Treatment planning III: field shaping, skin dose, and field separation

Chapter 13
F. M. Khan "The Physics of Radiation Therapy"

Outline

- Field shaping
    - Custom blocks
    - Use of independent jaws
    - Multileaf collimators
- Skin dose
    - Maintaining skin sparing of MV beams
- Filed separation techniques
    - Geometric
    - Dosimetric

Field shaping

- The shaping of a treatment field is dictated by two factors:
    - Complete coverage of the tumor with prescription dose, including local and distal disease
    - Dose to normal tissue should be minimized; vital organ tolerance observed
- Typical figure of merit: primary beam transmission of 5% or less through a blocked region

Field blocks

$$\left(\frac{1}{2}\right)^n = \frac{1}{2^n} = 0.05$$

$$2^n = \frac{1}{0.05} = 20$$

$$n = \frac{\log 20}{\log 2} = 4.32$$

TABLE 13.1 Recommended Minimum Thickness of Lead for Shielding[a]

Beam Quality	*Required Lead Thickness*
1.0 mm Al HVL	0.2 mm
2.0 mm Al HVL	0.3 mm
3.0 mm Al HVL	0.4 mm
1.0 mm Cu HVL	1.0 mm
3.0 mm Cu HVL	2.0 mm
4.0 mm Cu HVL	2.5 mm
^{137}Cs	3.0 cm
^{60}Co	5.0 cm
4 MV	6.0 cm
6 MV	6.5 cm
10 MV	7.0 cm
25 MV	7.0 cm

HVL, half-value layer.
[a] Approximate values to give ≤5% primary transmission.

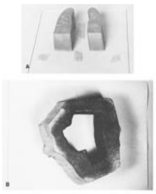
- Thickness of a block should be large enough to transmit only 5% of the primary photon beam
- n is the number of HVL's, thickness depends on the beam quality

Custom blocks

Styrofoam block cutter

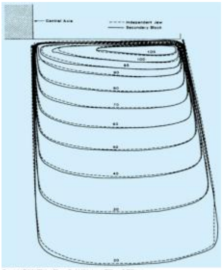
- The blocks should be shaped so that their sides follow the geometric divergence of the beam, minimizing the block transmission penumbra (partial transmission of the beam at the edges of the block)
- Straight blocks are used for beams with large geometric penumbra (^{60}Co source)

Custom blocks



- Custom blocks are made of melted Cerrobend based on shapes cut from Styrofoam
    - "Positive" or "negative"
- Mounted on a block tray in the accelerator head
- Transmission is ~3.5%

Independent jaws



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Comparison of isodose distribution with half the beam blocked by an independent jaw versus a block on a tray

- Used for rectangular filed blocking (asymmetric fields)
- Transmission ~1%
- The effect on the isodose distribution is very close to that of a custom block
  - Close agreement as well as the tilt of the isodose curves toward the blocked edge

Multileaf collimators

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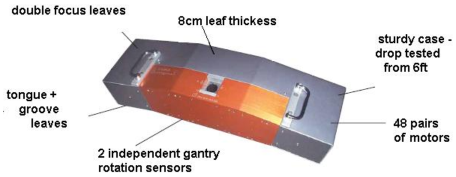
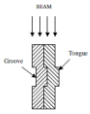
- MLC consists of a large number of collimating blocks (leaves) that can be driven automatically, independent of each other
- Can generate field of almost any shape
- Typical MLC consists of 40 pairs (80 leaves)
  - Made of tungsten
  - Each leaf 1 cm wide at the isocenter
  - Thickness 6 to 7.5 cm
  - Leaf transmission ~2%
  - Interleaf transmission ~3%

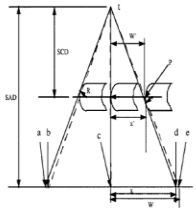
Multileaf collimators





- Micro-MLC's for stereotactic treatments: leaf width is 2 mm at the isocenter
- Interleaf leakage is minimized with tongue-and-groove design

