Motion management

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Motion management - in radiotherapy
Motion Management

What?

• How to handle the patient/tumor related motion during radiotherapy
  – measure and incorporate into margins
  – mitigate tumor motion
  – introduce space between organs
  – monitoring and control
Motion Management

When?

Patients with tumors moving more than 5 mm.

The management of respiratory motion in radiation oncology report of AAPM Task Group 76
Motion Management

Why?

• We want tightly conforming dose distributions
• ...but...everything moves
  – Tumor (lung, liver, breast, mediastinal lymphoma, prostate...)
  – Patient (set-up and weight variation)
  – Couch (e.g. CT and TomoTherapy)
  – Gantry and MLC (IMRT/VMAT/TomoTherapy)
Motion Management

**Why?**

**Intra-fraction motion**  
– during the fraction

- Heartbeat
- Swallowing
- Coughing
- Eye movement

**Inter-fraction motion**  
– in between the fractions

- Tumour change
- Weight gain/loss
- Positioning deviation

- Breathing
- Bowel and rectal filling
- Bladder filling
- Muscle relaxation/tension
Motion Management - Why?

Prostate

\textit{intra-fraction motion}

A significant predictor for intra-fractional prostate motion: rectum filling.

- Empty rectum
  - displacements of less than 3 mm can be expected within 20 min.
- Full rectum
  - 10% risk of motion beyond 3 mm within 1 min.

\textit{inter-fraction motion}

Chandra \textit{et al} 2003 used ultrasound to correct the prostate positioning for 147 patients and analyzed 3328 images.

The standard deviation for setup error and internal motion

- 4.9 mm the anterior–posterior
- 4.4 mm superior–inferior
- 2.8 mm in right–left

Ghilezan \textit{et al} 2005 recorded 400 MRT scans within 1 h and analyzed 11 anatomic points of interest.
Motion Management - Why?

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Motion Management - Why?

If target moves during radiotherapy...

Dose distribution from a static delivery to a stationary target

Dose distribution from a static delivery to a moving target
Motion Management - Why?

If both target and MLC move...

Risk of serious under- and over-dosage!
Interplay measurement using 3D dosimetry
Motion Management - Why?

Accounting for respiration during irradiation is a non-trivial issue!

• Respiration implies a non-rigid deformation
  – cyclic nature
  – elements of irregularity
  – complex physiological process
Motion Management - Why?

Figures illustrate intra- and inter-fraction characterizations of motion means for populations of patients.

Graphical representation of systematic (arrows) and random (ellipses) baseline variations projected on coronal and sagittal views of a schematic bronchial tree. Colors reflect average amplitude.

Inter- and Intra-fraction Motion of Lung Tumor

3D tumor traces on different weeks

Courtesy of Lei Dong
Motion Management - Why?

So everything in the lung moves.....
....maybye we can characterize the relationship between surrogates and tumor motion....
Motion Management - Why?

Variabilities in motion patterns for target and surrogate!

1) Baseline drifts

Motion Management - Why?

Variabilities in motion patterns for target and surrogate!

2) Amplitude scaling

Internally implanted gold marker (magenta) and a reflective marker placed on the chest wall (blue).

Motion Management - Why?

Variabilities in motion patterns for target and surrogate!

3) Fundamental change/model breakdown

Internally implanted gold marker (magenta) and a reflective marker placed on the chest wall (blue).

Motion Management - Why?

• All of these 3 variations can take place both on intra- and inter-fractional basis
  – Baseline drifts
  – Amplitude scaling
  – Fundamental change/model breakdown

• Several studies have characterized the relationship between surrogates and tumor motion...

• ...but also found that such a relationship is not stable over time

Motion Management - Why?

....and then we have protons!
Motion Management - Why?

....and then we have protons!

Moving targets are especially challenging during proton therapy because;

The position of the Bragg peak is dependent on
- beam energy
- density of the tissue encountered by the beam

It requires dedicated measures to compensate for the dosimetric influence of inter- and intra-fractional target motion.
- strong influence of the radiological depth on the delivered dose.
- interference effects of target motion and scanned beam can further cause under-dosage of the clinical target volume
- ....despite using margins!

Motion Management

How?

