Clinical Implementation of Respiratory Gating

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Presentation Outline

- Problems arising from respiratory motion
- Some methods to account for respiratory motion
- Varian Real-Time Position Management (RPM) implementation
- Future techniques
Problems Arising From Respiratory Motion

- Image acquisition limitations
- Treatment planning limitations
- Radiation delivery limitations
Image Acquisition Limitations

- Motion artifacts result if respiratory motion not accounted for
- This can result in target/normal tissue delineation errors
Image Acquisition Limitations
Treatment Planning Limitations

- Larger margins have to be used when creating PTV from CTV
- Increased margins mean greater volumes of healthy tissue treated
Radiation Delivery Limitations

- Intrafraction motion produces averaging/blurring of dose distribution over path of motion
- Interfraction motion produces shift of dose distribution
- Overall effect is blurring of the dose distribution near the beam edges
Methods to Account for Respiratory Motion

- Motion encompassing methods
- Respiratory gating methods
- Breath hold methods
- Forced shallow breathing with abdominal compression
- Real-time tumor tracking
Motion Encompassing Methods

- Slow CT scanning
- Inhalation and exhalation breath-hold CT
Slow CT Scanning

- CT scanner operated very slowly so that multiple respiration phases are recorded per slice
- Resulting tumor image should encompass full extent of respiratory motion
- Slow scanning geometry more representative of entire respiratory cycle that will occur during treatment
- Loss of resolution due to motion blurring (larger errors in tumor and normal tissue delineation)
Inhalation and Exhalation Breath-hold CT

- Acquire both inhalation and exhalation breath hold CT scans
- To reduce CT time, acquire free breathing full scan, with inhalation and exhalation scans through tumor volume only
- Fuse images for contouring
Respiratory Gating Methods

- CT scans are acquired and correlated with a concurrently acquired respiratory motion file.
- CT slices obtained can be sorted based on spatial (axial) and temporal (breathing phase) location.
- CT sets can be reconstructed for any portion of the respiratory cycle.
- Variations in respiratory pattern during acquisition can affect images, breath training techniques can help.
Respiratory Gating Methods

- Gating using external markers
  - External markers placed on patient’s surface used to monitor patient’s respiratory motion
  - Markers are commonly IR reflective devices used in conjunction with an infrared camera
- Gating using internal markers
  - Internal markers implanted in or near tumor used to monitor patient’s respiratory motion
  - Commonly gold seeds, which must then be imaged with stereotactic kV imaging system
Breath Hold Methods

- Deep-inspiration breath hold
- Active-breathing control
Deep-Inspiration Breath Hold

- Patient is trained to reproduce a deep inhalation breath hold during simulation and treatment
- Volume of air inhaled by patient monitored by spirometer
- Highly reproducible results possible
Active-Breathing Control

- Technique for suspending breathing at any predetermined position (usually moderate or deep inhalation)
- Monitoring apparatus consists of spirometer connected to balloon valve
- After a predefined volume of air (threshold volume) has passed through the spirometer, a small balloon valve inflates and occludes the tube, applying an assisted breath hold for a predefined period of time
Forced Shallow Breathing/Abdominal Compression

- Utilizes stereotactic body frame with attached plate or respiratory belt that presses against abdomen to reduce diaphragm motion and encourage shallow breathing.
Real-time Tumor Tracking

- Goal is to reposition beam dynamically to follow tumor motion during treatment
- To accomplish this, the system must be able to
  - Detect tumor position in real time
  - Compensate for time delays in beam-positioning response
  - Reposition the beam
  - Adapt the dosimetry to allow for these changes
History of Respiratory Management at OU Medical Center
Non-Gated Solution

- Acquire three separate series of scans:
  - Regular breathing
  - Full inhalation
  - Full exhalation
- The three sets of images are fused in the planning system, with the CTV contoured in each series
- A composite CTV can then be contoured which encompasses the extremes of motion of the CTV during the breathing cycle
Example