Multileaf collimators



The penumbra at any position is within 1–3 mm of that obtained with a focused system or for alloy blocks with divergent sides

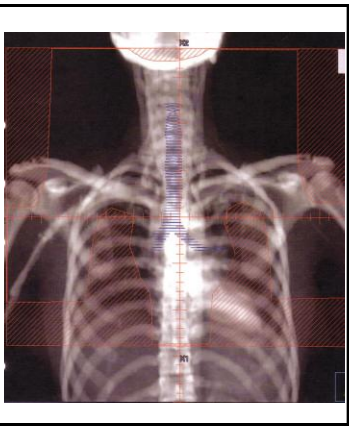
"Basic applications of multileaf collimators", Report of TG-50, AAPM 2001

- Adjustable collimator systems are designed to follow the beam divergence ("focused" design)
- Difficult to implement with independent leaves
- Leaf edges of different design; most common – rounded edge
- Single and double-focused (in both x and y directions) systems

Multileaf collimators

- MLC produces larger penumbra than either jaws or custom blocks (leaf edges of different design)
- MLC is ideally suited for multi-field treatments, and complex multi-field treatments (IMRT)
- Limitation of filed shaping: cannot produce blocked islands

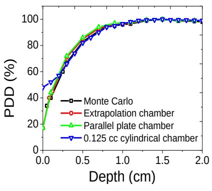
- Custom blocks
  - Cerrobend lung blocks used when MLC's may not be able to cover all critical structures adequately



Skin dose

- Skin sparing is highly desirable feature of MV beams
- Secondary electron contamination of photon beams may reduce this effect
- Sources of secondary electrons: beam shaping equipment and air
- Contamination depends on several factors: photon energy, field size, SSD, angle of incidence

Measurement of dose distribution in the build-up region



6 MV beam, FS=10x10

- Due to steep dose gradient the accurate measurement is difficult
- Extrapolation chamber is the best tool, but is not readily available, and is difficult to use
- Next best is plane-parallel plate chamber
- TLD can be used for measuring skin dose due to their small thickness

Skin dose

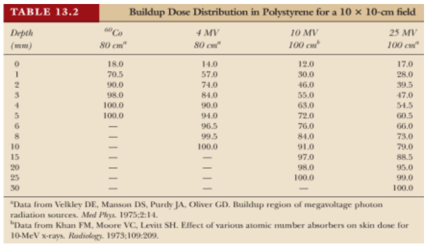


TABLE 13.2 Buildup Dose Distribution in Polystyrene for a 10 × 10-cm field

Depth (mm)	*^{60}Co 80 cm*[a]	*4 MV 80 cm*[a]	*10 MV 100 cm*[b]	*25 MV 100 cm*[a]
0	18.0	14.0	12.0	17.0
1	70.5	57.0	30.0	28.0
2	90.0	74.0	46.0	39.5
3	98.0	84.0	55.0	47.0
4	100.0	90.0	63.0	54.5
5	100.0	94.0	72.0	60.5
6	—	96.5	76.0	66.0
8	—	99.5	84.0	73.0
10	—	100.0	91.0	79.0
15	—	—	97.0	88.5
20	—	—	98.0	95.0
25	—	—	100.0	99.0
30	—	—	—	100.0

[a] Data from Velkley DE, Manson DS, Purdy JA, Oliver GD. Buildup region of megavoltage photon radiation sources. *Med Phys.* 1975;2:14.

[b] Data from Khan FM, Moore VC, Levitt SH. Effect of various atomic number absorbers on skin dose for 10-MeV x-rays. *Radiology.* 1973;109:209.

- Skin dose decreases with increasing photon energy
- For high-energy beams significant sparing is achieved for subcutaneous layers

Skin dose

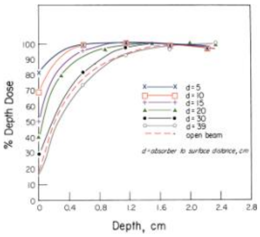


Figure 13.6.Effect of Lucites hadow tray on dose buildup for 10-MV x-rays. Percent depth dose distribution is plotted for various tray to surface distances (d). 10-MV x-rays, tray thickness =1.5 g/cm2, field size =15 x15 cm, SSD =100 cm, and source to diaphragm distance =50 cm.

