CHAPTER –2

2. WEDGE FILTERS

2.1. INTRODUCTION

Wedge filters are the most important beam modifiers used in radiotherapy which are placed in the path of photon beams to modify their isodose diistributions. The modified isodose distributions are invaluable in the treatment planning to achieve homogeneous isodose distributions. A wedge filter, which is usually made of dense materials such as steel, lead, brass, copper or any other heavy metal, is designed to create differential attenuation and hence progressive change in the intensity across the photon beam width. The resulting isodose distributions present tilting of isodose curves with respect to the normal of the photon beam central axis. The degree of isodose curve tilt towards the thin end of the wedge filter depends on the physical slope of the wedge filter.

2.2. WEDGE FILTERS

Wedge filters were first conceived and used in radiotherapy by Frank Ellis[1]. The beam intensity is gradually reduced by a wedge filter across the field there by changes the shape of the isodose curves. The wedge is placed between the source head and the patient at a fixed distance to avoid the electron contamination of the beam.

2.3. WEDGE ANGLE

As defined in section 1.2.1.1, clinical wedge angle is defined as the angle made by an isodose curve to the perpendicular to the central axis of the beam at a specified depth. A reference depth of 10cm has been recommended in general for all energies by the International Commission on radiation Units and Measurements(ICRU) for wedge angle specification(2). In defining the wedge angle, the choice of the field size has not been defined. A field size of 10 X 10 cm^2 is typically used(7,14). But for lower energy range such as cobalt-60 gammas and 4 MV x-raysetc., the wedge angle is measured corresponding to the 50% isodose line.

2.4. WEDGE FACTOR

The International Commission on Radiation Units and Measurements (ICRU) defines the wedge factor as the ratio of doses in water at a point on the central axis with and without the wedge, but otherwise with the same conditions(2). The out put of the machine will be decreased due to the presence of a wedge filter. This effect is characterised by the wedge transmission factor or simply wedge factor which is defined as above.

The wedge factor depends on the collimator setting, since the wedge contributes collimator scattered photons(6) and on the depth(17,18), since the wedge affects the attenuation characteristics of the beam. Dependence of the wedge factor upon depth has usually been attributed to a hardening of the incident beam through the wedge filter which absorbs and /or scatters the low energy photon beams(2,3,7,8,9). However , Kalend et. al.(10) have attempted to separate the beam hardening effect from that of increased phantom scatter due to the wedge induced dose gradient and have concluded that the dose gradient effect on the depth dependence of the wedge factor is just as significant as the beam hardening, particularly in the case of low energy x-ray beams produced by linear accelerators. For cobalt-60 gamma rays, no appreciable beam hardening effect was detected and demonstrated that the dose gradient effect dominates the depth dependence of the wedge factors(10). Dependence of the wedge factor on field size has been attributed to the change in phantom scatter(9,11) as well as to the scattered photons that reach the point of measurement after undergoing interactions in the flattening filter, the primary collimator and the wedge filter(12). A.Niroomand-Rad et. al.(13) evaluated the dependence of wedge factor on depth and field size for various beam energies, ie.,Cobalt-60 gamma rays, 4-, 6-, 10- and 18 MV photon beams using symmetric and half collimated asymmetric jaw settings. The degree of dependence of wedge factor on depth and field size varies with wedge angle, beam energy and collimator design. In clinical application, the magnitude of error in assuming one wedge factor for all depths and field sizes though minimal for small wedge angles, can be significant (>5%) for large wedge angles. For the half collimated asymmetric jaw settings, this dependence may be larger than for the corresponding symmetric jaw settings.

Conventionally , the wedge factor is determined at a specified reference depth such as depth of maximum dose (d_{max}) and for a reference field size such as 10x10 cm^2. The computation of timer settings or monitor unit settings for a wedged field usually involves the division of prescribed dose by the percentage depth dose for the unwedged field and the wedge factor. It is often assumed in clinical practice that wedge factor is independent of depth and field size, despite reports by Sewchand et. al.(3) and by Abrath et. al.(7) which showed discrepancies between depth dose values measured with and without wedge filters. As a general rule for 4- to 10 MV x-ray beams and for depths less than or equal to 10 cm, a maximum error of 2% in monitor units is accrued if the percentage depth dose for the unwedged field and the wedge factor for the depth of maximum dose are used.

In some situations, the wedge factor is incorporated into the isodose curves of the wedge filter itself. In this case, the depth dose distribution is normalised relative to the maximum dose without the wedge indicating that the wedge factor is already taken into account in the isodose distribution. If such distribution is used for treatment planning, then no further transmission correction should be applied to the output. In other words, the machine out put corresponding to the open beam should be used. A more common approach is to normalise the isodose curves relative to the central axis point of dose maximum with the wedge in the beam. In such situations, the output of the machine must be corrected using the wedge factor.

