Make margins simple:
Use real-time tumor tracking

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many contributors

“Everything should be made
as simple as possible.
But not simpler.”
Albert Einstein

Disclosures

- Patents
- Licenses: Nano-X, Respiratory Innovations, Standard Imaging, Varian
- Commercial grants: IBA, Philips, Varian
- Commercial ownership: Cancer Research Innovations, Respiratory Innovations, Nano-X


Outline

- What is tumor tracking?
- Why do tumor tracking?
- What is the clinical status of tumor tracking?
- What are the limitations of tumor tracking?
- What margins should I use for tumor tracking?
- Summary
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Tumor tracking components

Real time adaptation components:

1. Correlate and adjust
   reference and actual
   data sets.

2. Correct for
   treatment errors.

3. Determine and act
   on tumor motion.

Treatment goal:

- Find the target
- Hit the target

MLC motion during Tx:

- MLC motion during Tx:
  - Hit the target

kV imaging during Tx:

- kV imaging during Tx:
  - Find the target

Courtesy Vincent Caillet
Tracking is IGRT performed more frequently

Tracking can reduce treatment times

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Anatomical changes with time

- Twitching
- Swallowing
- Breathing
- Heart beating
- Converting coffee to brain function and bladder filling
- Processing last night's festivities

Why?

Variable frequency, baseline, range of motion, shape...

Dieterich et al., Med Phys 2008

CBCT-measured 18 mm intrafraction displacement during single fx 25 Gy NSCLC

Courtesy Hristov, Loo
Lung tumor motion

- Lung tumor motion varies between patients, between treatments and within each treatment

Real-time adaptive rationale

Real-time vs Standard

Planning

Delivery

Average 40% reduction in PTV

4D CT motion

Tracking benefit for lung SABR

- Target dose increase
- Normal tissue dose decrease

Courtesy Jeremy Booth
Dose with and without tracking

Red = PTV

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Real-time adaptation systems

Robotic linac
CyberKnife
Synchrony
Clinical 2004

MLC
Clinical 2013
Widely available
Smallest, lightest
6 DoF
Deformation

CyberKnife
Vero/
Mitsubishi
Clinical 2011

Robotic couch
Clinical 2019
Widely available
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Limitations

- Guidance independent issues - target delineation, dose calculation, ...
- Guidance dependent issues - surrogates, internal/external correlation, prediction, ...

Method – Endobronchial Implant

Implant snapshot

MIP of release

Courtesy Nick Hardcastle
Contour GTV on all phases

Find beacons on each phase

Surrogacy measurement – 4DCT

Motion is the largest error in the treatment delivery chain
Motion is the largest error in the treatment delivery chain

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Margins without tracking (van Herk ref)

![Table 2: Summary of Estimated Margin Requirements for Tumor, Osteosarcoma, and Prostate (v1)](image)
Assumptions for margins without tracking

- Margins are time independent
- The underlying motion follows a normal distribution
- The beam penumbra is uniform for all patients and within patients
- ...

Margins without tracking are time dependent

- Intrafraction motion of the prostate is neither static nor stationary
- Fixed margins (which over-compensate at the beginning and under-compensate at the end of a fraction) cannot optimally account for intra-fraction motion
- Tracking should be the approach to counter intrafraction motion

Margins with tracking

- Simply add 5 mm to account for other errors
IMRT Delivery: Interplay between anatomy and MLC leaf motion leads to motion artifacts

- Cannot be corrected for by margins
- Literature states 0 – 400% dose impact

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- Margins are simpler with real-time tracking
- Margins are smaller with real-time tracking
  - safer radiotherapy
  - better outcomes