Principles and Practice of Clinical Physics and Dosimetry
Michael L.F. Lim, CMD, ACT
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— CHAPTER 3 —

Inhomogeneity Corrections

I. EFFECT OF INHOMOGENEITY

Radiation therapy measurements such as %DD, TAR, TMR, and TPR are measured in a water phantom where the density is similar to that of muscle with a density of one (d = 1 g/cc). When treating a patient, however, the radiation beam traverses tissues of different densities such as lung and bone. Due to their different densities from that of muscle, the dose computation is altered. The degree of alteration is dependent on the tissue type, position of the tissue in the path of the radiation beam and on the energy of the radiation.

In order to deliver the correct dose of radiation to the point of interest, correction in the plan and in the monitor unit (MU) or treatment time must be made to account for the tissue density differences.

There are several ways to correct for the inhomogeneities. Given in this chapter are three methods for lung inhomogeneity correction. They are: (A) Isodose shift, (B) TAR ratio, and (C) Batho-Young *(Power Law)* method.

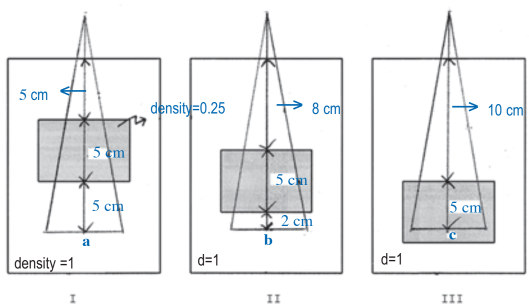


Figure 3.1 Diagrams show lung position in relation to points of interest a, b and c. Dose calculations are made to points a, b and c using each of the three methods of inhomogeneity correction.

II. LUNG INHOMOGENEITY CORRECTION (ON ^{60}Co)

A) Isodose Shift Method

This method calculates the ratio of the effective depth %DD to the real depth %DD. The effective depth %DD is corrected by a shift factor (n).

Point a (Figure 3.1 (I))

TAR for 10×10 cm² field size at 15 cm depth = 0.538

Corrected TAR = TAR × CF

$$CF = \frac{\%DD\ effective\ depth}{\%DD\ real\ depth}$$

Real depth = 15 cm, and the %DD at 15 cm depth = 38.71%

Effective depth = real depth + inhomogeneous path length × n = 15 + 5n = 15 + 5 × (-0.4) = 13 cm

Therefore, the percent depth dose (%DD) at 13 cm = 44.72%

Therefore, CF= (44.72/38.1) = 1.155

Therefore, the corrected TAR = 0.538 × 1.155 = 0.621

Inhomogeneity shift factor (n) for ^{60}Co & 4 MV photons: → Air: -0.6 ♦ Lung: -0.4 ♦ hard bone: 0.5 ♦ Spongy bone: 0.25

Point b (Figure 3.1 (II)) and Point c (Figure 3.1 (III))

Since the real depth and the lung thickness are the same as in the previous calculation to point a, the corrected TAR is the same, i.e., 0.621.

B) Tissue-Air Ratio Method

This method calculates the ratio of the effective depth TAR to the real depth TAR that is then used to correct the TAR for the real depth. The result is the effective depth TAR.

Point a (Figure 3.1 (I))

TAR for 10×10 cm² field size at 15 cm depth = 0.538

Corrected TAR = TAR × CF

$$CF = \frac{TAR\ effective\ depth}{TAR\ real\ depth}$$

Real depth = 15 cm, TAR = 0.538, and e = lung density = 0.25 gm/cc
Effective depth = 5 + (5 × e) + 5 = 5 + (5 × 0.25) + 5 = 11.25 cm

TAR at 11.25 cm depth = 0.660

Therefore, CF = (0.660/0.538) = 1.227

Therefore, the corrected TAR = 0.538 × 1.227 = 0.660

Point b (Figure 3.1 (II))

Real depth = 15 cm , TAR = 0.538
Effective depth = 8 + (5 × e) + 2 = 8 + (5 × 0.25) + 2 = 11.25 cm
TAR at 11.25 cm depth = 0.660
Therefore, CF = (0.660/0.538) = 1.227
Therefore, the corrected → TAR = 0.538 × 1.227 = 0.660

Point c (Figure 3.1 (III))

Real depth = 15 cm , TAR = 0.538
Effective depth = 10 + (5 × e) = 10 + (5 × 0.25) = 11.25 cm
TAR at 11.25 cm depth = 0.660
Therefore, CF = (0.660/0.538) = 1.227
Therefore, the corrected → TAR = 0.538 × 1.227 = 0.660

From the above calculation, it can be seen that the corrected TAR is the TAR for the effective depth.

