Minimizing effects of respiratory motion: principles, strategies and clinical implications

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Principles for minimizing effects of respiratory motion

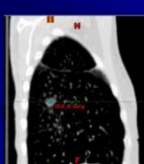
- Respiratory motion induces:
  – Large target volume to be treated
  – Uncertainties due to breathing irregularities and day to day variations
- Minimizing effects of respiratory motion:
  – Reduce the motion amplitude
  – Improve the breathing regularity and reproducibility
  – Adjust radiation delivery to account for the respiratory motion

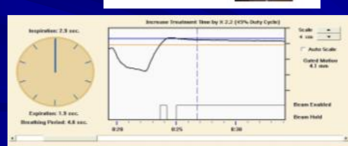
Strategies for minimizing effects of respiratory motion

- Reduce the motion amplitude:
  breath-hold, abdominal compression
- Improve the breathing regularity and reproducibility:
  coaching, automatic breathing control (ABC)
- Adjust radiation delivery to account for respiratory motion:
  gating, tracking

Breath-hold: simulation

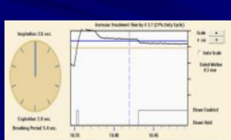
- BH CT scan using external breathing surrogates: Varian RPM, Phillips Bellows system, surface imaging
- Patient capable to hold for at least ~20s.
- Hold at end-inspiration or expiration phase. (Larger lung volume at end-inspiration phase to improve lung DVH).





Breath-hold: planning and treatment

- Contoured and planned with BH-CT. High dose rate for fast delivery
- Registration between BH-CT and BH-CBCT
- Fluoro and cine verification for lung or liver cases with markers



RPM Verification

Fluroscopy Verification

Cine-MV Verification

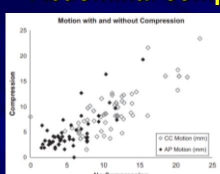
Breath-hold ≠ No Motion
Adequate margin is needed.

Abdominal Compression

Mampuya et al, *Medical physics* 40.9 (2013)

- Used mostly for abdominal lesions, such as liver cancer.
- Patients do free breathing with abdominal compression.
- Simulation: 4D-CT to assess residual motion

Abdominal compression for liver SBRT

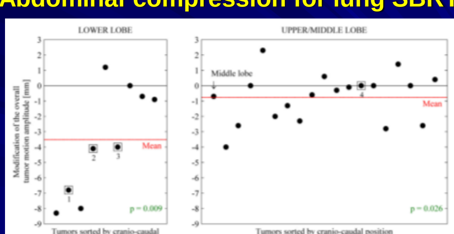


- Mean decrease in tumor motion of 2.3 and 0.6 mm in the SI and AP directions.
- Clinically significant (>3 mm) decrease in 40% of patients and an increase in SI tumor motion in < 2% of patients.

Eccles et al, Red J., 2011

- Heinzerling et al: tumor motion was 13.6 mm, 8.3 mm, and 7.2 mm with no compression, medium compression, and high compression, respectively. (*Red J, 2008*)
- Wunderink et al: mean tumor motion reduced to <5 mm in all directions for most patients. (*Red J, 2008*)

Abdominal compression for lung SBRT?



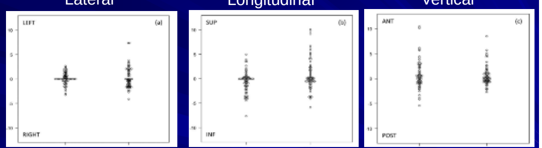
Abdominal compression is effective for lower lobe tumors, and has less or even negative effects for upper/middle lobe tumors.

Bouilhol et al, *Physica Medica* 29.4 (2013): 333-340.

Abdominal compression for lung SBRT?

Lateral | Longitudinal | Vertical

Inter-fraction variation of tumor position (mm)



No Compression | Compression | No Compression | Compression | No Compression | Compression

Abdominal compression introduces more interfraction variations of the tumor position in the lateral and longitudinal directions in lung SBRT. Accuracy of target matching is critical.

Mampuya et al, *Medical physics* 40.9 (2013)

Strategies for minimizing effects of respiratory motion

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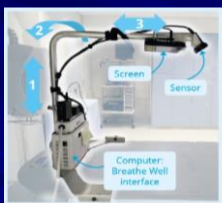
Coaching

Audio and video coaching

Varian Medical System

Coaching: Breathe Well (BW) system

- monitors a user-defined area of interest on patient's chest using a depth camera
- Visual feedback on a screen mounted to the couch



Courtesy of Yi Rong and University of Sydney

Coaching: Audio coaching

- Nakamura et al (Red J. 2009): internal/external correlation improved significantly to 0.93-0.99.
- Michalsky et al (Red J. 2008): coached correlation >0.7
- Goossen et al (JACMP 2014): coached correlation 0.72-0.98
- Hoisak et al (Red J. 2004): uncoached correlation 0.39-0.71
- Mageras et al (JACMP 2001): audio coaching improves breathing regularity
- Patients tend to breathe deeper with audio coaching

