Respiratory motion mitigation during radiation treatment delivery

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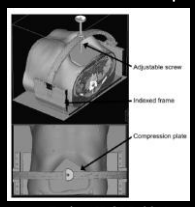
Types of respiratory motion management

- Abdominal compression
- Breath hold
- Respiratory gating
- Real-time motion tracking

- All the above methods in addition require image guidance for interfraction management

Abdominal compression

- Pressure device pushes down on upper abdomen
- Limits diaphragm excursion
- Most widely used motion management technique in clinical SBRT experience



Eccles IJROBP 2011

(Slide courtesy Michael Lovelock, MSKCC)

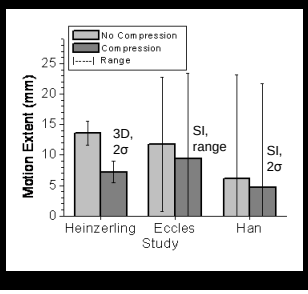
Abdominal Compression

Advantages:
- Technologically simple
- Allows continuous dose delivery

Disadvantages:
- Variably successful in reducing target motion
- Uncomfortable at times

Abdominal Compression – Studies

- Heinzerling IJROBP 2008: lower lung & liver tumors, med/high AC, RCCT, n=10
- Eccles IJROBP 2011: liver tumors, cine MR, n=60
- Han RO 2010: lung tumors, RCCT, n=24



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Which of the following statements about abdominal compression is true?

0% 1. It works by limiting chest wall expansion
0% 2. It eliminates almost all target motion
0% 3. It requires connection to the linac
0% 4. There is little or no discomfort
0% 5. It allows for continuous dose delivery

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ANS: 5. It allows for continuous dose delivery

REFs:

Timmerman RD, et al. Extracranial stereotactic radiation delivery. Semin Radiat Oncol 2005;15:202-207

Keall PJ, et al. The management of respiratory motion in radiation oncology report of AAPM Task Group 76. Med Phys 2006; 33:3874-3900

Breath hold methods

Advantages:

- Exploits physiological immobilization to minimize motion
- Deep or moderately deep breath hold exploits lung inflation to spare nearby normal tissues

Limitations:

- Requires patient cooperation; not all patients can perform
- Requires staff effort to train patients and coach them in a consistent manner

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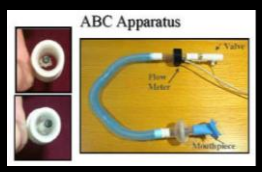
Verification of breath hold

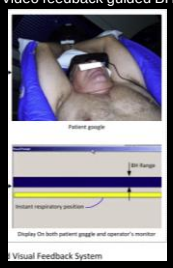
Spirometry:
- Wong 1999, Hanley 1999, Sixel 2001, Balter 2002, Remouchamps 2003, Cheung 2003, Wilson 2003, Dawson 2005, Eccles 2006, Jagsi 2007

Video tracking:
- Berson 2004, Pedersen 2004, Nelson 2005, Peng 2011



Wong 1999

Video feedback guided BH



Peng IJROBP 2011

Breath hold – components of a patient-specific QA program

- Patient screening and training
- Evaluation of reproducibility between BH, stability during BH
- Imaging to check organ position constancy at simulation & treatment
- Assess adequacy of treatment margins to account for inter- and intra-fractional BH variation

Intrafraction BH repeatability

Study	Site, #patients, measurement	Repeatability (1SD, SI,mm)
Hanley 1999	Lung, n=9, diaphragm	0.9
Remouchamps 2003	Breast, n=14, lung surface	1.1
Dawson 2001	Liver, n=8, diaphragm/microcoils	2.5
Eccles 2006	Liver, n=21, diaphragm/liver	1.5
Koshani 2006	Lung , n=10, GTV	1.4
Hurst 2010	Lung , n=9, GTV	mean <2 mm
Nakamura 2010	Pancreas, n=10, GTV	1.0
Peng 2011	Lung, n=13, GTV	1.3

Interfraction variation larger: requires image guidance

The following items should be part of patient-specific QA when using breath-hold EXCEPT

0% 1. Patient screening and training
0% 2. Compare performance of BH & gating
0% 3. Repeatability of breath hold
0% 4. Imaging check of organ positions
0% 5. Check adequacy of treatment margins

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1. Patient screening and training
2. ANS: Compare performance of BH & gating
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REFs:

Keall PJ, et al. The management of respiratory motion in radiation oncology report of AAPM Task Group 76. Med Phys 2006; 33:3874-3900