C) Batho-Young (Power Law) Method

This is the most commonly used method and is the most accurate of the three methods described in this chapter. As will be shown later on in the comparison of the three methods, this method takes into account the distance between the point of interest to the inhomogeneity.

Point a (Fig.3.1 (I))

TAR for 10 × 10 cm² field size at 15 cm depth = 0.538

Corrected TAR = TAR × CF

$$CF = \left(\frac{TAR(z_1)^{\partial_1 - \partial_2}}{TAR(z_2)^{1-\partial_2}} \right) \rightarrow \qquad CF = \left(\frac{(0.898)^{1-0.25}}{(0.705)^{1-0.25}} \right) = 1.199$$

Where; z_1 = *distance from point of interest to inner aspect of inhomogeneity*

z_2 = *distance from point of interest to outer aspect of inhomogeneity*

δ_1 = *density at point of interest*

δ_2 = *density of overlying tissue*

Calculate the corrected TAR knowing that:

$TAR(z_1 = 5\ cm) = 0.898$, $TAR(z_2 = 10\ cm) = 0.705$, $\delta_1 = 1$, and $\delta_2 = 0.25$

$$CF = \left(\frac{(0.898)^{1-0.25}}{(0.705)^{1-0.25}} \right) = 1.199$$

Corrected → $TAR = 0.538 \times 1.199 = 0.645$

Point b (Figure 3.1 (II))

For point b → $TAR(z_1 = 2\ cm) = 1.002$, $TAR(z_2 = 7\ cm) = 0.819$, $\delta_1 = 1$, and $\delta_2 = 0.25$

$$CF = \left(\frac{(1.002)^{1-0.25}}{(0.819)^{1-0.25}} \right) = 1.163$$

Therefore, Corrected → $TAR = 0.538 \times 1.163 = 0.626$

Point c (Figure 3.1 (III))

For point c → $TAR(z_1 = 5\ cm) = 0.898$, $TAR(z_2 = 15\ cm) = 0.538$, $\delta_1 = 0.25$, and $\delta_2 = 1.0$

Using the same formula as for point a and b calculation:

$$CF = \left(\frac{(0.898)^{0.25-1}}{(0.539)^{1-1}} \right) = 1.084$$

Therefore, Corrected $TAR = 0.538 \times 1.084 = 0.583$

Table 3.1 Comparison of the three methods of TAR correction to points in tissue.

	point a	*point b*	*point c*
Isodose shift	0.62	0.62	0.62
TAR ratio	0.66	0.66	0.66
Batho-Young	0.65	0.63	0.58

The above comparison shows that the isodose shift method and the TAR ratio method does not take into account the distance from the point of interest to the inhomogeneity. The effective attenuation method takes into account the distance from the point of interest to the inhomogeneity but to a limited degree. The Batho-Young method takes into account not only the distance from point of interest to inhomogeneity but also where the point of interest is situated.

Other methods such as the equivalent TAR method and the Monte-Carlo method are being incorporated in treatment planning computer programs. The same methods of correction may be applied to Linear Accelerator by using TMR or TPR instead of TAR.

1) Application of Batho-Young Method in Calculation

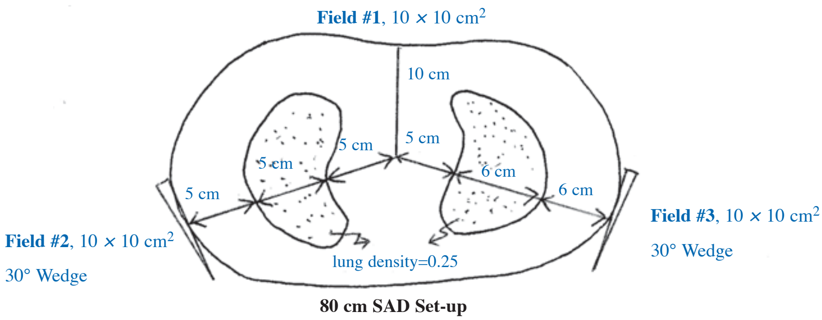


Figure 3.2 Three fields with the posterior oblique fields through lung.

In the diagram above, the esophagus is being treated using an anterior field and two posterior oblique fields. The depths are as shown in the diagram. A total tumor dose of 5000 cGy in 25 treatments is prescribed to isocenter with equal tumor dose to each field. Calculate the timer setting for each field for each treatment.

Calculation:

Total tumor dose is 5000 cGy in 25 treatments.

The total tumor dose to each field = 5000/3 = 1666.7 cGy.

The daily tumor dose to each field = (1666.7/25) = 66.7 cGy.

