Modes of inter-fraction correction in external beam radiotherapy

Marcel van Herk

On behalf of the image guided research and implementation team

Netherlands Cancer Institute, Amsterdam, The Netherlands

This work was sponsored by the Dutch Cancer Foundation, NIH and Elekta Oncology Systems

The patient is alive!

1. Use large margins, irradiating too much healthy tissues
2. Use small margins, and risk missing the target
3. Or: use image guided radiotherapy

Motion counts: prostate trial data (digital image analysis of 660 patients)

Risk+ = rectal distention

Aim of correction
- Minimize difference between planned and delivered treatment
- Benefit: Avoid misses, allows smaller margins
- Cost: Reduced throughput and patient comfort
- Safety concerns for complex protocols

This leads to two questions:
- When to correct and how often
- How to correct

When to correct
- Intrafraction: continuous tracking of anatomy changes
  - High demands on imaging, processing speed, and reliability
  - Only feasible for bone (necessity?), and markers
- On-line: corrects random and systematic errors, but is not capable of correcting complex anatomy changes
  - Moderate demands on imaging and processing
- Exception: get patient off the couch etc
  - Time consuming, need to repeat IGRT
- Off-line: corrects systematic errors only (i.e., only meaningful with enough fractions)
  - Moves decision making out of the time-critical path
  - Less time-constraints: full replanning feasible

Baseline motion: 4D scans taken within one week and matched on bone, displayed in same phase
IGRT lung treatment (3 x 18 Gy)

- 150 patients treated this far
- Applied margins: 7-9 mm

Danger: correction of target may compromise organ at risk

- Hypo-lung patients: 86
- OAR expansion < 10 mm: 12%
  - to meet planning constraints
  - Required compromising 7%
- 10 mm OAR expansion: 88%
  - Required compromising 3%

Planned dose distribution:
hypofractionated lung treatment 3 x 18 Gy

Realized dose distribution with daily IGRT on tumor (no gating)

9 mm margin is adequate even with 2 cm tumor motion

Methods of correction

- Shift the couch
- Rotate the couch
- Rotate gantry
- Rotate the beam (collimator)
- Shift the beam
- Change the energy of the beam (range shift)
- Change beam modulation (replanning)
- Change the patient

Effect of patient/couch shift for a proton beam

- Protons: strong effect
- No effect on photons

It is necessary to have a energy correction option, like a fast range shifter
Rotate the couch?

Rotation limited to 3 degrees
Depending on immobilization patient compensates motion
Is it maybe better to rotate the beam?

Movie courtesy of Stine Korreman

Correcting left-right rotation

Question: how to adjust collimator angles for oblique beam directions?

Answer: \( c = p \sin(g) \)

\( LR \ (g=90) \Rightarrow \ c=0 \)
\( AP \ (g=0) \Rightarrow \ c=0 \)

Collimator (beam) rotation for approximate correction for prostate rotation

Without correction

With correction

With spot scanning, the beam can be translated and rotated accurately without cost

Simple analog correction system for spot scanning

\( X \) control signal
\( Y \) control signal

\( X \), \( Y \) beam rotation
\( \Delta X \), \( \Delta Y \) = beam translation

Off-line correction

- SAL / NAL protocols: measure a few fractions and correct when needed (SAL) or always (NAL)

Setup accuracy at NKI (data from \(+/\sim 200 \) patients)

From my 1999 presentation here in Heidelberg

Adaptive radiotherapy (ART) for prostate:

Conventional plan, 10 mm

Average prostate & rectum adaptive plan, 7 mm *

CBCT first 5 days
3 cGy per scan
weekly monitoring treatment
(bony anatomy set-up protocol)

Applied large scale in Beaumont and NKI

* Nuer et al. UROBP 67 (2007)
** Nijkamp et al. UROBP 2007
Conclusions

- On-line correction by shifting the couch and/or changing energy is a good start but it is not enough in many situations!
- In the future a combination of on-line correction using machine parameters and off-line correction using replanning may be optimal
- Be aware that correcting the target position may compromise the organ at risk dose

Thank you for your attention