Modes of inter-fraction correction in external beam radiotherapy

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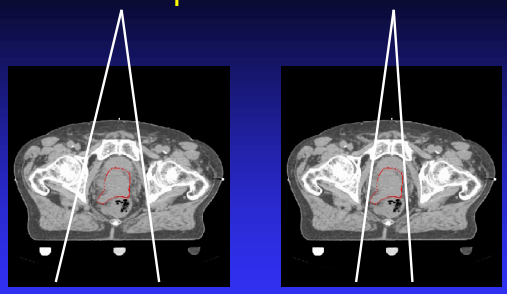
The patient is alive !

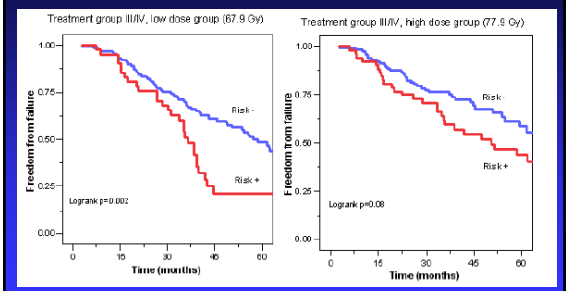


1. Use large margins, irradiating too much healthy tissues

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

Crevoisier et al, IJROBP 2004
Heemsbergen et al, IJROBP 2006

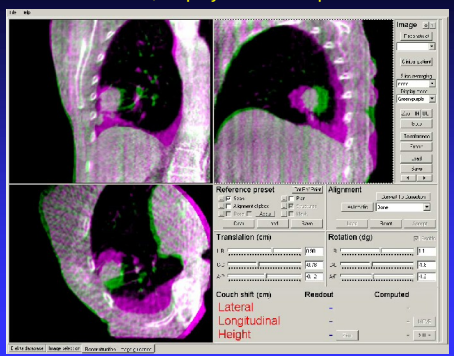
Why correct deviations ?

- 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

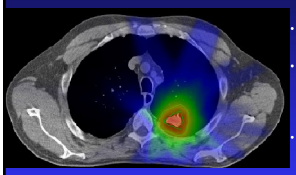


Imagine treating this patient with tracking and a small margin, without 4D cone-beam CT!

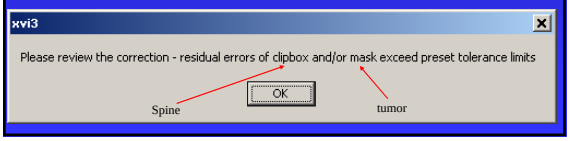
IGRT lung treatment (3 x 18 Gy)

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

Danger: correction of target may compromise organ at risk

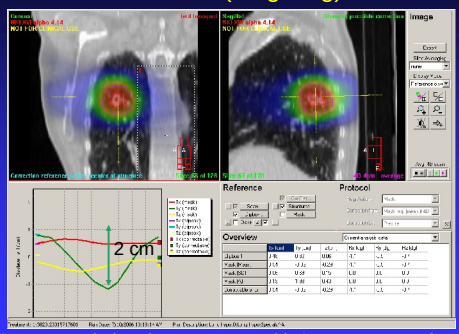


- Hypo-lung patients: 86
- OAR expansion < 10 mm: 12%
  - to meet planning constraints
  - Required compromising 7%
- 10 mm OAR expansion 88%
  - Required compromising 3%



Planned dose distribution: hypofractionated lung treatment 3x18 Gy

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



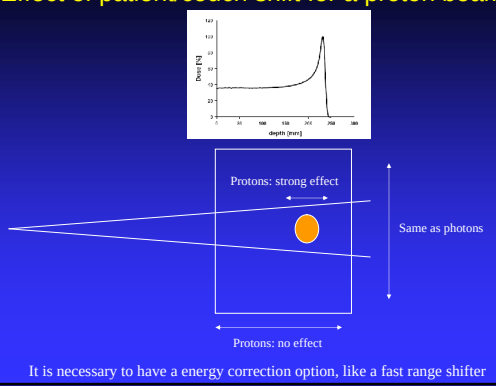
9 mm margin is adequate even with 2 cm tumor motion

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



It is necessary to have a energy correction option, like a fast range shifter

Rotate the couch ?

