An Overview of Motion Management in External Beam Photon Radiotherapy

Dr. Jenny Bertholet, Inselsspital, Bern University Hospital
Motivation

Hunt et al. Clin Onc 2018
Learning objectives

• Discuss margin considerations for motion mitigation
• Describe the main active motion monitoring and mitigation techniques
• Discuss practical considerations for the implementation of active motion management
Target definition for motion management

\[ M_{PTV} = 2.5 \Sigma + 1.64 \sqrt{\sigma^2 + \sigma_p^2} - 1.64\sigma_p \text{ (mm)}, \]

systematic  random  penumbra

Wolthaus et al. IJROBP. 2008
Margin recipes and uncertainties

\[ M_{PTV} = 2.5\Sigma + 1.64\sqrt{\sigma^2 + \sigma_p^2} - 1.64\sigma_p (\text{mm}), \]

CTV-PTV margin to deliver at least 95% of prescription dose to CTV for 90% of patients (1)

⚠️

Typical margin recipes (1,2) neglect the effect of fraction number on set-up-related uncertainties in \(\sigma\)

Adjustments needed, especially for hypofractionation/SBRT (3,4,5)

(1) Van Herk et al. IJROBP 2000
(2) Stroom et al. IJROBP 1999
(3) Gordon and Siebers, PMB 2007
(4) De Boer and Heijmen IJROBP 2001
(5) Herschtal et al. PMB 2013
Passive RMM

RMM = Respiratory Motion Management

Caveat:

Motion at 4DCT is not necessarily representative of motion during treatment delivery!


Active RMM

Caveats:

• Breath-hold (BH) level reproducibility
• Baseline drift when gating in free-breathing (FB)
• Currently low availability of respiratory synchronization (tracking)
Active mitigation

Real-time monitoring

Berholet et al. PMB. 2019 & AAPM 2020
Breathing surrogates for gating

- Available on standard linacs
- 1D breathing signal
- Low latency
- Non ionizing
- Suited for gating (FB/BH)

- Poor surrogate for internal target position
- Recommended to combine with intrafraction imaging
Triggered imaging for verification

• Possible to acquire kV images
  - Perpendicular to treatment beam
  - Triggered by time, gating thresholds or gantry angle (arc therapy)

• Verify the position of implanted fiducial markers against reference

• Beam-off and adjust if needed
  - Internal motion
  - Internal drift

• 68 pancreas SBRT patients

• Also applicable without gating (e.g. prostate)

Vinogradskiy et al. IJROBP 2018
Hybrid methods for gating or tracking

• ExacTrac system (add-on for any linac) for verification of the 1D signal.
• Tracking on Cyberknife, Radixact, or Vero (discontinued) systems with 3D internal monitoring based on external correlation model (ECM).
Surface monitoring for gating

- Add-on systems for linacs
- Projected light pattern on the patient
- Non-ionizing
- Detection of 6D motion
- Can automatically trigger beam-hold
- Suited for gating (FB/BH)
- Good surrogacy for chest wall and breast
Other add-on systems for gating

• Electromagnetic transponders (Calypso)
  - Specific for Varian systems
  - 3D monitoring
  - Transponder implantation required
  - Non-ionizing

• Ultrasound imaging (Clarity)
  - Specific for Elekta systems
  - Soft tissue monitoring
  - Limited to prostate
  - Non-ionizing
MR-based gating

• 2D cine imaging at 4 Hz
• Internal monitoring
• Non ionizing

• Gating FB/BH
• Specialized device
MLC-tracking

• Not yet clinically available


• Can adapt also to rotation or multiple targets moving differently

• Adaptation perpendicular to the leaves is slower and suboptimal

• Requires high frequency monitoring

• Temporal prediction algorithm may be used to compensate for monitoring latency
Considerations for active RMM

- Motion monitoring
  - Latency, dimensionality, ionizing
  - Availability/cost

- Mitigation
  - Latency requirements
  - Availability/cost

Treatment site
- Breathing motion or other
- Deep-seated/superficial
- Contrast on imaging
- …
The choice of RMM method impacts all the steps of the treatment.

Simulation
- Simulation CT:
  - 3D CT
  - Slow CT
  - 4D CT (#phases)
  - BH CT
- Supporting imaging:
  - MR (contrast)
  - PET
  - SPECT
  - 4D
- Definition:
  - Gating parameters
  - Compression level
  - Reference position

Generate MidPos image

Planning
- Generate MidPos image
- Target Volume definition:
  - Primary
  - Lymph nodes
  - Margins
  - ITV
  - MidVent
  - MidPos
  - PTV
- Plan Optimization:
  - Density overrides
  - Robust planning
  - Dose calculation
  - Algorithm

Simulation error \( \sigma \) propagation
- Systematic error
  - Motion artefact
  - Blurring
  - Distortions

Verification:
- Set-up (primary/LN)
- Compression level
- Gating parameters
- Reference position

Delivery (N\#)
- Set-up imaging:
  - Fluoroscopic
  - Stereoscopic
  - CBCT
  - 4D CBCT
  - Gated CBCT
  - MR
- Add-on device:
  - External
  - Surface
  - Air volume/ ABC
  - Compression
  - Transponders
- Real-time monitoring:
  - Imaging
  - Add-on
  - Gating
  - Synchronization
  - Trailing

Optional (technique)
- imaging/monitoring
- planning/RMM decision
- Uncertainties

Not so “random” for hypofractionation!
Practical considerations (1/2)

Survey of 200 centres in 41 countries (17 in USA, 2 in CA) (respiratory RMM only)

Breast:

- 56% of respondents used gating ((deep)-inspiration BH)
- Mostly with respiratory surrogates or surface imaging
  - 41% acquired verification images
- >50% had a dedicated coaching session
- >75% used audio and/or visual feedback to the patient

Anastasi et al. Radiat.Oncol. 2020
Practical considerations (2/2)

Lung / Liver / Pancreas

• 32% / 22% / 15% of respondents used gating

• Monitoring mostly with breathing surrogate. Of those:
  - 39% / 39% / 45% acquired verification images and look at them online

• 4 institutions with MR

• 10% / 8% / 5% used tracking (all except 1 with Cyberknife and hybrid x-ray/optical monitoring)

• <50% had a dedicated coaching session

• No coaching/feedback when tracking

Anastasi et al. Radiat.Oncol. 2020
Wishes and challenges

Main barriers:
1. Equipment/financial resources
2. Human resources
3. Capacity on treatment machine

Status and wishes to expand
- Do not gate/track, do not wish to implement
- Do not gate/track, wish to implement
- Gate/track, no wish to change or expand
- Gate/track, wish to change or expand

Percentage of responding centres (N=200)

- breast
- lung
- liver
- pancreas
- lymphoma

Anastasi et al. Radiat.Oncol. 2020
Summary

• Passive motion mitigation (margins, compression) ignores possible changes in breathing patterns

• Active mitigation requires compatible:
  - Motion monitoring method
  - Real-time adaptation method (gating, tracking)
  - And uncertainty budget!

• Applicability of different methods depends on the treatment site

• There is a large interest in implementing active motion mitigation, especially for lung
  - Mainly limited by financial and human resources
Thank you for your attention!

Acknowledgements:
Per Poulsen
Doan Trang Nguyen
Paul Keall
Martin Menten
Uwe Oelfke
Jennifer Dhont
Susan Harden
Gerry Hanna
Gail Anastasi
Marianne Aznar
Ben Heijmen

Questions?

Jenny.Bertholet@insel.ch