Regular breathing series merged with inhalation series
Example

Regular breathing series merged with exhalation series
Example

ITV drawn based on motion in all series
Gated Solution

- A respiratory gating system (Varian Real-time Position Management) is used to correlate the time of the acquisition of an image with a breathing signal it detects.
- Breathing-synchronized acquisition of these images ensures that the images used for planning correspond to a known breathing state that can be detected during treatment, enabling beam-on only when the patient is in that respiratory state.
Two Approaches to Image Acquisition

- Prospective
  - Images are acquired only during a portion of the respiration cycle
- Retrospective
  - Images are acquired during the entire respiration cycle and sorted later
Prospective

Respiration Waveform from RPM Respiratory Gating System

Inhalation

Exhalation

Scan
Axial scan trigger,
2nd couch position

Scan
Axial scan trigger.

CT Scan

Prospective
Respiration Waveform from RPM Respiratory Gating System

Inhalation

Exhalation

“Image acquired” signal to RPM system

X-ray on

1st couch position

2nd couch position

3rd couch position

Retrospective
Two Gating Methods

- Amplitude gating
  - The gated range is defined by upper and lower thresholds
- Phase gating
  - The gated range is defined by two points of the breathing cycle
Amplitude Gating

Chart Area: Playback for Treatment Review, Amplitude-Based
Phase Gating

Chart Area: Playback for Treatment Review, Phase-Based
Gating System Components

- Infrared camera with infrared light sources
- External reflective markers
- GE Discovery CT scanner
- GE 4D Software
- RPM switchbox
- RPM workstation
Acquiring Scan

- The patient is placed in treatment position in the CT room
- A reflective marker box is taped to the chest and it’s position is marked for reproduction during treatment
Acquiring Scan

- The camera is adjusted so that the reflective markers are visible on the monitor
Acquiring Scan

- The patient is coached to breathe normally
- Once a regular breathing pattern is established, the CT scan is acquired and exported to the 4D workstation
Preparing Scan For Planning

- The 4D workstation uses the patient’s respiratory file to sort the series images into one of ten segments of the breathing cycle.
Preparing Scan For Planning

- Once the images are sorted, the position of the tumor is noted in each of the ten phases, and those phases that exhibit minimal motion are chosen for treatment planning.
Preparing Scan For Planning

- A new CT series is created based on these phases and is exported to the treatment planning system.
Preparing Scan For Planning

- To confirm the proper choice of phases for gating, a movie mode is available in the 4D software for observing tumor motion
Treatment Planning

- Once the gated CT series is created, the physician delineates the ITV
- The dosimetrist creates the PTV by adding a 7mm margin to the ITV
- The CT series and associated contours are then exported to planning system, where planning proceeds as usual
Treatment Delivery

- The patient is repositioned on the treatment couch per CT simulation and planning
- A reflective marker box is repositioned on the chest per CT simulation and planning
- The camera response is adjusted until the markers are just visible in the monitor
- The patient is coached in previously established breathing technique
- At the treatment console, the RPM gating switch is turned on and respiratory tracking is begun
Treatment Delivery
Treatment Delivery

- Once a regular breathing pattern is established, the phase limits for gating established during treatment planning are selected.
Once respiratory motion recording has begun, treatment delivery is enabled, with radiation being delivered only during those portions of the breathing cycle which were established during planning.
Treatment Delivery

- When treatment is completed, the breathing pattern used for treatment is saved to the database.
Quality Assurance

- A breathing phantom in conjunction with the marker block is used to test the RPM system’s tracking ability in both the CT room and the treatment room daily prior to any respiratory gating procedure.
Quality Assurance

Breathing Phantom with Marker Block
Quality Assurance

- An IMRT dose verification phantom (Standard Imaging) in conjunction with a respiratory gating platform is used monthly to verify the RPM system’s gating capability in both the CT room and the treatment room.
Quality Assurance
Quality Assurance
Recently have begun using forced shallow breathing with abdominal compression
Future Techniques
Future Techniques

- Recent commission of ExacTrac with possibility of real-time tumor tracking
Future Techniques
Thank You!