- The block tray (shadow tray) increases the secondary electron scatter and thus the skin dose
- The amount of skin dose depends on the distance of the tray from the skin
- It is best to have the tray as far from the patient as possible

Skin dose

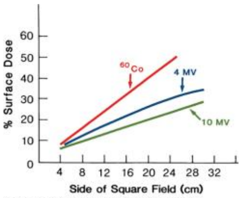


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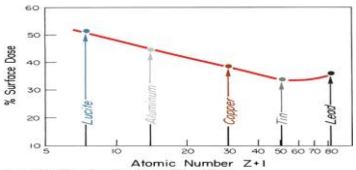
Figure 13.7.Percent surface dose as a function of field size. 60Co, Theratron 80, source to surface distance(SSD) =80 cm, source to diaphragm distance (SDD) =59 cm. 4 MV, Clinac 4, SSD =80 cm. 10 MV, LMR 13, SSD =100 cm, SDD =50 cm. 60Co and 4-MV.

- The larger is the field size, the more secondary electrons are emitted from the collimator and air
- Skin sparing is significantly reduced for the larger field sizes

Electron filters



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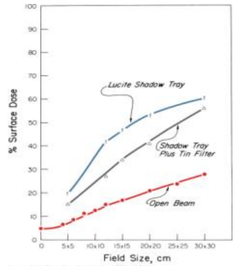
- Materials with medium Z produce less forward scattered electrons, Z=50 (tin) is the best
- Electron filters can be used when skin dose becomes excessive:
  - Large field size is large
  - The block tray distance is 15-20 cm from the skin

Electron filters



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- Tin filter should face the patient surface
- The thickness of filter should be equal to the range of secondary electrons (0.9 mm of tin for Co-60)

Oblique incidence

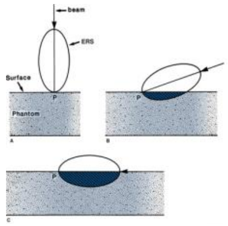

Figure 13.10.The use of electron range surface (ERS) to determine surface dose buildup at point P. A:Perpendicular beam incidence. B:Oblique beam incidence. C:Tangential beam incidence.

- The angle of incidence of a beam has an effect on skin dose and the depth of d_{max}
- High energy photon beams generate secondary electrons in the air around them

Oblique incidence

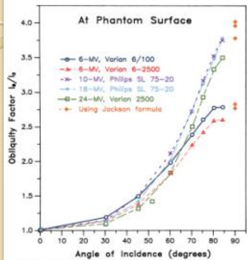

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Figure 13.11.Obliquity factor at the surface plotted as a function of beam angle for various energy beams. Jackson formula for tangential beam incidence is based on Equation 13.1.

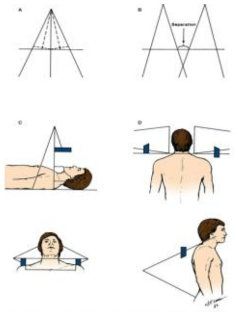
- Obliquity factor: a ration of doses at a point on CAX in phantom for oblique to normal incidence
- For tangential beams maximum skin dose can be estimated as (entrance dose – in normal incidence):

$$\%\text{Skin dose} = \frac{1}{2}(100\% + \text{entrance dose})$$

Separation of adjacent fields

- In some cases there is a need for treatments involving adjacent fields
  - Hodgkin's disease (lymphoma)
  - Craniospinal fields in treatment of medulloblastoma
  - Some head and neck treatment fields
- Problem: when photon fields are placed next to one another the divergence causes hot spots at depths and cold areas near the surface

