Chapter 12
Treatment Planning – Combination of 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

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Outline

- Opposing pairs of beams
- Combination of opposing pairs
- Angled fields and wedge pairs
- Three-field approaches
- Rotational therapy

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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

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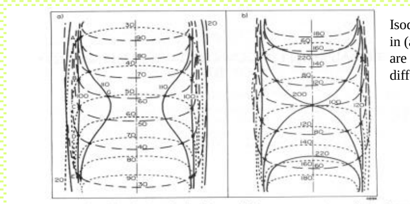
Opposing pairs of beams



Isodose lines in (a) and (b) are normalized differently

Figure 12-1. Isodose distribution obtained by combining two opposing radiation beams. Both are for 10 × 10 cm beams of cobalt radiation and the entrance surfaces are separated by 20 cm. (a) Fixed source-skin distance with dose values expressed relative to 100 at the maximum of each beam. (b) Isocentric arrangement with dose values expressed relative to 100 midway between the surface from each beam.

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

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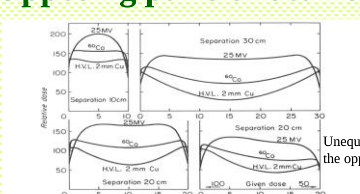
Opposing pairs of beams



Unequal dose to the opposing fields

Figure 12-2. Dose along the axis for 2 opposing 6 × 8 cm fields, for separations of 10, 20, and 30 cm, 25 MV radiation at SSD 100 cm; cobalt 60 at SSD 80 cm; 200 kV radiation, HVL 2.0 mm Cu SSD 50 cm. The 3 symmetrical diagrams were calculated for given doses of 1 Gy to both fields, while the graph in the lower right hand corner results when the given doses are 1 Gy to the left and 0.5 Gy to the right.

- The variation in dose along the axis of opposing pair of beams depends on the field separation and beam energy
- It can be made very small, yielding an almost uniform dosage from one beam entrance to the other

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Opposing pairs of beams

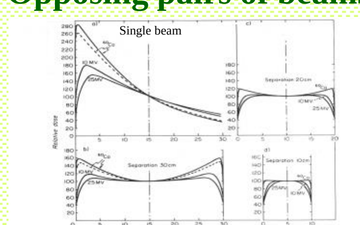

Figure 12-3. Relative dose for 10 × 10 cm beams of cobalt, 10 MV and 25 MV radiation. (a) Single beams with doses normalized at a depth of 15 cm. The dashed line for cobalt is for SAD = 100 cm, the solid line is for SAD = 80 cm. (b) As in a but an opposing beam is added with a separation of 30 cm. (c) and (d) Opposed beams with separations of 20 and

- 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

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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 (>15cm) 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)

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Opposing pairs of beams

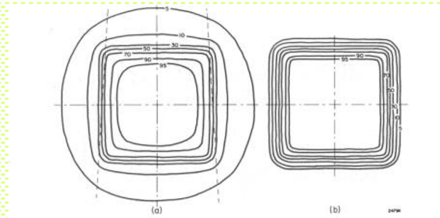

Figure 12-4. Isodose distributions in planes perpendicular to the axis of opposing fields of (a) cobalt-60 and (b) 25 MV radiations. The beams are isocentric, 10 × 10 cm and the separation is 20 cm.

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

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Opposing pairs of beams

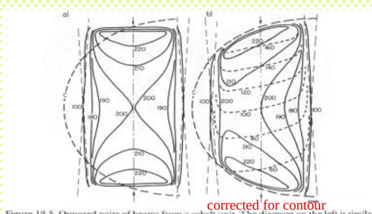

Figure 12-5. Opposed pairs of beams from a cobalt unit. The diagram on the left is similar to Figure 12-1b. The distribution on the right has been corrected for contour shape, the dashed curves being the distribution from the top beam corrected for patient contour as discussed in section 11.02.

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

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Combination of opposing pairs

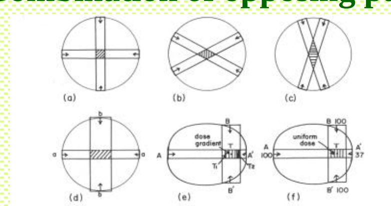

Figure 12-6. Schematic diagram showing possible arrangement of fields. (a) Two opposing pairs at right angles. (b) Two opposing pairs at 120°. (c) Two opposing pairs at 35°. (d) Two opposing pairs of different widths at right angles. (e) Two opposing pairs at right angles treating an off-center tumor. (f) Two opposing pairs at right angles treating an off-center tumor with field A' being given 37% of the amount given the other fields.

