Chapter 11-12
Treatment Planning:
Single Beams,
Combination of Beams
Radiation Dosimetry I

http://www.utoledo.edu/med/depts/radther

Patient dose calculation

- The aim of treatment planning is to find the beam arrangement that provides the adequate radiation dose to the tumor while sparing surrounding normal tissues
- Terms used in treatment planning:
  - Reference dose (normalization point, calculation point)
  - Tumor dose
  - Skin (entrance) dose, exit dose

Patient dose calculation

- Reference dose: R
- Tumor dose: T
- Skin dose: S; Exit dose: E

Effect of the curved contour surface

- Isodose lines are shifted on one side due to “missing” tissue
- Need to correct for curved contour surface

Correction for curved contour surface

- Effective attenuation coefficient method: based on data in Table 11-1 (Co-60) dose to P should be increased and to Q decreased by Ad x 5% (no general account for FS)
- The ratio of tissue-air ratios method: take ratios of TAR’s at proper depths; takes into account FS
- The effective SSD method: adjust the dose by the inversed square law ratio
- These approaches do not account for changes in scatter

Bolus and compensating filters

- Shape of isodose curves can be preserved with use of tissue-equivalent bolus
- For high energy beams use of bolus prevents skin sparing

<table>
<thead>
<tr>
<th>Relation</th>
<th>90</th>
<th>100</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue</td>
<td>90</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>Air</td>
<td>80</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>Tissue</td>
<td>70</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>Air</td>
<td>60</td>
<td>55</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 11-1: Ratios of Tissue-air ratios for Co-60
Bolus and compensating filters

- Compensating filter of the same shape can be placed at some distance from the skin
- The filter introduces scatter, and can truly compensate at only one depth

Oblique incidence

- Skin doses increases with increasing angle of incidence
- The depth of maximum buildup decreases
- The dose build-up region is compressed into a more superficial region: skin reactions

Example 1

- Which of the following is false? The skin dose, as a percentage of dose at \( d_{\text{max}} \) in a 6 MV photon beam will increase when:
  
  A. The SSD is decreased.
  B. The field size is decreased.
  C. Bolus is used.
  D. Fields are treated at oblique incidence

Wedge filters

- Specially shaped isodose curves utilize wedges
- Wedge thickness \( x \) at each point can be calculated based on the amount of attenuation needed to reduce the dose: \( D' / D = e^{-x} \)
- Need to account for scatter effectively reducing the angle

Wedge filter implementations

- Hard wedge: set of fixed wedge angles
- Motorized (universal) wedge: physical wedge of the largest wedge angle (steepest gradient) combined with open beam to produce the required isodose tilt
- Dynamic or Virtual wedge: fluence gradient across the beam is produced by progressively moving one of the collimator jaws across the treatment field during the exposure. The amount of MU’s can also be varied during the treatment

Example 2

- A field with an effective wedge angle of 30 degrees could be achieved by all of the following except:

A. Combining open and 60-degree wedged fields for equal doses at the isocenter.
B. Combining open and 60-degree wedged fields for equal MUs
C. A Universal wedge, combining wedged and open fields.
D. A dynamic wedge.
E. A custom compensator.

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Dose corrections for inhomogeneities

- Dose at all points will be altered due to the presence of inhomogeneity
- Two factors:
  - Change in primary fluence due to change in attenuation
  - Change in scatter contribution

Dose corrections for inhomogeneities

- Use methods similar to correction for curved surfaces
- In TAR correction method introduce dose correction factor for a field size $r_d$:
  \[ C = \frac{T_{a}(d',r_d)}{T_{a}(d,r_d)} \]
- The equivalent thickness $d' = d_1 + \rho_3 d_2 + d_3$
- Density $\rho_3$ is relative to water

Dose corrections for inhomogeneities

- More accurate correction factor takes into account the proximity of the inhomogeneity (power law method):
  \[ C = \frac{T_{a}(d_1,r_d)^{\rho_3/r_2}}{T_{a}(d_2 + d_3,r_d)^{\rho_2}} \]
  - $\rho_3$ is the density of the material in which the point lies
  - $\rho_2$ is the density of the overlying material

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Energy absorption in biological material

In electronic equilibrium condition dose in tissue can be calculated based on the dose measured in a phantom

\[ D_{\text{tis}} = D_{\text{wat}} \left( \frac{\mu_\text{tis}}{\mu_\text{wat}} \right)^{\rho_\text{tis}/\rho_\text{wat}} \]
Dose discontinuities at the interfaces with bone and air are the largest for the kV energy range.

Dose corrections for inhomogeneities:
- The greatest attenuation difference occurs:
  - For the lowest energy
  - For the greatest density difference

<table>
<thead>
<tr>
<th>Material</th>
<th>Density, g/cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1</td>
</tr>
<tr>
<td>Muscle</td>
<td>1.04</td>
</tr>
<tr>
<td>Bone</td>
<td>1.65</td>
</tr>
<tr>
<td>Fat</td>
<td>0.916</td>
</tr>
<tr>
<td>Lung</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Densities of biological materials

Example 3
- If heterogeneity corrections are not done, which of the following is likely to give the greatest discrepancy between calculated and actual dose at a point on the beam axis beyond the heterogeneity?