- Imaging
  - Fluoroscopy
  - Slow CT
  - Breath hold CT
  - 4DCT

- Breath Hold
  - DIBH
  - ABC
  - Patient controlled
  - Spirometry
  - Audiovisual feedback

- Abdominal Compression
  - Forced shallow breathing
  - Compression plate
  - Stereotactic body frame

- Tracking
  - External or internal markers
  - Can assist with gating
  - Real time delivery of treatment

- Gating
  - Can be phase based or amplitude based
  - External or internal markers
  - Increases treatment time

A.J. Cole et al. 2014 Clinical Oncology
Volume_{\text{sphere}} = \frac{4}{3}\pi r^3
Motion Management - How?

- A strategy to compensate for respiration motion may be warranted
  - In the mid-1980s
- The beam gating concept is developing
  - In the mid 1990s
- Respiratory gating techniques developed into clinical settings
  - Wong et al 1999, Kubo and Wang 2000
- The concept of 4DCT is launched
Motion Management - How?

Retrospective 4D CT Image Acquisition
Planning using 4DCT

- The average scan over all the phases
  - Woolthaus et al. 2008

- Produce the maximum intensity projection (MIP) of all the phases and use this composite scan as the planning scan
  - Underberg et al. 2005

- The mid-ventilation CT scan. This scan represented the tumor in its time-averaged position over the respiratory cycle.
  - Woolthaus et al. 2006

- A Novel Fast Helical 4D-CT Acquisition Technique to Generate Low-Noise Sorting Artifact
  - Thomas et al. 2014
Motion Management - How?

How Do We Do This?

- Fast helical CT scan, 32 or 64-slice CT
  - Pitch 1.2, fastest rotation (approx 0.26s), 40 mAs, approx 1.5-2.5s per scan
- Scan both directions, minimum pause, whole lungs
- 25 times (research protocol)
- Measure breathing cycle during image acquisition
  - Bellows
Motion Management - How?
Clinical 4D-CT

New Technique

Thomas et al. 2014 International Journal of Radiation Oncology Biology Physics
Synchronize beam-on/beam-off with tumor position
- Free breathing gating
- Exception gating

Plus introduce space between organs or stabilise tumor motion
- Deep Inspiration Breath Hold (DIBH)
- Enhanced Inspiration Gating (EIG)
- Dual Quasi Breath Hold (DQBH)
Motion Management

How?
Motion Management

How?

• High duty cycle
• Faster treatment
• Two targets!

Dual Quasi Breath Hold (DQBH)
Motion Management – How?

Tracking

• Robotic arm
  • 2005 CyberKnife (Accuray) (Ozhasoglu et al 2008, Seppenwoolde et al 2007)

• Gimbaled x-ray head

• Treatment couch

• Dynamic MLC
Motion Management

How?

The first clinical implementation of electromagnetic transponder-guided MLC tracking


The direct tumor position measurement via electromagnetic tracking rather than internal-external correlation model building.

An electromagnetic transponder-based positioning system (Calypso) was modified to send the target position output to in-house-developed MLC tracking code, which adjusts the leaf positions to optimally align the treatment beam with the real-time target position.
How?
Motion monitoring

- Imaging techniques has to be applied to obtain actual tumor/target position which must be derived.
- Fluoroscopy - 50 mGy/min
- CBCT - 10 mGy
- .....each treatment
How?
Lung gating
Motion Management - How?

....and then we have protons!
Motion Management protons - How?  

intra-fractionally moving organs

*Scanned beam*

- Abdominal pressure
- In jet-ventilation
  - the patient is intubated and the lungs are ventilated by an oscillating air flow of high frequency and low amplitude such that the effective breathing amplitude is reduced.

- Apnea under intubation and anesthesia
- Gating in combination with rescanning
  - Phase controlled rescanning (PCR)
Motion Management protons - How?
Prostate motion

- prostate motion
  - water-filled rectal balloon
  - minimizes the (uncontrolled) amount of air in the rectum and also distends the posterior rectal wall out of the treatment field

- drinking and voiding schemes to control the filling status of the bladder.

Motion Management

Who?

- Us
Motion management
- in radiotherapy
References

TOPICAL REVIEW
Motion in radiotherapy: particle therapy
C Bert and M Durante

TOPICAL REVIEW
Motion in radiotherapy: photon therapy
Stine S Korreman