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

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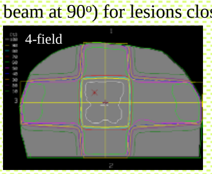
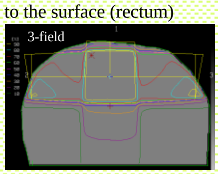
Combination of opposing pairs

- 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)





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Split fields

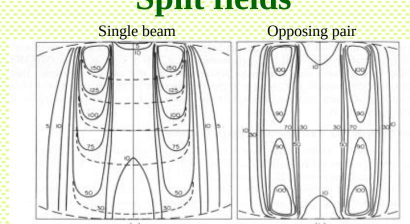

Figure 12-10. Dose distributions for split fields produced by blocking off the central portion of 12 × 10 cm cobalt 60 fields. The block is made of Pb, is 5 cm (approx. 5 HVL) thick, and blocks a region 5 cm wide at the isocenter. The SAD is 80 cm. (a) Single field with isodose curves for unblocked field shown as dashed lines. (b) Opposing pair.

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

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Angled fields and wedge pairs

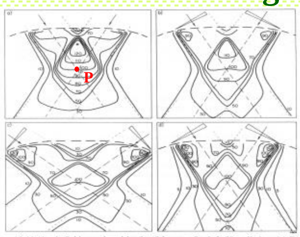

Figure 12-11. Angle fields produced by 6 × 6 beams of cobalt-60 radiation. (a) Beams at 30° from vertical and crossing at point, P, 7 cm below the contour surface. (b) Same as a but with 45° wedge filters added. (c) Same as b but angle increased to 50°. (d) Same as b but with 60° wedges.

- Often used for irradiation of a small tumor through the same skin surface
- Although the fields are directed towards the point P, the high dose region occurs much nearer the surface, therefore the beams should be aimed considerably below P ("past pointing")

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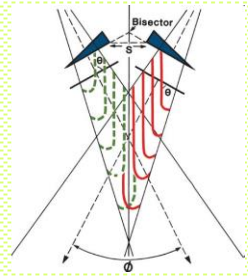
Angled fields and wedge pairs



- Parameters of the wedge beams: θ is wedge angle, Φ 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 θ and the hinge angle Φ that provides the most uniform distribution of radiation dose in the plateau:

$$\theta = 90^o - \Phi / 2$$

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Three field technique

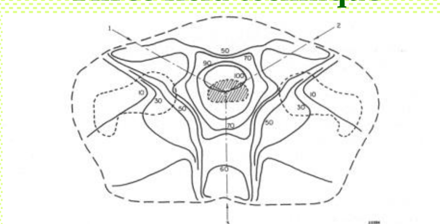
Figure 12-12. Isodose distribution for three 6 × 6 cobalt 60 beams at SAD 80 cm directed toward a bladder tumor. The beams are symmetrically arranged at 120° to each other.

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

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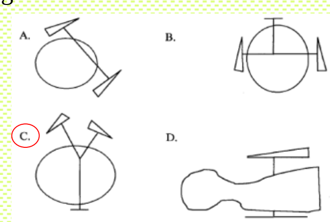
Example 1

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



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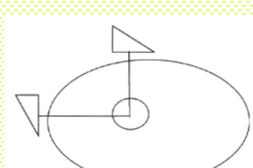
Example 2

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

A. 10
B. 20
C. 30
D. 45
E. 60



$$\theta = 90^o - \Phi / 2 = 90^o - 45^o = 45^o$$

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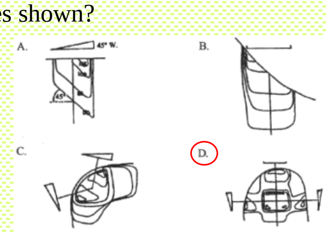
Example 3

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



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Rotation therapy

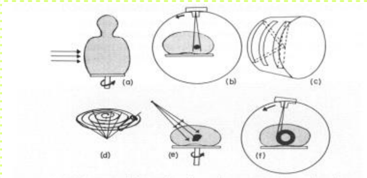

Figure 12-22. Diagrams illustrating the various types of rotation therapy.