- Medium Thickness Photon energy
  - A. Lung 10 cm 6 MV
  - B. Lung 10 cm 18 MV
  - C. Fat 10 cm 6 MV
  - D. Dense bone 5 cm 6 MV
  - E. Dense bone 5 cm 18 MV

Combination of beams
- Achieve high dose conformity to the target
- Spare healthy surrounding tissues
- Several general approaches:
  - Opposing pairs of beams and their combination
  - Angled fields and wedge pairs
  - Rotation therapy

Opposing pairs of beams
- The simplest combination of two fields is achieved by directing them along the same axis from opposite sides.
Opposing pairs of beams

- An arrangement often used for treatment of a tumor situated approximately midway between two parallel surfaces
- High energy beams must be used to avoid the dip in the middle

Opposing pairs of beams

- For small separations (<10 cm) low MV energy beams are well suited: extended region of uniform dose with relatively flat plateau between the maxima
- For larger separations (>15 cm) high energy beam are required to avoid hot spots in the regions of both maxima
- Many anatomical sites can adequately be treated with parallel-opposed beams (lung, brain, head and neck lesions)

Opposing pairs of beams

- A uniform “box” coverage is achieved in planes perpendicular to the axis of opposing fields

Opposing pairs of beams

- In practice the isodose distribution is altered by curved surfaces and has to be properly adjusted (blocks, etc.)

Combination of opposing pairs

- Using setup at different angles, equal or unequal width, and beam intensities, can achieve conformity to the tumor shape/depth

Combination of opposing pairs

- Allows for higher dose in the beam intersection region
- Four-field box (two opposing pairs at 90° angle) used most often for treatment of pelvis with centrally located lesions (prostate, bladder, uterus)
- Three-field box (two wedged opposing beams and 3rd beam at 90°) for lesions closer to the surface (rectum)
Split fields

- Can be used to protect sensitive critical structures in the middle of the field

Angled fields and wedge pairs

- Parameters of the wedge beams: \( \theta \) is wedge angle, \( \Phi \) is hinge angle, and \( S \) is separation
- Isodose curves for each wedge field are parallel to the bisector
- An optimum relationship between the wedge angle \( \theta \) and the hinge angle \( \Phi \) that provides the most uniform distribution of radiation dose in the plateau:

\[
\theta = 90^\circ - \Phi / 2
\]

Three field technique

- Provides better dose homogeneity within the tumor
- Homogeneity can be further improved with tissue compensators

Example 4

- Which one of the following plans has the wedges in the correct orientation?

A. 
B. 
C. 
D. 
E.

Example 5

- The wedge angle that would give the most homogeneous distribution in the "wedged pair" in the diagram below is \( \theta \) degrees. (Field axes are at 90°).

\[
\theta = 90^\circ - \Phi / 2 \Rightarrow 90^\circ - 45^\circ = 45^\circ
\]

Options:
A. 10
B. 20
C. 30
D. 45
E. 60
Example 6

- Which of the following isodose patterns is consistent with the field configurations and wedges shown?

![Image]

Example 7

- In a 3-field plan to treat the rectum using open PA and wedged lateral fields, a homogeneous distribution can be obtained in the PTV with either 45° or 60° wedges. With 60° wedges, the relative dose at the isocenter for the PA field would be ___ that in the 45° wedged plan.

A. Greater than  
B. Less than  
C. The same as

Lateral wedges compensate for depth-dose fall-off of the PA field. The greater is the contribution from PA field, the larger is the wedge angle required.

Rotation therapy

- Provides maximum dose uniformity within the tumor and the most of healthy tissue sparing: a) patient in a rotating chair; b) source is moved around a stationary patient; c) source moves in a circular path and simultaneously transverse horizontally to cover the surface of a cylinder; d) X-ray head moves about a circle with the beam always directed to one point below the surface; e) patient lies on a couch that rotates about a vertical axis; f) beam is offset from the axis of rotation to cover an annular ring about the center of rotation (shaded wall irradiation).

Rotation therapy: isodose distributions

- Calculations are generally based on the superposition of single beam isodose charts, with isodose lines normalized to 100% at the axis of rotation.
- The total dose at a point in a patient is obtained by adding together the contributions from a series of fixed fields spaced at equal angular intervals.

Rotation therapy: effect of energy

- Penetration depth and skin sparing govern the choice of the beam energy.

Rotation therapy: effect of arc length

- As the degree of rotation becomes less than 360°, the isodose curves are deformed in such a way that the side opposite the beam entrance surface become flatter with the decrease in the arc angle.
- When the arc angle is 180° or less, the isodose curves tend to be pinched in at the sides and the lower portion again moves further from the axis.
Rotation therapy: effect of field size

The length of the field has a little effect, while the width has a profound effect on the isodose distribution.

Rotational therapy is not recommended if wide fields must be used, due to high dose delivered outside of the target.

Comparison of fixed field and rotation therapy

In rotation therapy the skin dose is less than with fixed field therapy (~15 vs. 40%) because rotation therapy is equivalent to using 8 to 12 fields.

The isodose curves for rotation therapy are smoother around the tumor region, with fixed fields "horns" between adjacent fields are present.

However, with fixed fields some areas can be completely spared.

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Summary

- Single beam
  - Isodose distribution with depth is affected by surface contour and tissue inhomogeneities
  - Beam modifiers
- Multiple beams
  - Combination of beams allows for conformal therapy
- Rotation therapy