Chapter 11
Treatment Planning – Single Beams

Radiation Dosimetry I

Text: H.E Johns and J.R. Cunningham, The physics of radiology, 4th ed.

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

Outline

- Basic terminology
- Curved contour surface correction (bolus, compensators, wedges)
- Oblique beam incidence
- Correction for tissue inhomogeneities

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

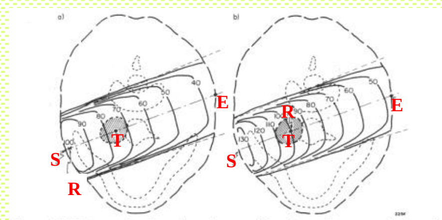


Figure 11-1. Diagrams showing a beam from a cobalt unit treating a tumor in the region of the tonsil. (a) is for a fixed SSD technique and (b) is for an isocentric technique.

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

Example 1

- As photon energy increases, surface dose _____ and depth of d_{max} _____ .

A. Increases, increases

B. Decreases, increases

C. Increases, decreases

D. Decreases, decreases

Effect of the curved contour surface

X - axis of rotation
Points P and Q at 100% isodose line require corrections for the new curved surface SS

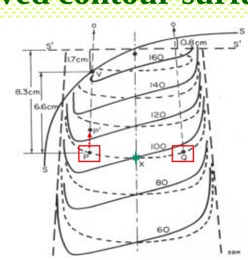


Figure 11-2. An isodose chart for a 10 × 10 field from a cobalt unit. The dashed lines are as determined in a water phantom. The solid lines show the distortion of the isodose pattern produced by the curved contour surface.

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

Correction for curved contour surface

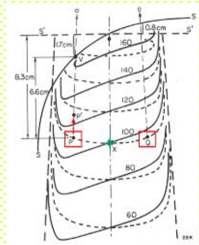
- *Effective attenuation coefficient method*: based on data in Table 11-1 (Co-60) dose to P should be increased and to Q decreased by Δd x 5% (no general account for FS)
- *The ratio of tissue-air ratios method*: take ratios of TAR's at proper depths; takes into account FS
- *The effective SSD method*: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

TABLE 11-1
Parameters Useful in Correcting Isodose Patterns for Air Gaps

Radiation	SSD (cm)	Attenuation (per cm)	k
x rays up to 1 MV	50	10%	0.8
cobalt 60	80	5%	0.67
x rays from 1 to 5 MV	100	4%	0.7
x rays from 5 to 15 MV	100	3%	0.6
x rays from 15 to 30 MV	100	2%	0.5
x rays above 30 MV		2%	0.4

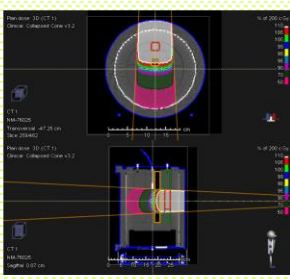
Derived from data for 10 × 10 cm fields. Values for k taken from van der Giessen (V4).

Correction for the curved contour surface



- *Effective attenuation coefficient method*: dose at P should be 1.7x5%=8.5% higher (dose at Q 0.8x5%=4% lower)
- *The ratio of TAR's method*: take TAR(d=8.3cm)=0.755 and TAR(d=6.6cm)=0.843 hence dose at P: 0.843/0.755=1.088
- *The effective SSD method*: dose at depth of P' is ~114, SSD correction factor is $(80+6.6)^2/(80+8.3)^2=0.962$, hence corrected dose: 114x0.962=109.7

Correction for the curved contour surface

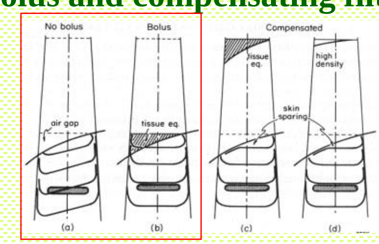


Isodose distributions for ArcCheck QA device in 2 planes

Image of ArcCheck from: http://www.peo-radiation-technology.com/en/product/arccheck-4d-sun-nuclear/

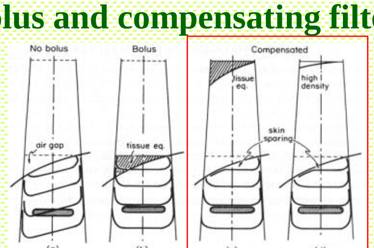
- In reality we are dealing with 3D shapes, proper corrections are required for contours behind and before the 2D plane
- Computerized treatment planning systems

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

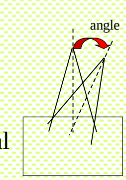
Bolus and compensating filters



- 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 2

- Which of the following is false? The skin dose, as a percentage of dose at d_{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