Air dose rate (ADR) for 10 × 10 cm^2 field size = 143.2 cGy/min

TAR (10 × 10 cm^2, 5 cm depth) = 0.898 , TAR (10 × 10 cm^2, 10 cm depth) = 0.705

TAR (10 × 10 cm^2, 11 cm depth) = 0.669 , TAR (10 × 10 cm^2, 15 cm depth) = 0.538

TAR (10 × 10 cm^2, 17 cm depth) = 0.481, Timer Correction = + 0.02 min

Wedge factor (W.F) for 30° wedge = 0.791

Field 1

$$Treatment\ \ time = \frac{DTD}{ADR \times TAR} + TC = \frac{66.7}{143.2 \times 0.705} + 0.02 = 0.68 \quad \text{min}$$

Field 2

TAR for 10 × 10 cm^2 field size at 15 cm depth = 0.538

Corrected TAR = TAR × CF

$$CF = \left(\frac{(TAR(5cm))^{\delta_1 - \delta_2}}{(TAR(10cm))^{1-\delta_2}} \right), \quad where; \quad \delta_1 = 1 \quad and \quad \delta_2 = 0.25 \longrightarrow CF = \left(\frac{(0.898)^{1-0.25}}{(0.705)^{1-0.25}} \right) = 1.199$$

Corrected TAR = 0.538 X 1.199 =0.645

Therefore, the treatment time is calculated as follows:

$$Treatment\ \ time = \frac{DTD}{ADR \times corr.TAR \times WF} + TC = \frac{66.7}{143.2 \times 0.645 \times 0.791} + 0.02 = 0.93 \quad \text{min}$$

Field 3

TAR for 10 × 10 cm² field size at 17 cm depth = 0.481

Corrected TAR = TAR × CF

$$CF = \left(\frac{(TAR(5cm))^{\delta_1-\delta_2}}{(TAR(11cm))^{1-\delta_2}}\right),\quad where;\ \delta_1 = 1 \quad and \quad \delta_2 = 0.25, \longrightarrow CF = \left(\frac{(0.898)^{1-0.25}}{(0.669)^{1-0.25}}\right) = 1.247$$

Corrected TAR = 0.481 × 1.247 = 0.600

$$Treatment\ time = \frac{DTD}{ADR \times corr.TAR \times WF} + TC = \frac{66.7}{143.2 \times 0.600 \times 0.791} + 0.02 = 1.00 \quad \min$$

2) Calculation of Dose to a Point in Lung

(a) Single field

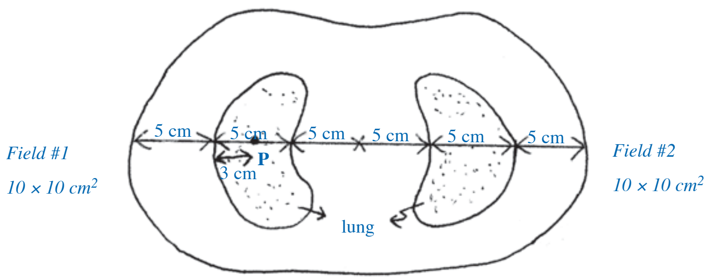


Figure 3.3. Point of calculation P in lung (lung density is 0.25 g/cc).

Total tumor dose (T.D) to isocenter field 1 = 1000 cGy

$$Dose\ to\ lung\ at\ point\ P = \left(\frac{TD}{corr.TAR(10 \times 10, 15)}\right) \times corr.TAR(10 \times 10, 8) \times \left(\frac{SAD}{SSD + d}\right)^2$$

$$Corrected\ TAR(10 \times 10,\ 15) = \left(\frac{TAR(5cm)^{\delta_1-\delta_2}}{TAR(10cm)^{1-\delta_2}}\right) \times TAR(15)$$

Where $\delta_1 = 1.00$ *and* $\delta_2 = 0.25$

TAR (10 × 10 cm², 15 cm depth) = 0.538, TAR (10 × 10 cm², 5 cm depth) = 0.898, and TAR (10 × 10 cm², 10 cm depth) = 0.705

$$Corrected\ TAR(10 \times 10,\ 15cm\ depth) = \left(\frac{0.898^{1-0.25}}{0.705^{1-0.25}}\right) \times 0.538 = 0.645$$

$$Corrected\ TAR(10 \times 10,\ 8cm\ depth) = \left(\frac{TAR(3cm)^{\delta_1-\delta_2}}{TAR(8cm)^{1-\delta_2}}\right) \times TAR(8cm)$$

Where → $\delta_1 = 1.00$ *and* $\delta_2 = 0.25$

TAR (10 × 10 cm², 3 cm depth) = 0.971, TAR (10 × 10 cm², 8 cm depth) = 0.780

$$Corrected\ TAR(10 \times 10,\ 8cm\ depth) = \left(\frac{0.971^{0.25-1}}{0.780^{1-1}}\right) \times 0.780 = 0.797$$

$$Dose\ to\ point\ P\ in\ lung = \left(\frac{1000}{0.645}\right) \times 0.797 \times \left(\frac{80}{73}\right)^2 = 1484\ \ cGy$$

