Modes of imaging in external beam radiotherapy – focus on intrafraction motion

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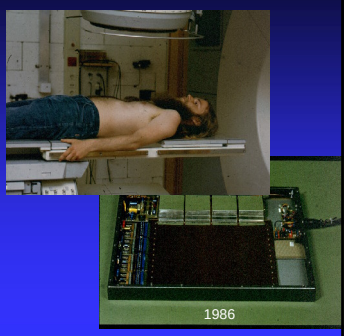
This work was sponsored by the Dutch Cancer Foundation, NIH and Elekta Oncology Systems

Modes of imaging

- MV imaging (not for protons or heavy ions)
- kV imaging
- Active markers
- Cone beam CT
- MRI on the machine
- In-room CT
- Ultrasound
- Optical imaging
- Surface scanning
- Proton tomography

First project – a liquid filled portal imaging device

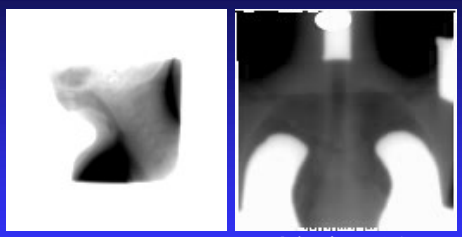


1984

1986

With Harm Meertens, Joost Weeda, Jan de Gans, Albert van Dalen

First clinical images with liquid filled EPID at NKI (May 1986)

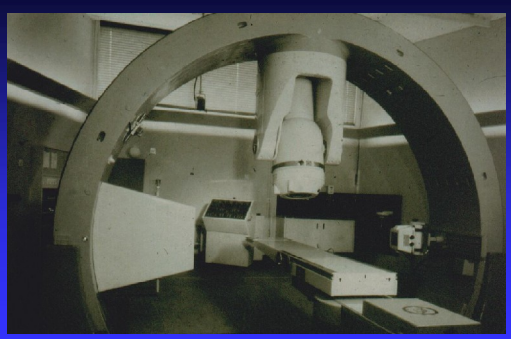


Look: intrafraction motion !

128 x 128 pixels, scan time 3 s

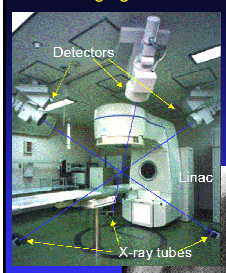
With Harm Meertens, Joost Weeda, Jan de Gans, Albert van Dalen

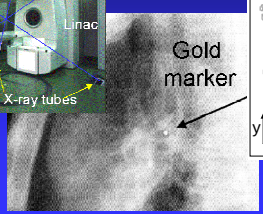
kV image guidance: not a new idea !

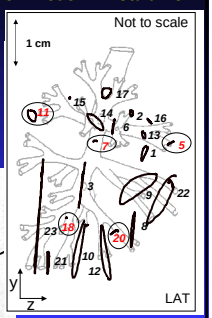


First isocentric Co-60 machine in Netherlands at NKI (1960)

kV imaging of markers to track respiration motion in real time







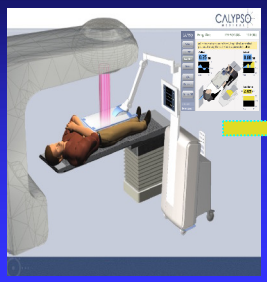
With Yvette Seppenwoolde, Hiroki Shirato et al (at Hokkaido University, Japan)

Intra-fraction correction in the Accuray CyberKnife $

- Tracks motion using stereoscopic x-ray
- Treats tumors anywhere in the body
- Patient-centric design providing "a relaxed treatment experience"
- System in use at Erasmus MC - Rotterdam

Issues: kv skin dose, reliability of tracking

Active markers for intra-fraction motion detection and correction



Markers have limited use in case of deformations

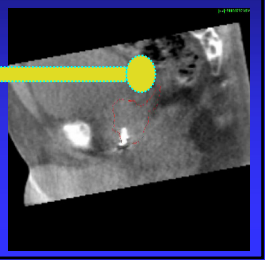
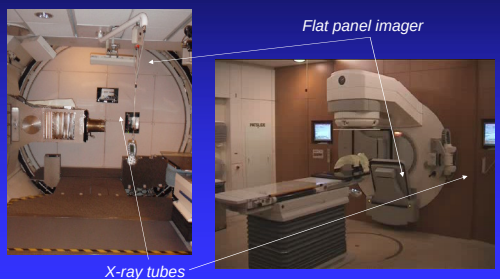
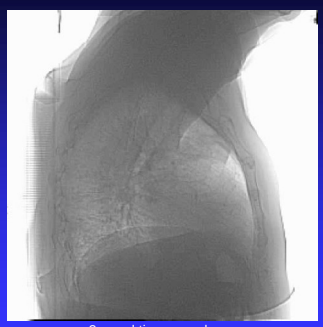


Image guidance: typical proton facility versus 'ordinary' linac



Cone beam CT for intrafraction motion ?