- 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 spiral 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 (chest wall irradiation)

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Rotation therapy: isodose distributions

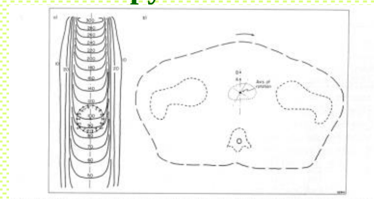

Figure 12-23. Isodose pattern for a cobalt 60 field normalized to 100 at a depth of 15 cm. Source-to-skin distance 65 cm, source-to-axis distance 80 cm, field size at axis 6 × 6 cm. The right side of the diagram shows the contour of the patient, the axis of rotation, and the points A and B at which the dose is to be determined.

- Calculations are generally based on the superposition of single beam isodose charts, with isodes 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

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Rotation therapy: effect of energy

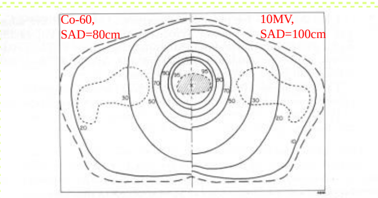

Figure 12-24. Isodose distributions for 360° rotation technique in treatment of cancer of the bladder using 6 × 6 cm field at the tumor. Left-hand side, cobalt 60 with a source-to-axis distance (SAD) of 80 cm. Right-hand side, 10 MV linear accelerator radiation, SAD = 100 cm. These isodose distributions were calculated by the method described in Example 12-6 and by Tsien et al. (T6).

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

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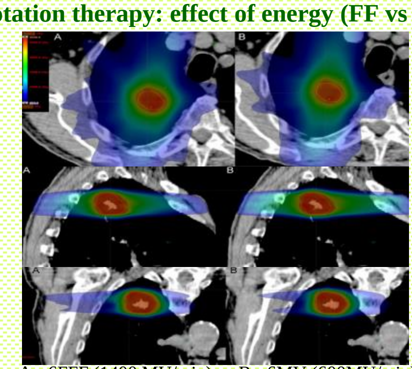
Rotation therapy: effect of energy (FF vs FFF)



A - 6FFF (1400 MU/min) vs B - 6MV (600MU/min)

Barbiero et al., Single-fraction flattening filter–free volumetric modulated arc therapy for lung cancer: Dosimetric results and comparison with flattened eams technique, Medical Dosimetry, 41, 2016, pp. 334-338

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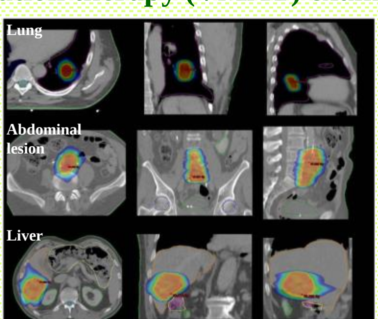
Rotation therapy (VMAT) examples



Scorsetti et al., Feasibility and early clinical assessment of flattening filter free (FFF) based stereotactic body radiotherapy (SBRT) treatments, *Radiation Oncology* 2011 **6**:113

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Rotation therapy: effect of arc length

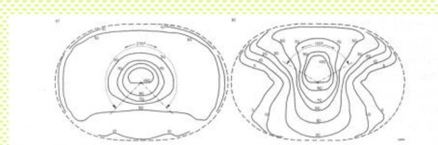

Figure 12-25. Isodose distributions for two angles of arc on an oval phantom. The one on the left is for 270° and the one on the right is for 120°. Both are for cobalt 60 radiation. The high dose region is moved toward the bisector of the arc; the smaller the arc, the greater is this shift.

- 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

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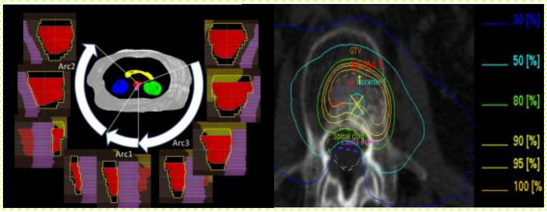
Rotation therapy: effect of arc length



- An example of dynamic-arc conformal avoidance plan for reirradiation of spinal metastases

Nishiyama *et al., Journal of Diagnostic Imaging in Therapy*. 2015; 2(2): 35-40

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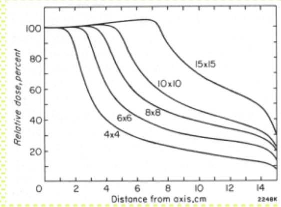
Rotation therapy: effect of field size



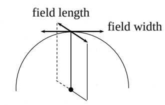


Figure 12-27. Dose profiles for 360° rotation about a 30 cm diameter cylindrical phantom for field sizes from 4 × 4 to 15 × 15 cm.