Separation of adjacent fields



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- Various techniques used for field matching:
  - A: Angling the beams away from each other so that the two beams abut and are aligned vertically
  - B: Fields separated at the skin surface. The junction point is at a depth where dose is uniform across the junction
  - C: Isocentric split-beam technique for head and neck tumors
  - D: Craniospinal irradiation using penumbra generators

Methods of field separation

- Two basic approaches: geometric and dosimetric
- In geometric approach fields are joined at 50% isodose line, producing 100% at the junction point
  - The lateral dose distribution at the junction depth can be more or less uniform, depending on the interfield scatter contribution
- In dosimetric approach the goal is to produce a composite isodose distribution which is uniform at the desired depth

Separation of adjacent fields

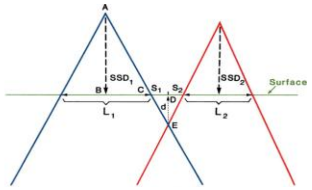


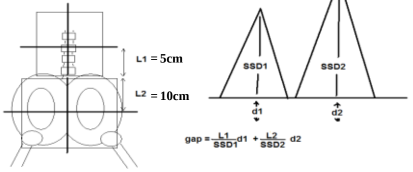
Figure 13.13. Geometry of two adjacent beams, separated by a distance S1+S2 on the surface and junctioning at depth d.

- Finding distances S1 and S2 from similar triangles, obtain the total filed separation:

$$S = S_1 + S_2 = \tfrac{1}{2} L_1 \frac{d}{SSD_1} + \tfrac{1}{2} L_2 \frac{d}{SSD_2}$$

Separation of adjacent fields

- An example gap calculation



SSD1 for para-aortic = 95cm, SSD2 for pelvis = 98cm

Matching fields at 8cm depth gives:

$$gap = \left(\frac{5cm}{95cm} \times 8cm\right) + \left(\frac{10cm}{98cm} \times 8cm\right) = 1.24cm$$

Separation of adjacent fields

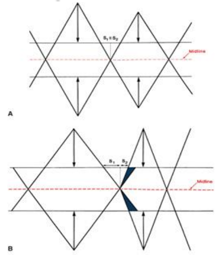


Figure 13.14.Two pairs of parallel opposed fields. Adjacent fields are separated on the surface so that they all join at a point on the midline. A:Ideal geometry in which there is no three-fields overlap. B:Arrangement in which there are two regions(shaded) of three-fields overlap.

- A high-dose region of three-field overlap is created when bigger fields diverge into opposing smaller fields
- The maximum overlap region is at the surface

$$\Delta S = S_1 - S_d = 0 \text{ if } \frac{L_1}{L_2} = \frac{SSD_1}{SSD_2}$$

- Overlap can be avoided by adjusting SSD's of adjacent fields
- Another approach: increase of ΔS (produces cold spots)

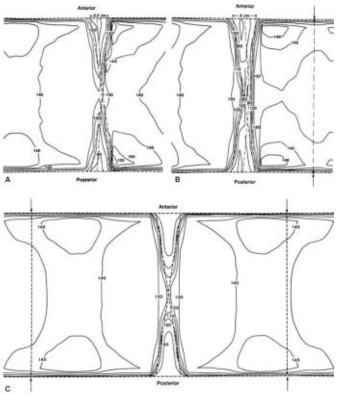


Figure 13.15.Geometric separation of fields with all the four beams intersecting at midpoint. Adjacent field sizes: 30 x30 cm and 15 x15 cm; source to surface distance (SSD) =100 cm; anteroposterior thickness =20 cm; 4-MV x-ray beams; each beam weighted 100 at its depth of Dmax.
A: Field separation at surface =2.3 cm. A three-field overlap exists in this case because the fields have different sizes but the same SSD.
B: The adjacent field separation increased to 3 cm to eliminate three-field overlap on the surface.
C: Field separation adjusted 2.7 cm to eliminate three-field overlap at the cord at a 15-cm depth from anterior

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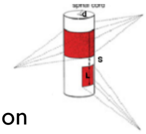
Orthogonal field junctions