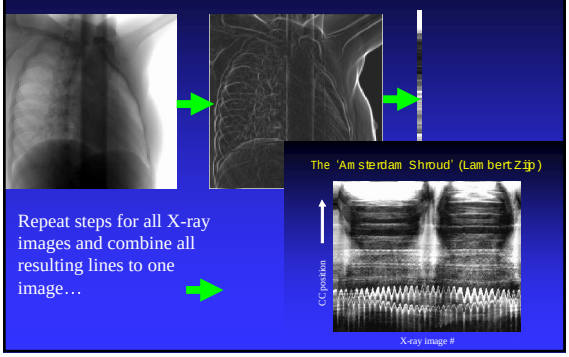


2 x real time speed

3D reconstruction

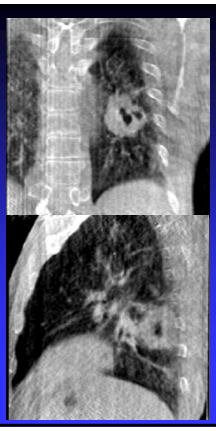
OK as long as the motion is stationary at the time scale of one beam

Detecting the respiratory phase

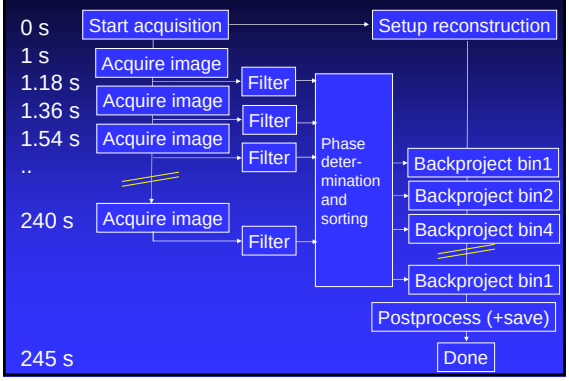


Repeat steps for all X-ray images and combine all resulting lines to one image…

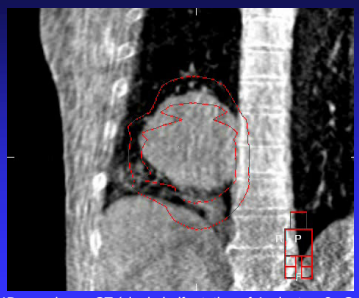
4D CBCT



In-line 4D image reconstruction (1200 frames)

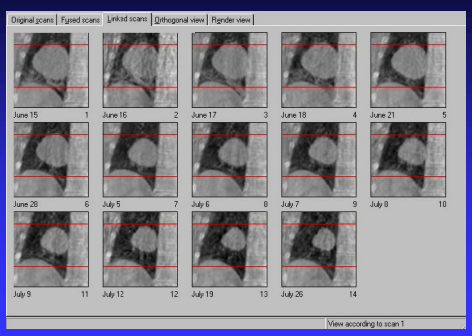


Visualization of tumor motion with 4D cone beam CT



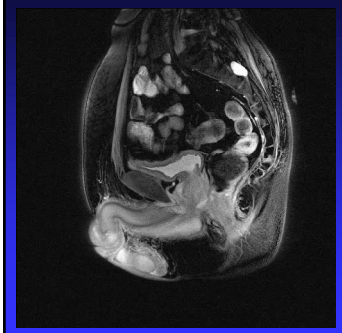
4D cone beam CT (single half rotation of 4 minutes, 2 cGy)
(Sonke et al Med Phys 2005)

Repeated 4D CBCT



Note the high stability of the respiratory motion, even though the tumor shrinks significantly

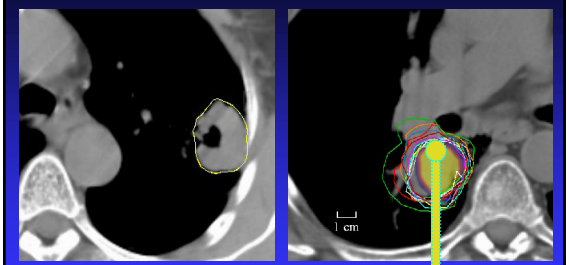
MRI on the treatment machine ?



- Utrecht (Raaymakers, Lagendijk et al.): 1.5 T MRI operation during irradiation shown to be feasible
- Issues:
  - Effect of magnetic field on linear accelerator
  - Electron return effect
- Would this be feasible for particles ?

Data courtesy of Jaffray and Gilhezan, Beaumont

Main problem:



Strong need for pathology validation and outcome monitoring, especially in proton radiotherapy

Margins for protons

- In protons, errors lead to dose differences, when these are described as shifts and deformations of isodose lines:
- This is the required margin:

$$M = 2.5\Sigma + 1.64\sqrt{(\sigma_p^2 + \sigma^2)} - 1.64\sigma_p^2$$

- The penumbra (σ_p) for the distal edge is much sharper: larger margin required

Conclusions

- All modes of imaging used on a linear accelerator should be used at proton facilities
- And actually, due to the steeper dose gradients in proton and particle radiotherapy, there is a stronger need for:
  - Image guidance
  - Correct target definition
  - Monitoring density changes
  - Clinical trials because the target volume is uncertain
- What are you waiting for ?