Respiratory Motion Management Systems

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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

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

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
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
- Infrared reflectors
- Infrared camera
- Surface tracking
- 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
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

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
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
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
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 sends 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

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

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