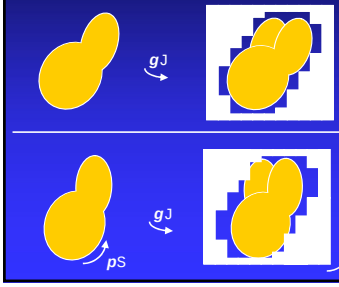
Rotation limited to 3 degrees
Depending on immobilization patient compensates motion

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?

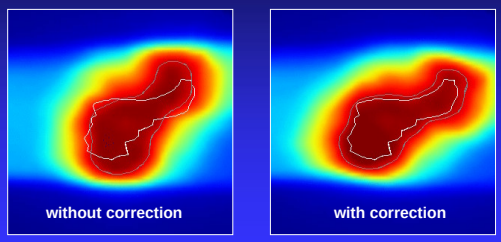


Answer: $c = p \sin(g)$

LR (g=90) ➔ c=p
AP (g=0) ➔ c=0

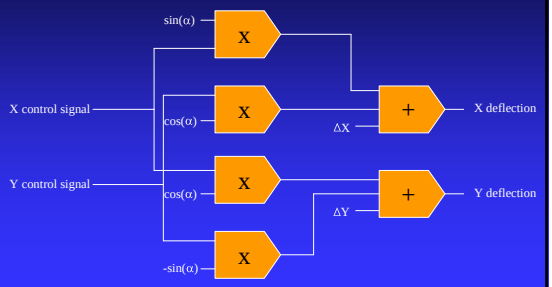
Erik-Jan Rijkhorst, IJROBP 2007

Collimator (beam) rotation for approximate correction for prostate rotation



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

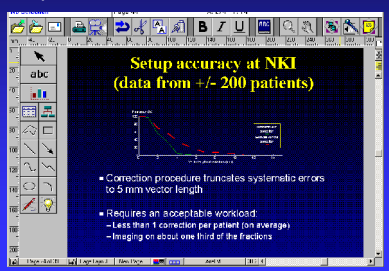
Simple analog correction system for spot scanning



α = beam rotation ΔX, ΔY = beam translation

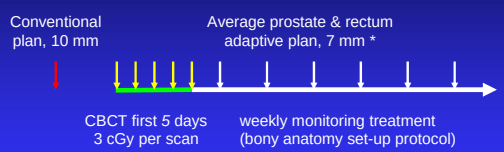
Off-line correction

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



From my 1999 presentation here in Heidelberg

Adaptive radiotherapy (ART) for prostate:

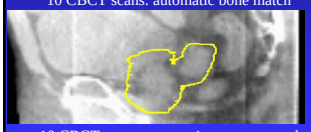


Applied large scale in Beaumont and NKI

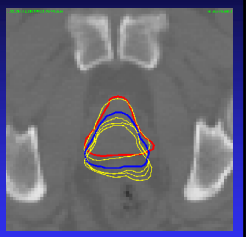
** Nuver et al. IJROBP 67 (2007)*
*** Nijkamp et al. IJROBP 2007*

Adaptive radiotherapy for prostate

10 CBCT scans: automatic bone match

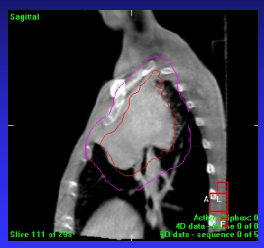


10 CBCT scans: automatic prostate match
help line (GTV+3.6 mm)

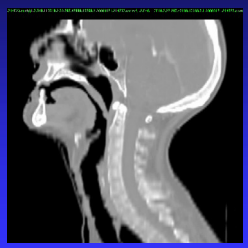


Average prostate position from CBCT measurements

Adaptive radiotherapy for:



Anatomical changes



Complex deformations

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