2.5. CLASSIFICATION OF WEDGE FILTERS

There are two types of wedges filters available which are used in clinical situations. They are : universal wedges and individualised wedges. Universal wedge is a single wedge which serves for all beam widths. Such a filter is fixed centrally in the beam while the field can be opened to any size. Only a small part of this wedge is effective in producing the given wedge angle. The rest being unwedged, does not contribute to the isodose tilt, but unnecessarily reduces the radiation output.

The individualised wedge systems requires a separate wedge for each beam width, optimally designed to minimise the loss of beam output. A mechanism is provided to align the thin end of the wedge with the border of the light field. Since the

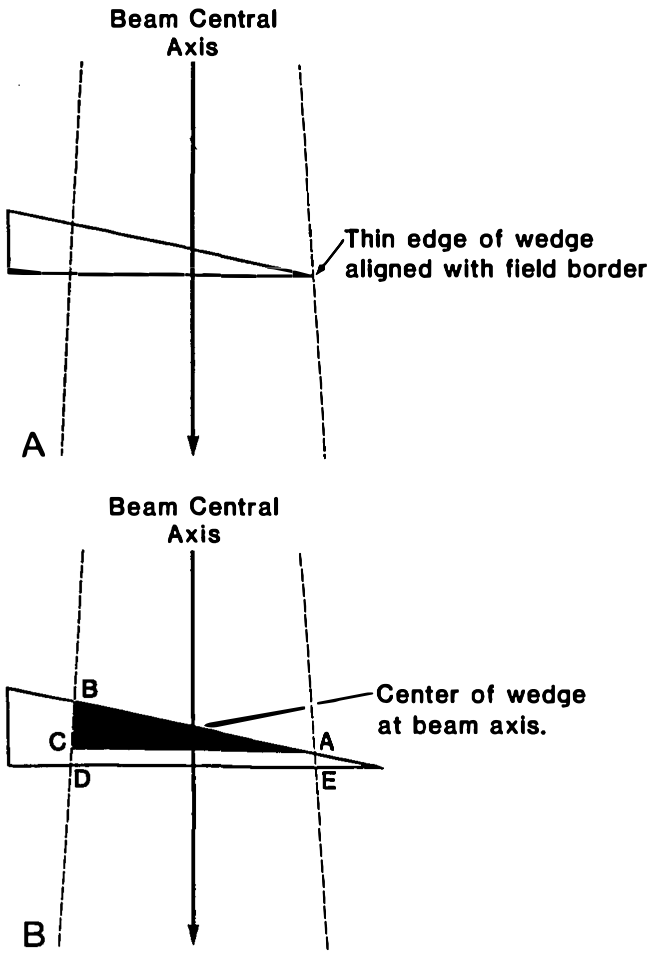

Figure 2.1. Schematic represantation of **(A)** an individualised wedge for a specific field width in which the thin end of the wedge is always aligned with the boarder and **(B)** a universal wedge in which the center of the wedge filter at the beam axis and the field can be opened to any width.

individualised system economises on the beam output, it is preferred for use in cobalt teletherapy. The universal wedge, on the other hand, is useful for linear accelerator beams where the output is plentiful.

2.6. EFFECT OF WEDGE FILTERS ON BEAM QUALITY

The wedge filter alters the beam quality by preferentially attenuating the lower energy photons and to lesser extent by Compton scattering which results in decrease in energy. The presence of a wedge filter does not significantly alter the central axis percentage depth dose distribution in the case of cobalt-60 beam as the primary beam is essentially monoenergetic. On the other hand, for megavoltage x-rays, there can be some beam hardening and consequently the depth dose distribution can be some what altered, especially at large depths(3). Although the wedge filters produce some change in beam quality, the effect is not large enough to alter other calculation parameters such as the backscatter or the equivalent square, which may be assumed to be the same as for the corresponding open beams. Even central axis percentage depth doses, Tissue Air Ratios (TAR) or Tissue Maximum Ratios (TMR) may be assumed unchanged for small depths. eg:- less than 10cm depths. The error caused by this assumption is minimised if the wedge transmission factor has been measured at a reference depth close to the point of interest(4).

2.7. WEDGE TECHNIQUES USED IN RADIOTHERAPY

Generally wedge filters are used to treat superficial tumours extending from the surface to a depth of few centimetres say upto 7-10cm. Wedge filters can be used in three principal ways: as a wedge pair, as parallel opposed wedge beams to make up for the fall off in depth dose of a field perpendicular to their axis, and to compensate for oblique incidence. These combinations were used with orthovoltage radiation and later proved to be an advancement in therapy with megavoltage radiations[5].