Coaching: Audio-Video coaching

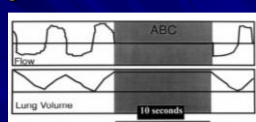
- Audio-video approach achieved better reproducibility than audio alone (tumor motion of 7.2 mm ±1mm vs. 8.6 mm ± 1.8 mm, breathing motion of 14.9 mm ± 1.2 mm vs.13.3 mm ± 3.7 mm)
- Audio-video coaching achieved better internal/external correlation reproducibility than audio alone for tumor motion along AP direction.
- Audio-video achieved smaller gating errors than audio alone.

Goossens et al, JACMP, 15(1), 47-56, 2014

Coaching

- Improve reproducibility of the respiratory motion
- Improve the correlation between internal tumor motion and external breathing signals
- Audio-video coaching is preferred to audio coaching alone
- Not applicable to patients with difficulties to follow audio/video instructions

Active Breathing Control

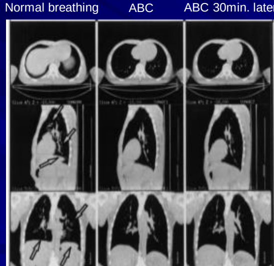


Wong, et al, Red J 1999

- Breathing temporarily suspended in a reproducible phase of the respiratory cycle by controlling the air flow. (controlled breath hold)
- CT and delivery only at the suspended breathing.
- Wong et al reported liver volumes were reproducible at about 1%, and lung volumes were reproducible to within 6% in scans with ABC.

Active Breathing Control

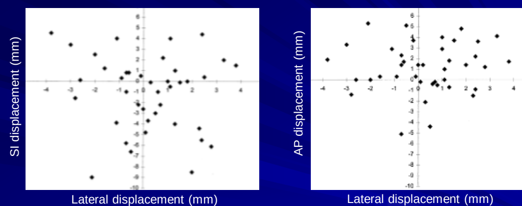
Normal breathing ABC ABC 30min. later



Wong, et al, Red J 1999

Active Breathing Control

Inter–breath hold displacements of daily GTV positions with ABC



- Inter–breath hold variation of lung tumor position is greater for lower-lobe tumors. Limited reduction of PTV margin.
- ABC is not an absolute spirometer. Baseline lung volume changes.

Cheung, et al, Red J 2003, Mittauer et al, MedPhys, 2014

Strategies for minimizing effects of respiratory motion

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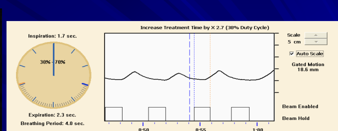
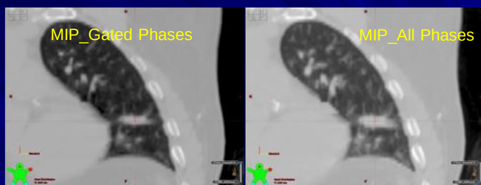
Respiratory gating: simulation



- Only applicable to patients with regular breathing pattern
- Patient breathe freely and is scanned with 4D CT
- Review 4D images to determine the gating phase windows (around end of expiration phases, 3-5 phases)

Respiratory gating: planning

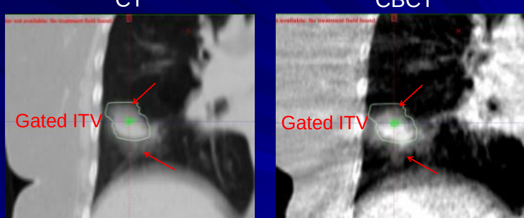


4DCT
- MIP_GatedPhases (30%-70%) → ITV, PTV
- AIP_GatedPhases (30%-70%) → Dose calculation
- AIP_AllPhase (0%-90%) → CBCT online match

Use high dose rate in planning to account for low duty time

Respiratory gating: CT-CBCT registration

CT CBCT



Match superior portion of the tumor volume between CT and CBCT for gating at end-expiration phase.

Respiratory gating: Fluoro and cine for treatment verification

Fluroscopy Verification

Cine-MV Verification

Respiratory gating

- Tumor respiratory motion range is similar as in free breathing treatments
- Beam is only delivered to certain gating phase window
- Patient breathing regularity is crucial
- Imaging verification of gating window before and during treatment is critical

Summary

- Effects of respiratory motion can be minimized by reducing the tumor motion, improving the breathing reproducibility/regularity or adjusting radiation delivery.
- The optimal motion management strategy needs to be determined based on the patient scenario and clinical setting.
- It's crucial to consider the limitations of each strategy and account for their uncertainties in the planning and treatment process.

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