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 Belloes 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
- Fluro and cine verification for lung or liver cases with markers

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.

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)

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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

- 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
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.


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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

- MIP_GatedPhases (30%-70%)
- AIP_GatedPhases (30%-70%)
- AIP_AllPhase (0%-90%)

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

Respiratory gating: CT-CBCT registration

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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