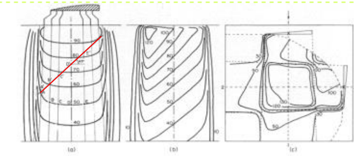


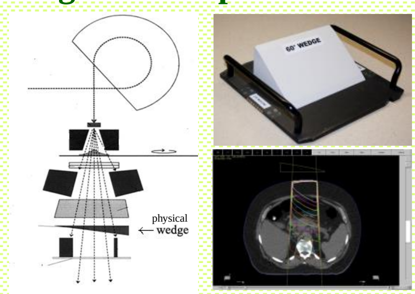
Figure 11-9. (a) Diagram to illustrate the design of a wedge filter to tilt the isodose lines through 45° for an 8 × 8 cm beam from a cobalt unit. (b) Isodose chart for the wedge of a. (c) Dose distribution produced by combining two wedged beams at right angles to produce a region of uniform dose.

- 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: $D'/D = e^{-\mu x}$
- 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

Wedge filter implementations



Images from: http://www.posterus.sk; http://titan.radonc.unc.edu/dose/

Example 3

- Modern linacs can be equipped with either a "universal wedge" (i.e., a "hard" 60° wedge in the head of the linac that can be remotely moved in or out of the beam) or a "dynamic wedge" (i.e., programmable collimator jaw to simulate a hard physical wedge). For the same nominal beam energy:

A. The dynamic wedge will have a more penetrating depth dose
B. The dynamic wedge will require fewer monitor units for the same central axis dose
C. There will be more scatter dose outside the field edge for a universal or dynamic wedge than for a "hard" wedge
D. The effective "wedge transmission factor" varies with field size ONLY for the dynamic wedge

Both the universal and dynamic wedges are physically higher in linac head, producing less scatter
The universal wedge attenuates the beam along the central axis -> more MU's to deliver the same dose

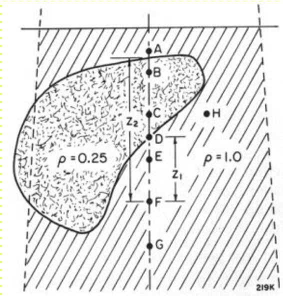
Example 4

- 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

Doses should be equal, MU's in a wedge field will be higher compared to the open field

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

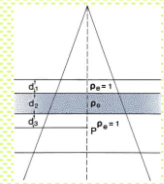
- Use methods similar to correction for curved surfaces
- In *TAR correction method* introduce dose correction factor for a field size r_d:

$$C = T_a(d', r_d) / T_a(d, r_d)$$

- The equivalent thickness

$$d' = d_1 + \rho_e d_2 + d_3$$

density ρ_e is relative to water



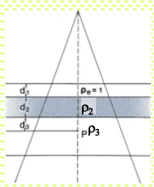
Dose corrections for inhomogeneities

- More accurate correction factor takes into account the proximity of the inhomogeneity (*power law method*):

$$C = \frac{T_a(d_3, r_d)^{\rho_3 - \rho_2}}{T_a(d_2 + d_3, r_d)^{1-\rho_2}}$$

ρ_3 is the density of the material in which the point lies

ρ_2 is the density of the overlying material



Dose corrections for inhomogeneities

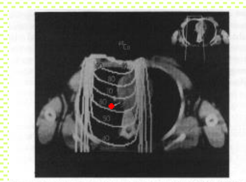


Figure 11-7. A CT image of the chest with isodose curves for a 12 × 10 beam from a cobalt unit superimposed. The placement of the beam is shown in the insert. The isodose curves have been obtained by allowing for the curvature of the patient's anterior surface but neglecting the structures inside of the chest.

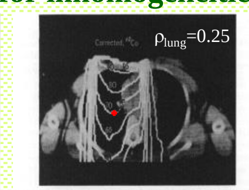


Figure 11-8. The isodose distribution of Figure 11-7 corrected for the tissue inhomogeneities of the chest. Eight CT images were used and dose correction factors were obtained using equations 11-3 and 11-4.