- 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

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Comparison of fixed field and rotation therapy

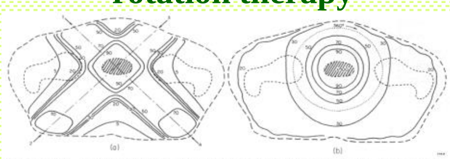

Figure 12-28. Isodose distributions for the treatment of cancer of the bladder using cobalt 60. Left side, distribution for four 6 × 6 cm fields at a source-to-axis distance (SAD) of 80 cm. Right side, rotation therapy using a 6 × 6 cm field at the tumor, also with a source-to-axis distance (SAD) of 80 cm.

- 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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Comparison of fixed field and rotation therapy

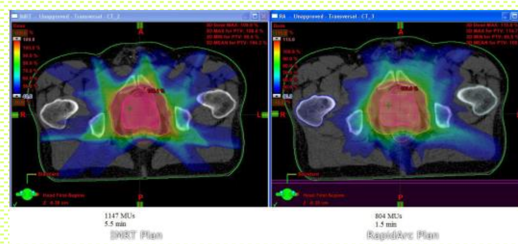

Image from: http://www.varian.com/us/oncology/treatments/treatment_techniques/rapidarc/comparison.html

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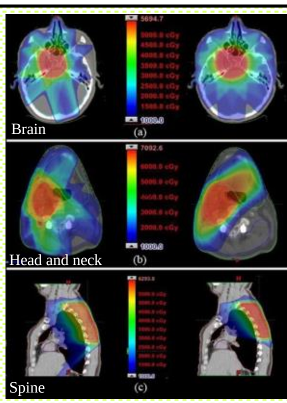
Comparison of fixed field and rotation therapy



IMRT DAC (Dynamic conf. arc)

- In more advanced IMRT approaches non-coplanar fixed fields can be used
- Multiple non-coplanar arcs are also often used (Brain, LHS figure)
- Again, with fixed fields some areas can be completely spared

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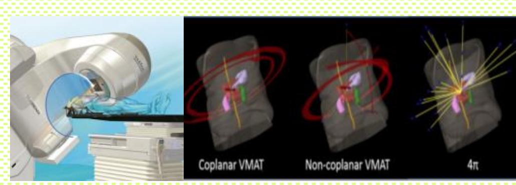
Rotation therapy trends



- Coplanar arcs: gantry/collimator rotations, couch does not move
- Non-coplanar approach involves addition of fixed angle couch rotations for each arc with intensity modulation optimization
- In "4π" approach – theoretically everything is optimized, including gantry/couch/collimator angle and intensity modulation

Pictures from: https://www.uabmedicine.org/-/uab-first-in-u-s-to-use-hyperarc-high-definition-radiotherapy-on-brain-cancer
K Woods et al., Viability of Noncoplanar VMAT for liver SBRT compared with coplanar VMAT and beam orientation optimized 4π IMRT, Adv. Rad. Onc., 2016, pp.65-75

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Figure of merit

- A treatment plan should deliver a high and uniform dose over a target volume, but minimum dose to all outside structures
- Figure of merit: $f = \frac{\text{Energy imparted to the target volume}}{\text{Total energy imparted to patient}}$

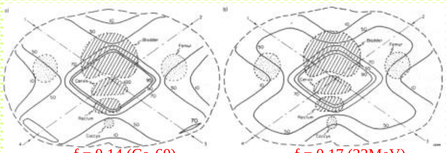

Figure 12-31. Four field dose distributions used by Allt (A8) in treating cancer of the cervix. The left hand diagram is for cobalt radiation and the right hand diagram is for a 22 MeV betatron. Both irradiate the tumor uniformly but the high energy beams deliver considerably less radiation to healthy tissues.

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Example 4

- A patient is planned for equally weighted, parallel-opposed 6 MV photon fields treating the mediastinum, AP thickness 22 cm. If the beam energy is changed to 18 MV photons, all of the following would decrease ***except:***

A. MU
B. Skin dose
C. Depth of maximum tissue dose
D. Percent variation in dose across the treated volume

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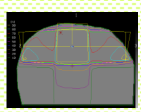
Example 5

- 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^o or 60^o wedges. With 60^o wedges, the relative dose at the isocenter for the PA field would be ___ that in the 45^o 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



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Summary

- Opposing pairs of beams
- Combination of opposing pairs
- Angled fields and wedge pairs
- Three-field approaches
- Rotational therapy

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