ENGG 167
MEDICAL IMAGING

Lecture 21: Friday, Nov. 17

Radiation Therapy I


Radiation Therapy – Part I

1) Dose response
2) Cobalt Therapy
3) Linear Accelerators
4) Depth Dose Curves
5) Treatment Planning
6) Model-based treatment planning
Radiation Therapy

Additional Physicist functions:

- System specification
- Treatment room planning
- Construction supervision
- System purchasing
- System installation
- System Quality Audit

Ref: Van Dyke

Radiation dose-response curves

Figure 1.6 Schematic dose-response curves for tumor control and normal tissue response. (a) The classical presentation. (b) A more realistic representation of dose-response curves for both tumors and normal tissues. The small arrows in (a) near the 5% and 95% response levels give an indication of the effect on dose response when there is a 5% deviation from the intended dose.

Ref: Van Dyke
Radiation treatment planning

Figure 1.8
Schematic representation of target volumes in radiation therapy. The treatment portal is the actual irradiation field and includes the tumor volume (GTV), potential areas of local and microscopic spread (CTV), a margin to allow for uncertainty in patient setup and organ motion (PTV), and finally a margin to allow for the variation in dose falloff between the high-dose region and the actual beam edge. (Reprinted from reference [20], "Overview" by C. A. Perez, L. W. Brady, and J. L. Rott, in Principles and Practice of Radiation Oncology, C. A. Perez, L. W. Brady (Eds.), 1998, pp. 1-78, by permission of Lippincott-Raven, Philadelphia, PA.)

Orthovoltage X-ray therapy device
-- Pantak 300 (300 kVp)

Figure 9.1
View of the Pantak DXT300 orthovoltage x-ray unit with a variable collimator attached for use at 50 cm SSD.

Ref: Van Dyk
Cobalt-60 therapy device - older therapy system

Figure 10.4
Drawing of typical cobalt-60 therapeutic therapy device. (Reprinted with permission of Therastronics International Limited, Kanata, Ontario.)

Ref: Van Dyk & Washington

Cobalt-60 therapy device - older therapy system

Figure 10.5
Cobalt-60 therapy device. (Reprinted with permission of Therastronics International Limited, Kanata, Ontario.)

Ref: Van Dyk & Washington
Linear Accelerator (LINAC)

Ref: Van Dyk

Figure 11.3
Schematic diagram of a typical S-band medical linac.

Ref: Van Dyk
Different LINAC designs

![Different LINAC designs](image)

**Figure 11.4**
Design configurations for isocentric medical linacs:
(a) straight-through beam design: electron gun and target are permanently embedded into the accelerating waveguide; (b) accelerating waveguide in the gantry parallel to isocenter axis, electrons brought to the target through a beam transport system; (c) accelerating waveguide in the gantry stand.

Ref: Van Dyk

Electron gun pulses electrons into waveguide

![Electron gun pulses electrons into waveguide](image)

**Thermionic emission of electrons.**

In static emission, typically near –20kV used for acceleration of beam into waveguide.

In pulsed emission, pulses of –150V and +180V oscillate with respect to the cathode.

Ref: Van Dyk
Waveguide accelerator

Evacuated or dielectric filled cylindrical cavities, tuned for a specific frequency. (2.856 GHz)

Must be modified such that phase velocity, \( v_{\text{ph}} < c \), since \( v_{\text{ph}} = v_{\text{part}} \), particle velocity.

This is accomplished with cylindrical disks placed at quarter wavelength spacings

Ref: Van Dyk
Waveguide accelerator

The spacing of the cavities is matched to the wavelength of the microwaves. The spacing allows the electric and magnetic fields to repeat their pattern every three cavities. Electrons or positrons in the beam come through the cavities in small bunches. The arrival of each bunch is timed so that it gets a “push” from the electric field across the cavities.

RF generation for electron pulse acceleration – magnetrons and klystrons

Magnetron
Resonant cavities deliver energy to electrons as they spiral around a magnetic field. Coupling of electrons to aerial delivers RF power. Typically used for < 6MeV powers.

Klystron
Resonant cavities deliver energy to electrons as they travel from cathode to beam dump. Design of buncher and catcher cavities provides maximal coupling of RF power to and from electron beam. Typically used for > 6 MeV powers.
Microwave power transfer to accelerator

Typical frequency is 2.856 GHz for medical linacs.

$\text{TE}_{01}$ mode waveguides used to transfer RF power

Pressurized with dielectric gas (freon or SF$_6$) to 2 atm. pressure

Circulator also required, which is a component allowing one way transfer of the RF (composed of a ferrite such as ceramic mixed with iron), making back reflections into klystron impossible.

