In-room imaging


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Classic radiotherapy procedure

Tattoo, align and scan patient

Align patient on machine on tattoos and treat (many days)

Draw target and plan treatment on RTP

In principle this procedure should be accurate but

Problem: patient position differs from day to day

Daily video images

With Lennert Ploeger, Joanne de Bois, Michel Frenay

The patient moves: how to solve this problem?

1. Use large margins, irradiating too much healthy tissues
2. Use small margins, and risk missing the target
3. Or: use image guidance with margin depending on remaining error

Image Guided Radiotherapy

Increase precision by imaging target and/or healthy tissues just prior to treatment

Available systems:
- MV imaging
- Ultrasound
- kV imaging with or without implanted markers
- Optical imaging
- Accelerator integrated on CT scanner gantry
- CT integrated on accelerator gantry

Many of these systems became recently available

EPID on machine
Day to day setup error

Intrafraction motion visualized with EPID

Prostate – not visible

Lung

Erridge et al, RO 2003

Ultrasound-guided RT

First proposed by Troccaz et al, Grenoble, 1993

Study on pressure effect with Xavier Artignan and Mariquee Smitsmans

Patient contour based setup

Courtesy of Chris Moore, Christie Hospital, Manchester

kV image guidance: not a new idea!

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

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
Varian On-Board Imager™ (OBI)

- Robotic Arms
  - Active position feedback
  - Completely retractable
- Modes of operation
  - Radiographic
  - Cone Beam CT
  - Fluoroscopic
In use at VUMC - Amsterdam

HI-ART Tomotherapy Unit

Is a single slice CT scanner and slice-based treatment machine in one
Delivery of radiotherapy from all angles around the patient
System in use in RISO - Deventer

Proposed by Rock Mackie, Wisconsin, AAPM 1992

Elekta Synergy (co-developed by us)

Typical patient dose for prostate imaging:
- 3 cGy in isocenter, 3 cGy at the skin (with bowtie filter)
Number of image frames: 651
130 kV 32 mA 40 ms Half offset field of view

Typical patient dose for prostate imaging:
3 cGy

Selected dose levels for cone beam CT versus EPID at NKI

<table>
<thead>
<tr>
<th></th>
<th>Center dose</th>
<th>Skin dose</th>
<th>Sample image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck / 25 cm field of view (520 frames, 65 sec)</td>
<td>1.0 cGy</td>
<td>1.0 cGy</td>
<td>Sample image</td>
</tr>
<tr>
<td>Prostate / 40 cm field of view (640 frames, 120 sec)</td>
<td>&lt; 2.8 cGy</td>
<td>&lt; 2.8 cGy</td>
<td>Sample image</td>
</tr>
<tr>
<td>4D Lung / 25 cm field of view (640 frames, 240 sec)</td>
<td>&lt; 2.2 cGy</td>
<td>&lt; 2.2 cGy</td>
<td>Sample image</td>
</tr>
<tr>
<td>EPID – 2 x 5 MU</td>
<td>&lt; 8 - 9 cGy</td>
<td>&lt; 2 - 4 cGy</td>
<td>Sample image</td>
</tr>
</tbody>
</table>

Please spend a few cGy to get those 7000 cGy in the right place!

Kilovoltage CBCT image analysis: comparison with reference image

Reference image (planning CT)
Localisation image (cone beam CT, 1 cGy, 1 minute)
Mixed image (not matched)

Automatic matching on region of interest built-in in Synergy system

Tumor in top of neck
Required table shift: (-3.2, -1.5, -0.6) mm

Tumor in lower part of neck
Required table shift: (+1.5, -3.2, -6.1) mm
With such a system, this is no longer needed to precisely irradiate a brain tumor. We can use this instead: focus on patient stability, but let computer position the patient with better than one mm precision.