(b) Opposed field

Dose to lung at p from Field #1= 1484 cGy, and TTD from Field #2 at isocenter = 1000 cGy

$$Dose\ to\ point\ P\ in\ lung = \left(\frac{TTD}{corr.TAR(10\times 10, 15)}\right)\times corr.TAR(10.9\times 10.9cm^2, 20)\times\left(\frac{SAD}{SSD+d}\right)^2$$

Note: Field size at p from Field #1= (87/80) × (10×10)= 10.9 × 10.9 cm^2

$$Corrected\ TAR(10\times 10cm^2,\ 15cm\ depth) = \left(\frac{TAR(5)^{\delta_1-\delta_2}}{TAR(10)^{1-\delta_2}}\right)\times TAR(13)$$

Where → $\delta_1 = 1.00$ *and* $\delta_2 = 0.25$

TAR (10 × 10 cm^2, 15 cm depth) = 0.538, TAR (10 × 10 cm^2, 5 cm depth) = 0.898, and TAR (10 × 10 cm^2, 10cm depth) = 0.705

$$Corrected\ TAR(10\times 10cm^2,\ 15cm\ depth) = \left(\frac{(0.898)^{0.75}}{(0.705)^{0.75}}\right)\times 0.600 = 0.719$$

$$Corrected\ TAR(10.9\times 10.9cm^2,\ 20cm\ depth) = \left(\frac{TAR(2)^{\delta_1-\delta_2}}{TAR(7)^{1-\delta_2}}\right)\times\left(\frac{TAR(12)^{\delta_1-\delta_2}}{TAR(17)^{1-\delta_2}}\right)\times TAR(20)$$

Where → $\delta_1 = 0.25$ *and* $\delta_2 = 1.00$ (for the left bracket)
Where → $\delta_1 = 1.00$ *and* $\delta_2 = 0.25$ (for the right bracket)

TAR (10.9×10.9, 2cm depth) = 1.007, TAR (10.9×10.9, 7cm depth) = 0.829, TAR (10.9×10.9, 12cm depth) = 0.645, TAR (10.9×10.9, 17cm depth) = 0.492, and TAR (10.9×10.9, 20cm depth) = 0.417

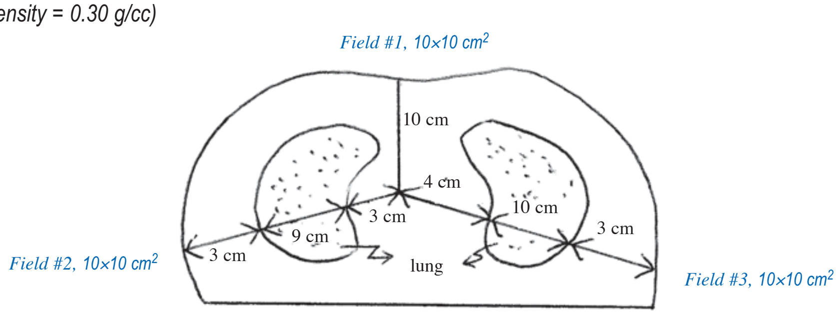
$$Corrected\ TAR(10.9\times 10.9cm^2,\ 20cm\ depth) = \left(\frac{(1.007)^{-0.75}}{(0.829)^{0}}\right)\times\left(\frac{(0.645)^{0.75}}{(0.492)^{0.75}}\right)\times 0.417 = 0.509$$

Therefore, → $$Dose\ to\ lung\ at\ P = \left(\frac{1000}{0.719}\right)\times 0.509\times\left(\frac{80}{87}\right)^2 = 599\ cGy$$

Therefore total dose to point P in lung from the two opposed fields = 1484 + 599 = 2083 cGy

Problem 3.1

Using the Batho-Young (Power Law) method, calculate the corrected TAR to isocenter from fields 2 and 3 on the ^{60}Co. *(Lung density = 0.30 g/cc)*



80 cm SAD Set-up

Solution:

TAR for Field #2 = TAR (real depth) × (CF)

$$CF = \left(\frac{TAR(3cm)}{TAR(12cm)}\right)^{0.7} = \left(\frac{0.971}{0.634}\right)^{0.7} = 1.348$$

Therefore, $\rightarrow$ *TAR for Field #2 = 0.538 × 1.348 = 0.725*

TAR for Field #3 = TAR (Real depth) × CF

$$CF = \left(\frac{TAR(4cm)}{TAR(14cm)}\right)^{0.7} = \left(\frac{0.936}{0.568}\right)^{0.7} = 1.419$$

Therefore, $\rightarrow$ *TAR for Field #3 = 0.481 × 1.419 = 0.682*

III. PUBLICATIONS OF INTERESTS

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