Electron beam steering systems

![Diagram of electron beam steering systems](image)

Figure 11.11
Schematic diagram of three systems for electron beam bending: (a) 90° bending; (b) 270° bending; and (c) spiral system incorporating two 45° magnets and a 112.5° magnet.

Ref: Van Dyk
LINAC head components – photon and electron modes

Figure 11.13
Schematic diagrams of main medical linac head components: (a) for the photon mode with target and flattening filter in the beam and (b) for the electron mode with scattering foil in the beam. (Reprinted from reference B11, Medical Electron Accelerators by C. J. Kuzmick, C. Numa, and R. Rando, copyright 1992, McGraw Hill. Reproduced with permission from the McGraw-Hill Companies.)

LINAC beam parameters which need to be measured

**Percentage depth-dose** – measured with small ionization chamber translated vertically down along the central line. Max value called $d_{\text{max}}$.

**Beam profiles** – horizontal measure of dose falloff in penumbral regions between 20% and 80% maximum dose.

Flatness - $F = 100 \times \frac{(D_{\text{max}} - D_{\text{min}})}{(D_{\text{max}} + D_{\text{min}})}$ across the region >80%

**Dose field factors** – correction factor for doses generated from different field sizes. Most machines set for 1 MU = 1 cGy delivered at $d_{\text{max}}$ in water on the central axis for 10x10 cm² field.
Depth-dose curves for different photon & electron energies

**Figure 11.19** Percentage depth dose curves in water for 10 x 10 cm² fields at an SSD of 100 cm for various linear photon beam energies. Data for a cobalt-60 beam are shown dashed for comparison. Data are from reference [20].

Ref: Van Dyk

Dose versus field size

**Figure 11.17** Surface dose against side of square field for 6 and 18 MV beams from a Clinac 2100C linac (Varian, Palo Alto, CA). Measured in solid water phantoms with an SSD of 100 cm.

**Figure 11.18** A family of 18 MV percentage depth dose curves in water for various field sizes between 4 and 40 cm at an SSD of 100 cm. Data are from reference [20].

Ref: Van Dyk
Iso-dose lines in water and inhomogeneous phantoms

![Diagram of iso-dose lines in water and inhomogeneous phantoms](image)

Figure 8.12
FLUENCE and DOSE distributions for a beam of 6.0 MeV photons (a) and a 6 MeV beam (b, c) in water and inhomogeneous phantoms. (d) DOSE distribution in a water-cork/water phantom. (e) DOSE distribution in a water-honeycomb phantom. (f) Note the dose reduction in the central region of the cork and the peripheral region of the beam. [Adapted with permission from reference (23)]

Ref: Van Dyk

Cobalt-60 beam profile vs. 6 MeV beam

![Diagram of Cobalt-60 beam profile vs. 6 MeV beam](image)

Figure 10.11
Comparative transverse beam profiles for an 18 cm x 18 cm field at 100 cm SSD for a cobalt 60 (solid curve) with inserts at 45 cm and a 6 MeV linac (dashed curve) at 1.0 cm depth (left panel) and 10.0 cm depth (right panel).

Ref: Van Dyk
Cobalt-60 beam profile vs 6MeV beam

Figure 10.16
Comparisons of a 100 cm SSD 14 cm × 14 cm T-1000 beam to a 6 MV beam.

Ref: Van Dyk

Treatment Planning

- Prediction of dose delivery in heterogeneous patient tissues.
- Each patient requires a separate dose plan.
- Prediction of tissues to hit and tissues to spare
- Model-based simulation based upon CT scan
- Optimization

Ref: Van Dyk
Model-based prediction of dose

Figure 5.12
Target volume contours showing the use of an automated margin on transverse image for the same patient of Figures 5.6 and 5.8.

Ref: Van Dyk

Treatment planning with CT scans - I

Table 5.4
Special Considerations for CT Scanning for Radiation Therapy Planning in Contrast to Diagnostic Scanning

