IGRT

ICTP SCHOOL ON MEDICAL PHYSICS
Radiation Therapy:
Dosimetry and Treatment Planning
for Basic and Advanced Applications
ICTP, Trieste 2019

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IGRT1 technologies

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IGRT

- The aim
  - to ensure that the delivered dose distribution is as close as possible to the planned dose distribution
  - to solve the problem of set-up uncertainties,
  - to resist the changes of patient anatomy during the course of treatment,
  - to resist the changes of position of the target during single treatment session.

ANSWER: imaging
Image-guided radiation therapy (IGRT)

- How does it go
  - the process of frequent two and three-dimensional imaging, before, during a course of radiation treatment
  - adaptation the actual plan to the intendet one

EPID

Cone beam CT
Technologies

- **Construction**
  - source of ionizing radiation
  - detector

- **Systems**
  - planar – 2D
  - spatial – 3D

- Ultrasound and laser systems are also used.
Radiation sources

- MV
  - therapeutic beam is used

- kV
  - additional source of radiation
What is the essential difference between kV and MV images?
Radiation sources

- **MV**
  - therapeutic beam is used
    - Compton effect
      - very weak contrast – no dependence on atomic number
        - differences in radiological thickness only
  - kV
    - additional source of radiation
      - a little photoelectric effect, but it is enough to have
        - much better contrast – dependence on the atomic number
          - bones are visible very well
Contrast

Definition

\[ C = \frac{signal}{mean\_signal} = \frac{\Phi_{P2} - \Phi_{P1}}{(\Phi_{P2} + \Phi_{P1})/2} \]

1-cm-thick bone embedded within 20 cm of soft tissue

100 kVp; contrast 0.5

6 MV; contrast 0.037
Image detectability (SNR)

- Signal - to - noise - ratio

\[
SNR = \frac{signal}{noise} = \frac{\Phi_{p2} - \Phi_{p1}}{\sqrt{(\Phi_{p2} + \Phi_{p1} + 2\Phi_S)/2}}
\]

\[
SNR = \frac{mean \cdot signal}{dispersion} = \frac{\bar{S}}{\sigma}
\]

<table>
<thead>
<tr>
<th></th>
<th>100 kVp</th>
<th>6 MV</th>
<th>6 MV</th>
<th>6MV</th>
<th>6 MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient dose (cGy)</td>
<td>0.05</td>
<td>0.05</td>
<td>1.00</td>
<td>10.00</td>
<td>55.00</td>
</tr>
<tr>
<td>SNR</td>
<td>71</td>
<td>&lt;1</td>
<td>4.8</td>
<td>15</td>
<td>35</td>
</tr>
</tbody>
</table>
Three the most important technical achievements for radiotherapy?
Three the most important technical achievements for radiotherapy?

- CT
- EPID
- IMRT
Commisioning and QA of EPIDs

- **What must be verified**
  - mechanical and electrical safety
    - safety of mounting the EPID; risk of dropping the device on a patient (for older detachable systems)
    - operation of collision systems (EPIDs are expensive!)
  - geometrical reproducibility
    - the center of EPID should conform to the central axis
  - image quality
    - spatial and contrast resolution
  - software performance
Commisioning and QA of EPIDs

- Vendors usually recommends some tests
- Calibration should be made regularly
  - dark current or noise (image acquired without beam)
  - uniformity of the image
    - for open field intensity across the beam should be uniform
    - dead pixels
Commisioning and QA of EPIDs

- **Linearity**
  - distortion of images should be eliminated (simple phantoms with regularly placed objects)

- **Image quality**
  - specialized phantoms are used
    - Aluminium Las Vegas (AAPM)
    - PTW phantom

Journal of Applied Clinical Medical Physics, Vol 12, No 2 (2011)

A quality assurance phantom for electronic portal imaging devices

Indra J. Das, Minsong Cao, Chee-Wai Cheng, Vladimir Misic, Klaus Scheuring, Edmund Schüle, Peter A.S. Johnstone

Quality Control of Portal Imaging with PTW EPID QC PHANTOM

Csilla Pesznyák, Gábor Fekete, Árpád Mózes, Balázs Kiss, Réka Király, István Polgár, Pál Zaránd, Árpád Mayer

EPID QC phantoms

- Las Vegas phantom

- PTW phantom
EPIDs’ software

- Image quality may be improved with
  - changing window and level
  - more sophisticated digital filtering techniques
  - for edge detection of bones
    - high pass filter
    - Canny and Sobel

- How we recognize objects?

www.cse.unr.edu/~bebis/CS791E/Notes/EdgeDetection.pdf
How objects are recognized?
We all are experts!

Recognition is driven by edges!
Leszek Chmielewski                                           Przetwarzanie obrazów

Specyfika PO: Wszyscy jesteśmy “ekspertami” w rozpoznawaniu najważniejsze są krawędzie
Edges

Edge is a second derivative of intensity.

