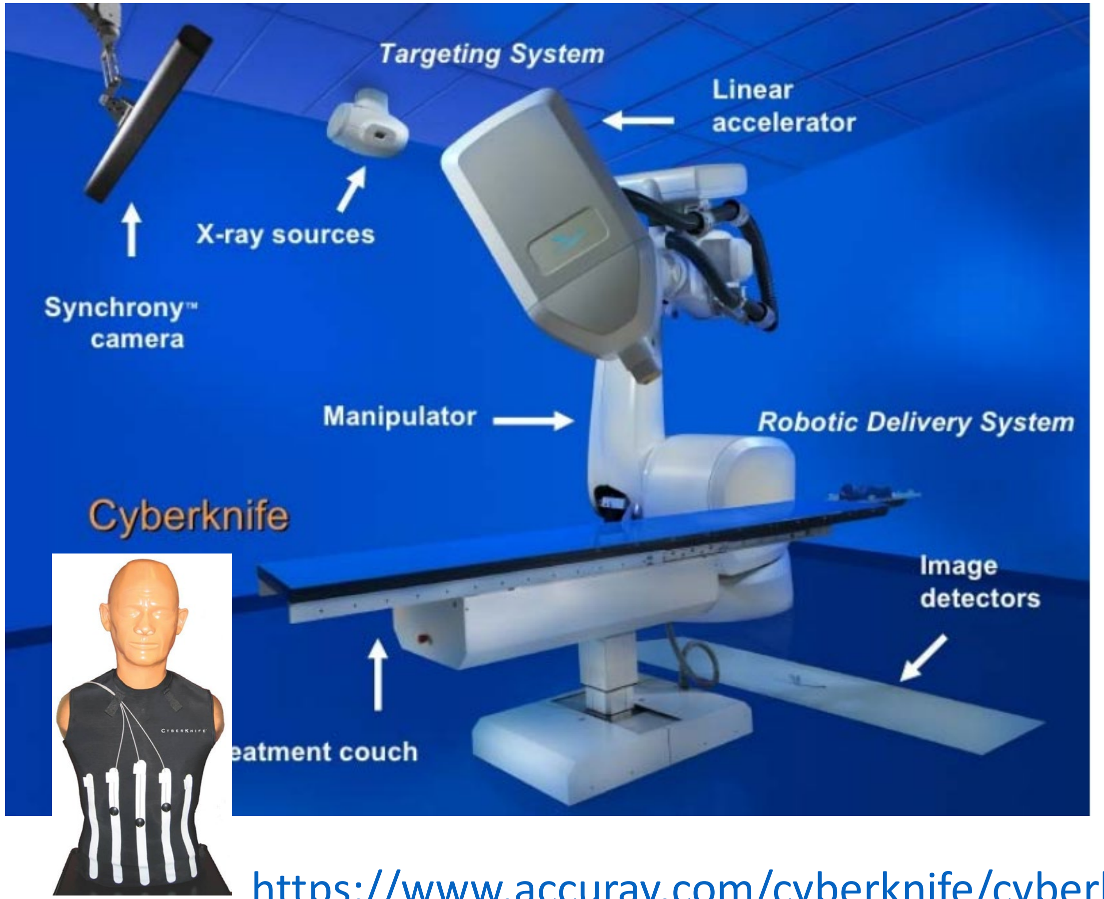




Keall P et al. 2021. Med. Phys.

Accuray Synchrony for Cyberknife

- Track tumor with combination of robotic arm movement and MLC shaping
- Tumor motion signal from two sources
  - Reflective vest/surface LEDs in combination with camera
  - Oblique x-ray imaging
    - Fiducials
    - Tumor



https://www.accuray.com/cyberknife/cyberknife-treatment-delivery/

Anatomical and functional tracking

- MR-guided radiotherapy
  - Cine MR during treatment could be used to track targets
  - Motion prediction model based on MR imaging

- Biology-guided radiotherapy (BgRT) – RefleXion
  - PET/CT combined with a linear accelerator
  - PET signal is used to localize, track, and deliver radiation to multiple targets in a single treatment
  - BgRT aspect not yet FDA approved

Summary

- Respiratory motion management is needed for accurate delivery of radiation to moving targets
- Many methods exist for accounting for target and OAR motion
- In general, multiple vendor solutions exist for any given method of respiratory motion management

Thank you!

Questions?

Contact

Christopher Peeler, Ph.D.
Assistant Professor, Thoracic Service
Department of Radiation Physics
The University of Texas M.D. Anderson Cancer Center
crpeeler@mdanderson.org

THE UNIVERSITY OF TEXAS
MD Anderson ~~Cancer~~ Center
Making Cancer History®