- *Effective TAR method*: correction $C = T_a(d', \hat{r}) / T_a(d, r)$
- Equivalent circular field size $\hat{r} = r \cdot \hat{\rho}$ is scaled to allow for the way the scattering structures are configured around the point with effective density $\hat{\rho}$

Energy absorption in biological material

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

$$D_{tis} = D_{wat} \cdot (\bar{\mu}_{ab} / \rho)_{wat}^{tis}$$

TABLE 11-2

Values of $(\bar{\mu}_{ab}/\rho)_{wat}^{tis}$ for Muscle, Fat, and Bone and $(\bar{\mu}_{ab}/\rho)_{med}^{mus}$ for Polystyrene, Lucite, and A150 Tissue-Equivalent Plastic Determined Using Equation 7-12 for the Photon Spectra Listed in Table 7-2

Photon Spectrum	$(\bar{\mu}_{ab}/\rho)_{wat}^{tis}$			$(\bar{\mu}_{ab}/\rho)_{med}^{mus}$		
	Muscle	Fat	Bone	Polystyrene	Lucite	A150
1. 60 kV_p	1.040	0.607	4.796	2.617	1.687	1.176
2. 100 kV_p	1.035	0.653	4.409	2.227	1.572	1.085
3. 250 kV_p	0.995	0.973	1.294	1.071	1.051	1.004
4. 270 kV_p	0.997	0.964	1.391	1.089	1.062	1.008
5. 270 kV_p	1.011	0.861	2.486	1.317	1.194	1.038
6. 400 kV_p	0.994	0.988	1.098	1.044	1.034	1.003
7. ^{137}Cs	0.991	1.000	0.957	1.023	1.020	1.001
8. ^{60}Co	0.992	1.001	0.954	1.024	1.049	1.002
9. ^{60}Co	0.992	0.996	0.995	1.029	1.024	1.002
10. 6 MV	0.991	0.998	0.959	1.026	1.021	1.003
11. 8 MV	0.990	0.995	0.962	1.028	1.022	1.005
12. 12 MV	0.990	0.987	0.979	1.039	1.029	1.014
13. 18 MV	0.989	0.980	0.993	1.047	1.033	1.022
14. 26 MV	0.989	0.973	1.004	1.055	1.038	1.029
15. 26 MV	0.990	0.981	0.991	1.047	1.034	1.022
16. 35 MV	0.989	0.965	1.019	1.068	1.044	1.039
17. 45 MV	0.989	0.961	1.027	1.073	1.047	1.044

Energy absorption in biological material

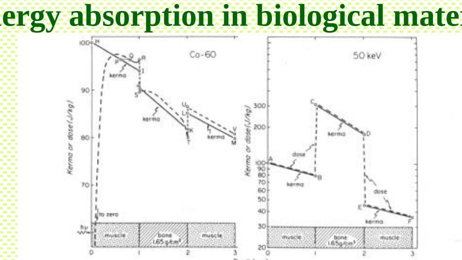


Figure 7-13. Diagram showing kerma and dose in a composite phantom irradiated from the left by cobalt 60 radiation and 50 keV radiation.

- 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

Material	Density, g/cm^3
Water	1
Muscle	1.04
Bone	1.65
Fat	0.916
Lung	0.25

Densities of biological materials

Example 5

- 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

Energy imparted

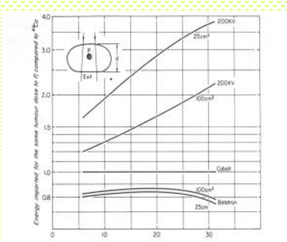


Figure 11-12. Graph comparing the energy imparted by 200 kV x rays and 25 MV radiation with that resulting from cobalt 60. Results are shown for 2 sizes of field as a function of the thickness of the patient. The energies imparted have been compared on the basis that for the 3 cases the same tumor dose is given to the point P at the center of a patient

- Energy imparted, or integral dose is an estimate of the total energy absorbed by patient, not just within the tumor volume

$$\Sigma = 1.44 \cdot D_0 \cdot A \cdot d_{1/2}\rho \left(1 + \frac{2.88\, d_{1/2}}{f}\right)$$

- Dependence on FS, beam energy, and the patient thickness provides guidelines on the reduction of this value

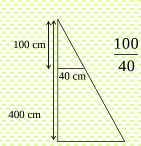
Total body irradiation (TBI)

- Indication: leukemia (cancer of blood-forming tissues, including bone marrow), lymphoma (cancer of lymphocytes), myeloma (cancer of plasma cells), some solid pediatric tumors
- Tasks: elimination of the clonogenic malignant cells (often followed by chemotherapy) and/or induction of immuno-suppression before bone marrow stem cell transplantation
- Risks: dose limited by skin, lung

Example 6

- The maximum collimator setting on a linac is 40 x 40 cm at 100 cm SAD. To cover a TBI patient 160 cm tall, with no collimator rotation, the patient's midline must be at a minimum distance of ____ cm.

A. 200
B. 350
C. 400
D. 425
E. 500



$$\frac{100}{40} = \frac{x}{160}$$

Summary

- Basic terminology
- Curved contour surface correction (bolus, compensators, wedges)
- Oblique beam incidence
- Correction for tissue inhomogeneities