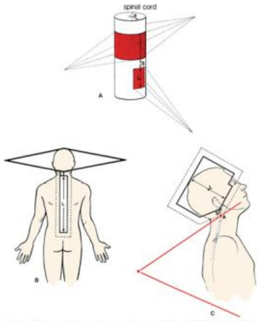
- An arrangement in which the central axes of the adjacent fields are orthogonal
- A geometrical method of field separation with

$$S = \tfrac{1}{2} L \frac{d}{SSD}$$



- d is the depth of field junction

Orthogonal field junctions



- Figure 13.16.
  - A: A general diagram showing the separation of orthogonal fields.
  - B: An example of orthogonal fields used for craniospinal irradiation.
  - C: A lateral view of B, illustrating the geometry of orthogonal field separation.

Orthogonal field junctions

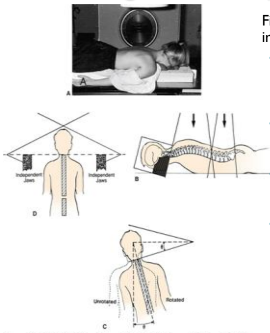
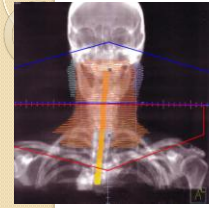
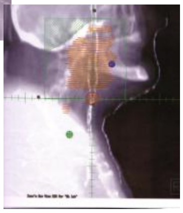


Figure 13.17. Craniospinal irradiation technique.

- A: Patient setup showing Styrofoam blocks and Alpha Cradle mold to provide stable position for abdomen, chest, and head.
- B: Lateral view of fields showing cranial field rotated to align with the diverging border of the spinal field.
- C: Couch rotated to provide match between the spinal field and the diverging border of the cranial field.
- D: Elimination of cranial field divergence by using an independent jaw as a beam splitter. This provides an alternative to couch rotation in C.

Orthogonal field junctions





- An example of orthogonal field junctions. The AP field (red) is the s.clav or yoke.
- The is abutted to a LT LAT and RT LAT (blue)

Guidelines for field matching

1. The site of field matching should be chosen over an area that does not contain tumor or a critical structure
2. If the tumor is superficial at the junction site, the fields should not be separated because a cold spot on the tumor will risk recurrence.
   - They will overlap at depth, which may be clinically acceptable, provided the excessive dosage delivered to the underlying tissues does not exceed their tolerance.
   - In the case of a superficial tumor with a critical organ located at depth, one may abut the fields at the surface but eliminate beam divergence using a beam splitter or by tilting the beams

Guidelines for field matching

3. For deep-seated tumors, the fields may be separated on the skin surface so that the junction point lies at the midline. Care must be taken in regard to a critical structure near the junction region.
4. It is not necessary anatomically to reproduce the line of field matching every day because variation in its location will only smear the junction point, which is desirable. For the same reason some advocate moving the junction site two or three times during a treatment course.
5. A field-matching technique must be verified by actual isodose distributions before it is adopted for general clinical use. In addition, beam alignment with the light field and the accuracy of isodose curves in the penumbra region are essential prerequisites.

Key points

- Thickness of lead required to give 5% primary beam transmission is 4.3 half-value layer
- Half-beam blocking gives rise to tilting of the isodose curves toward the blocked edge. This effect is due to missing electron and photon scatter from the blocked part of the field into the open part of the field
- Physical penumbra with MLC is wider than that with the collimator jaws or Cerrobend blocks
- Surface dose in MV beams is predominantly due to the electron contamination of the incident photon beam

Key points

- Dose at the surface or in the buildup region is best measured with an extrapolation or a plane-parallel chamber
- Surface dose depends on beam energy, field size, SSD, and tray to surface distance
- Electron filters are medium-atomic-number absorbers (Z~50) that reduce the surface dose by scattering contaminant electrons more than generating them
- Surface dose increases with increasing angle of obliquity
- Separation of adjacent fields, when needed, may be accomplished geometrically. Hot and cold spots in the resultant dose distribution must be assessed by viewing composite isodose curves