<table>
<thead>
<tr>
<th>CT Scanning for Radiation Therapy Planning</th>
<th>CT Scanning for Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat table top</td>
<td>Curved table top</td>
</tr>
<tr>
<td>• Used for simulating treatment position</td>
<td>• Provides better diagnostic images</td>
</tr>
<tr>
<td>• Reduced image quality compared to curved couch</td>
<td></td>
</tr>
<tr>
<td>Laser positioning lights</td>
<td>Laser positioning lights not needed</td>
</tr>
<tr>
<td>• Necessary for accurate repositioning on treatment</td>
<td>Patient positioning is not critical</td>
</tr>
<tr>
<td>Patient positioning</td>
<td>• Only interested in obtaining best quality image</td>
</tr>
<tr>
<td>• Dependent on treatment site</td>
<td>Full breath hold inspiration</td>
</tr>
<tr>
<td>• Supine vs. prone</td>
<td>• Minimizes motion artifacts</td>
</tr>
<tr>
<td>• Axial orientation</td>
<td>• Image contrast in supine</td>
</tr>
<tr>
<td>Respiratory conditions</td>
<td>Reference marks not needed</td>
</tr>
<tr>
<td>• Slow breathing as will occur on treatment</td>
<td></td>
</tr>
<tr>
<td>• Reduces image quality due to respirations</td>
<td></td>
</tr>
<tr>
<td>Beam reference marks</td>
<td></td>
</tr>
<tr>
<td>• Essential for daily patient setup</td>
<td></td>
</tr>
<tr>
<td>• Should be radio-opaque but should not cause image distortions</td>
<td></td>
</tr>
<tr>
<td>Immobilization/treatment devices</td>
<td></td>
</tr>
<tr>
<td>• Essential for minimising uncertainties in setup</td>
<td></td>
</tr>
<tr>
<td>• Devices must be x-ray transparent</td>
<td></td>
</tr>
<tr>
<td>Fillable organs</td>
<td></td>
</tr>
<tr>
<td>• Can cause changes from day to day resulting in loss of accurate reproducibility and possible inaccuracies in the planning process</td>
<td></td>
</tr>
<tr>
<td>Patient's size and shape of reconstruction</td>
<td></td>
</tr>
<tr>
<td>• Missing components of the patient could create problems with respect to dose calculations</td>
<td></td>
</tr>
<tr>
<td>• Patient outside of circle of reconstruction could reduce image quality</td>
<td></td>
</tr>
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</table>

Ref: Van Dyk
Treatment planning with CT scans - II

Table 5.4
Continued

<table>
<thead>
<tr>
<th>CT scanning for radiation therapy planning</th>
<th>CT scanning for diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate CT numbers</td>
<td>Accurate CT numbers</td>
</tr>
<tr>
<td>• Essential for accurate dose calculations</td>
<td>• Not as critical for diagnosis since relative abnormalities are important for diagnosis and not absolute CT numbers</td>
</tr>
<tr>
<td>Slice thickness</td>
<td>Slice thickness</td>
</tr>
<tr>
<td>• Important for 3-D reconstructions and DRRs</td>
<td>• Important for diagnosis and minimization of partial volume effects</td>
</tr>
<tr>
<td>Transmission scatter</td>
<td>Transmission scatter</td>
</tr>
<tr>
<td>• Useful for determining upper and lower scan limits</td>
<td>• Useful for determining upper and lower scan limits</td>
</tr>
<tr>
<td>Contrast agents</td>
<td>Contrast agents</td>
</tr>
<tr>
<td>• Useful for enhancing distinction between tumor and soft tissues</td>
<td>• Essential for various diagnostic procedures</td>
</tr>
<tr>
<td>Protheses</td>
<td>Protheses</td>
</tr>
<tr>
<td>• Could generate major image artifacts impacting both target localization and dose calculations</td>
<td>• Could generate major image artifacts impacting diagnosis</td>
</tr>
<tr>
<td>Scan time</td>
<td>Scan time</td>
</tr>
<tr>
<td>• Dependent on number of images required for 3-D reconstructions and DRR calculations</td>
<td>• Rapid scans minimize image artifacts</td>
</tr>
</tbody>
</table>

Ref: Van Dyk

Patient immobilization procedures

Figure 3.16
The Gill Thomas-Oseren (GTO) stereotactic frame connects to a dental impression and an acrylic plate, formed to the posterior surface of the patient’s head, and a strip that forces the impressions against the head. (Courtesy of Radionics, Inc., Burlington, Massachusetts.)

Figure 3.13
Designing the thermoplastic immobilization mask to include the shoulders may improve the accuracy of field matching between opposed fields and an anterior beam-eliminating posterior field. (Courtesy of MRD-THG, Inc., Orange City, Iowa.)

Ref: Van Dyk
Accuracy limits in positioning

### Table 3.3
Limitations of Positioning Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Accuracy Limit (MM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser alignment using skin marks</td>
<td>2.0 – 2.5</td>
</tr>
<tr>
<td>Radiographic alignment using anatomy</td>
<td>1.0 – 2.0</td>
</tr>
<tr>
<td>Radiographic alignment using point markers</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Mechanical positioning of indexed patient</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>Visual image alignment</td>
<td>~1.0</td>
</tr>
</tbody>
</table>

Ref: Van Dyk

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**Journal Club IV– Industrial/Product Review**

- Look through journals handed out, as well as web links on class website.

- Choose a product/company to present.

- Give me the name of the product/company before Wednesday.

**Things you need to present:**

- Overview of product (pictures)
- Technical specifications
- How is it used? (main medical imaging procedures)
- Who has used it? (search360 or medline?)
- What competition is there for this product? (other companies etc.)