MV image problem of noise!
Improving quality of images

- kV radiation

The idea and first solution.
Haynes Radiation

Home of the RAD II

- Bi-Planer Tumor Verification
- Therapy Attached Simulator & Verification Device

Click here to enter
2D system for set-up control

1 MU – 3 MU
3D Technology

- A set of 2D images → 3D image
  - Computerized tomography
    - conventional (on rails) tomograph
    - cone beam tomograph
    - MV cone beam CT
3D Technology
cone beam CT

Difference between the fan (narrow) beam and cone-beam tomography.

\[ SNR_{fan} > SNR_{cone} \]
3D Technology cone beam CT

- With kilovoltage radiation
  - Elekta –
  - Varian - On Board Imaging
- Specialized software for image registration
Image quality

- Worse than for conventional CT
  - smaller SNR

- Good enough for soft tissue registration in some clinical situations
  - distortions due to patient movement

Megavoltage Cone Beam CT

treatment beam
Megavoltage Cone Beam CT image quality
Improving quality of images

- kV radiation

Home of the **RAD II**
- Bi-Planer Tumor Verification
- Therapy Attached Simulator & Verification Device

Click here to enter

The idea and first solution. Haynes Radiation

CyberKnife

Exact Track BrainLab
IGRT in practice

- When and why?
  - Set-up control
    - interfraction differences
    - intrafraction differences
  - Adaptive treatment
    - new idea in radiotherapy
      - to match the treatment plan to actual anatomy
  - Special procedures
IGRT examples

- Preparation for treatment

Marian System – OptiNav technology
IGRT examples

- CBCT performed before treatment
  - set-up control
    - bone matching
      - two perpendicular portals
    - soft tissue matching
      - prostate
      - SBRT liver
      - gynecological cancers
Examples of IGRT

- Plan of the day
  - dose distribution matched to the actual anatomy

‘Plan of the day’ adaptive radiotherapy for bladder cancer using helical tomotherapy

Vedang Murthy  Radiotherapy and Oncology 99 (2011) 55–60
Examples of IGRT

- Prostate
  - Gold fiducials
    - Inter- and intrafraction movement
CyberKnife

- Specialized software
  - Synchrony
  - Xsight Lung
  - XSight Spine

Deformable registration

Courtesy of Accuray
CyberKnife

- Synchrony

Imaging system takes positions of fiducials at discrete points of time

Markers are monitored in real time by a camera system

Courtesy of Accuray
Reliable evaluation of treatment effect

- Rectum dose

Planning

Treatment
Mean dose to rectum

PhD Anna Grzelec
The only dose quantity that allows any intercomparison of stochastic risk between the different imaging scenarios ... is **effective dose**, which combines the quality and distribution of radiation throughout the body with its effect on a number of specific organs.

- If 10,000 individuals received 0.01 Sv each over background during their life, 4 additional deaths would occur of the 2,000 that would naturally occur; (0.01 Sv – 1 cGy – 10 mSv)

Radiation protection of a patient
Effective dose

\[ E = \sum_{T} (w_T \cdot w_R \cdot D_{T,R}) \]

- \( w_T \) = tissue weighting factor
- \( w_R \) = radiation weighting coefficient
- \( D_{T,R} \) = average absorbed dose to tissue \( T \)

for radiation used in conventional radiotherapy \( w_R = 1 \)
Effective dose

For photons and electrons $W_R = 1$

<table>
<thead>
<tr>
<th>Organ/Tissue</th>
<th>$W_T$</th>
<th>Organ/Tissue</th>
<th>$W_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone marrow</td>
<td>0.12</td>
<td>Lung</td>
<td>0.12</td>
</tr>
<tr>
<td>Bladder</td>
<td>0.04</td>
<td>Liver</td>
<td>0.04</td>
</tr>
<tr>
<td>Bone Surface</td>
<td>0.01</td>
<td>Oesophagus</td>
<td>0.04</td>
</tr>
<tr>
<td>Brain</td>
<td>0.01</td>
<td>Salivary glands</td>
<td>0.01</td>
</tr>
<tr>
<td>Breast</td>
<td>0.12</td>
<td>Skin</td>
<td>0.01</td>
</tr>
<tr>
<td>Colon</td>
<td>0.12</td>
<td>Stomach</td>
<td>0.12</td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
<td>Thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Liver</td>
<td>0.05</td>
<td>Remainder</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Doses from CBCT

Dose from Elekta XVI kV cone-beam CT.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Head</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean dose at center (mGy)</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Mean skin dose (mGy)</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>3.0</td>
<td>8.1</td>
</tr>
</tbody>
</table>


Effective dose from 6 MV portal images 18 cm x 15.6 cm taken at SSD=88 cm.

<table>
<thead>
<tr>
<th>Port View</th>
<th>Gender</th>
<th>Effective Dose $E$ (mSv/MU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP pelvis</td>
<td>Male</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.52</td>
</tr>
<tr>
<td>Lat pelvis</td>
<td>Male</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>0.7</td>
</tr>
<tr>
<td>AP chest</td>
<td>Male</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1.8</td>
</tr>
<tr>
<td>Lat chest</td>
<td>Male</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>2.23</td>
</tr>
<tr>
<td>Lat neck</td>
<td>N.A.</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Concomitant dose MCBCT

Irradiation of rectum patient
8 MU protocol

In practice for MVCBCT we use about 4 MU.
Doses from CBCT

- To be accounted for in total dose delivered to a patient?
  - different policies

- My opinion: in general there is no reason to take into account the CBCT concomitant dose unless CBCT is performed each fraction
  - on-line protocol
Summary

- The modern radiotherapy is imaged based
  - CT information for planning
    - fusion with other modalities

- Several solutions
  - visualizing high contrast objects
    - bones
    - gold markers
  - visualizing low contrast objects
    - soft tissue
Summary

- Several solutions
  - pre-irradiation information (low frequency)
    - inter-fraction changes
  - continuous (high frequency)
    - Intra-fraction changes
  - There are also other very sophisticated solutions
    - very expensive
Good news!

- in more than 80% of cases (my estimation) conventional portal control with EPID is enough,

- IF

- The right protocols are used, and applied properly
  - the structure, organization and personnel are the most important!
Thank you very much for your attention!

Images keep alive our memories!