Results stereotactic brain treatment (25 patients)

- Setup errors before and after correction
- Intra-fraction motion (scan after treatment)

<table>
<thead>
<tr>
<th></th>
<th>Left-right (mm)</th>
<th>Cranial-caudal (mm)</th>
<th>Ant-post (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean SD</td>
<td>Mean SD</td>
<td>Mean SD</td>
</tr>
<tr>
<td>Before correction</td>
<td>-0.8 1.5</td>
<td>-0.1 2.3</td>
<td>0.5 2.0</td>
</tr>
<tr>
<td>After correction</td>
<td>-0.1 0.7</td>
<td>-0.1 1.0</td>
<td>0.1 0.9</td>
</tr>
<tr>
<td>Intra-fraction</td>
<td>-0.1 0.3</td>
<td>-0.1 0.3</td>
<td>0.1 0.2</td>
</tr>
</tbody>
</table>

Couch shift largest error source!

More difficult: accurate lung radiotherapy

Visualization of tumor motion with 4D cone beam CT

Baseline tumor position changes: scans taken within one week and matched on bone

Sonke et al. Med Phys 2005
Sonke et al. IJROBP 2007
Hypofractionated lung treatment (3 x 18 Gy)

>100 patients treated this way

typical 50% smaller margins possible (7 mm) – much less damage to healthy tissues

Sonke et al, IJROBP 2008

Planned dose distribution

Realized dose distribution

7 mm margin is more than adequate even with 2 cm tumor motion

With image guided RT, margins cannot be zero

- Imaging (planning CT) and planning errors: 5 mm margin
- Observer errors in image guidance: 1 mm margin
- Short-term motion during treatment: 1 mm margin
- Respiration: 0-5 mm margin
- Anatomical changes during the course of therapy – for some patients

Use of animation for validation of CBCT prostate registration (for Adaptive Radiotherapy)

First week scans (10 mm margin)

Automatic bone match

T, R mean prostate position

Automatic prostate match

help line (GTV+3.6 mm)

Smitsmans et al., IJROBP 2004, 2005
### Prostate Adaptive Radiation Therapy

- **Planning CT**: 10 mm margin
- **Re-plan using average prostate & rectum 7 mm margin**
  - First 6 days: cone beam CT
  - Weekly monitoring treatment: cone beam CT

Margin derived from simulation with follow-up CT data of 19 patients (11 scans per patient)*:
- Average prostate + 7 mm
- Convex hull of all prostates + 4 mm

Results derived from simulation with follow-up CT data:
- Average prostate + 7 mm
- Convex hull of all prostates + 4 mm

**Methods: average prostate**

- **Plan → CBCT1: T1/R1**
- **Plan → CBCT2: T2/R2**
- **...**
- **Plan → CBCT6: T6/R6**

\[
\frac{T_{AVG}}{R_{AVG}} = \text{prostate from plan CT in average position}
\]

- With this CTV the margin can be safely reduced from 10 mm to 7 mm

### Results: monitoring the treatment

Done 50 patients: for 5 patients there was a marginal miss on 1 scan

### Bladder cancer

- Bladder tumor markers

- **Adapt RT for bladder cancer**

- **Bladder tumor markers**

*Nuver et al, IJROBP 2007 (accepted)*
Surgical clips (AMC)  

Lipiodol injections  

Lipiodol washout (6 weeks)  

Image guidance on lipiodol  

Was this patient perfectly aligned after shifting the couch with IGRT?  

Tools for analyzing deformations

B-spline deformable registration: Simon van Kranen
The better you look, the more you find. Would deformable registration have picked this up?

Typical margin applied in head and neck: 5 mm


Conclusions (1)

- In-room imaging is essential to guarantee accurate radiotherapy
- The accuracy of each system depends on the application
  - Optical: good for breast
  - MV or kV imaging with markers: good for prostate
  - CT and CBCT: good for bone and (some) soft tissue

Conclusions (2)

- Even though image guidance improves accuracy, there are remaining errors that need to be taken care of:
  - Definition of the target volume
  - Observer and correction errors during image guidance
  - Intra-fraction motion
  - Changes in the anatomy of the patient