Jiang SB, et al. QA challenges for motion-adaptive radiation therapy: gating, breath holding, and 4DCT. Int J Radiat Oncol Biol Phys 71(1 Suppl):S103-7 (2008)

Respiratory gating

- Intermittent delivery of radiation occurring within a portion of breathing cycle (gate)
- Gate onset/duration determined by resp. monitoring, either external signal or internal fiducial markers
- Usually gate set around end expiration: tumor motion ↓
- In some apps, gate set at enhanced inspiration with coached deep breathing: normal tissue sparing ↑

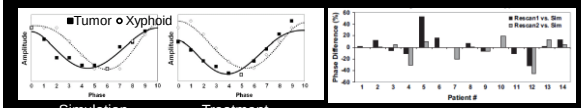
Respiratory gating, cont'd

Advantages:

- Patient cooperation easier than BH

Limitations:

- 2-5x longer treatment time
- Residual tumor motion: trade-off with beam duty cycle (20-50%)
- Drift of external resp. signal wrt gating thresholds
- Variations in time shift between external signal & tumor motion (Ionascu 2007, Korreman 2008, Redmond 2009)



Simulation Treatment

(Redmond IJROBP 2009)

Gating: residual intra-fx motion

Study	Monitor	Site, #patients, measurement	Residual (1SD, SI, mm)
Shimizu 2001	Internal	Lung, n=4, implanted fiducial	<5.3 all directions
Wurm 2006	External	Lung/liver, n=6, implanted fiducial	1.5±0.7 to 4.1±2.0 (Mean±SD)
Briere 2009	External	Liver, n=5, implanted fiducial	2.0 inter-fx 1.0 intra-fx

Imaging with internal markers

Accuracy via marker localization limited by

- Marker migration
- Tumor & OAR motion relative to markers
- SD discrepancies between liver centroid & marker 2.5 mm (Kitamura 2002)
- Markers near peripheral lung tumors: accurate within ±2 mm in first 1-2 weeks, relationship can change after 2 weeks (Shirato 2007)

Motion tracking

- Refers to continuous adjustment of radiation beam or patient position to follow the changing position of the target or its surrogate
- A means of localizing the target in real-time is coupled to a target alignment control system

Motion tracking – Methods of target localization

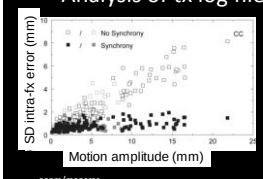
- Direct methods detect implanted fiducial or anatomical landmarks, using
  - X-ray radiographs, MRI, US, electromagnetic
- Indirect methods monitor external motion & infer target position, using
  - Optical patient surface, respiratory belt, airflow
- Indirect usually combined with imaging to establish internal/external correlation

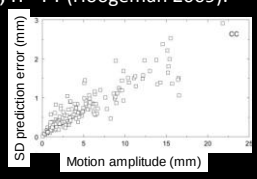
Motion tracking – Methods of target alignment

- Linac attached to robotic arm
- Gimbaled linac
- Multileaf collimator
- Magnetic deflection of particle beam
- Treatment couch translations

Accuracy of external/internal correlation models

- Cyberknife: correlates external optical signal with imaging of internal fiducials every 30-60 s
- Correlation may fail with irregular breathing, baseline drift, or large target rotation
- Analysis of tx log files, n=44 (Hoogeman 2009):





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Methods of target realignment for motion tracking include all of the following EXCEPT

0% 1. Treatment couch translation
0% 2. Linac attached to robotic arm
0% 3. Magnetic deflection of particle beam
0% 4. X-ray imaging
0% 5. Multileaf collimator

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3. Magnetic deflection of particle beam

ANS: 4. X-ray imaging

5. Multileaf collimator

REF:

Dieterich S, et al. Locating and targeting moving tumors with radiation beams. Med Phys 35:5684-5694 (2008)

Summary: residual intrafraction errors

Resp. motion, deviation from planned position, SI direction

Source of uncertainty	SD uncertainty before mitigation (mm)	Mitigation strategy	SD uncertainty after mitigation (mm)
Lung/liver tumor intrafraction motion	5 (range 3 – 8)	Abdominal compression	3 (range 2 – 4)
"	"	Active breath hold	2 (range 1 – 3)
"	"	Voluntary breath hold	2 (range 1 – 3)
"	"	Gating with internal fiducials	2 (range 1 – 3)
"	"	Gating with external fiducials	3 (range 2 – 4)
"	"	Real-time motion tracking	2

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