From the isodose distribution of two angled beams without wedges in the beam, it is seen that in the region of overlap of the beams, the dose distribution is quite non-uniform. The dose is highest in the superficial or proximal region of overlap and falls off to lower values towards the deeper areas. By placing appropriate wedge filters in the beam and positioning them with the thick ends adjacent to each other , the angled field distribution can be made fairly uniform. Each wedged beam in this case has a reduced dose in the superficial region relative to the deeper region so that the dose gradient in the overlap region is minimised. The dose falls off rapidly beyond the region of overlap or the plateau region, which is clinically desirable feature. If one or both of the wedges are positioned such that the thinner ends are together, then the resultant isodose distribution will be non-uniform. Moreover, under such circumstances the dose distribution will be worse than that when wedges are not used at all[16]. The parameters that affect the plateau region in terms of its depth, shape and dose distribution are the wedge angle (θ), hinge angle (Φ) and the separation (s). The hinge angle is the angle between the central axes of the two beams and the separation (s) is the distance between the thick ends of the wedge filters as projected on the surface. The optimum relationship between the wedge angle θ and the hinge angle Φ which provides the most uniform distribution of radiation dose in the plateau can be arrived as follows:

For any radiation field combination, one could generalise that the isodose curves for the two fields within the treatment volume must be parallel in order

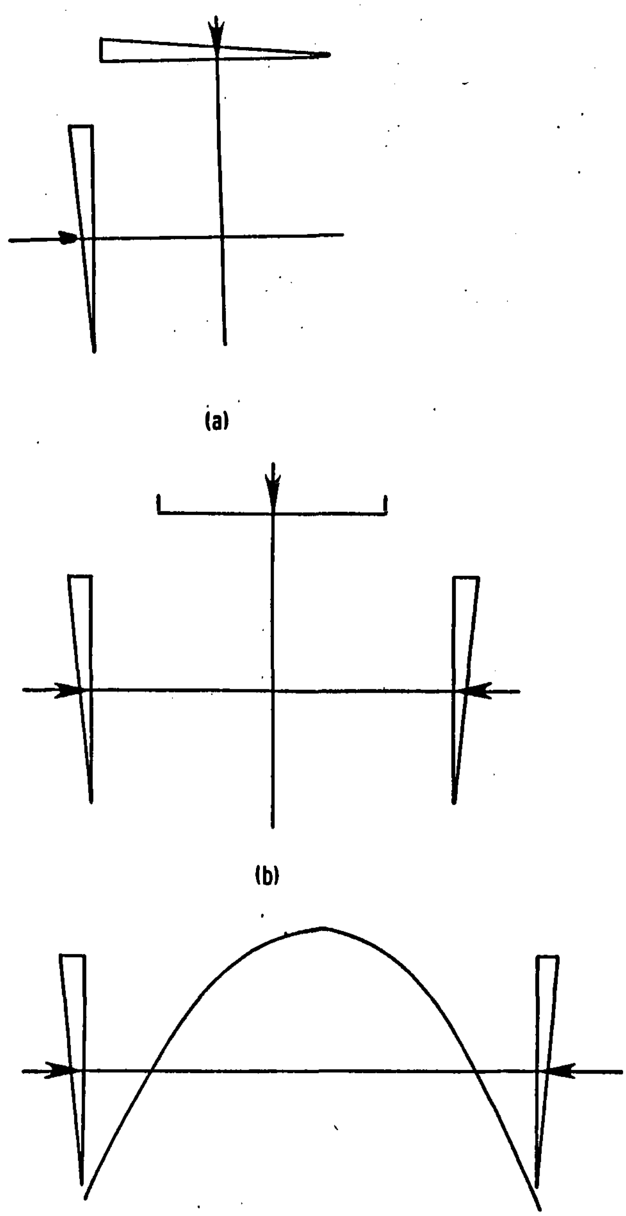

Figure 2.2. Typical methods of using wedge fields.(a) A wedge pair with axis at right angles to each other treating a lesion on one side of the body. (b) Two opposing wedge fields creating a dose gradient increasing from anterior to posterior in order to balance the reverse dose gradient of an unwedged anterior field. (c) Two opposing wedge fields to compensate for oblique incidence and prevent excessive dosage where the thickness of tissue is least.

to achieve the most uniform dose distribution For example, the most uniform dose distribution for two open or normal fields are such that they are opposing to each other. This is because under such conditions, the isodose curves from the two fields are parallel to each other. But if both the fields are originating from the same direction is equivalent to a single field and therefore uniform dose is not expected. Now let us assume a general case where $\theta 1$ and $\theta 2$ are the wedge angles of the two fields and for a given hinge angle, the wedge angles should be such that the isodose curves from each field are parallel to the bisector of the hinge angle . Under these conditions, when the isodoses are combined, the resultant distribution is uniform.

Since EBF and GDH are parallel lines, one can draw a line AI, such that it is parallel to both EBFand GDH. Then in ABCD, LA = $\theta_1 + \theta_2$. But LABC = L ADC = 90° by definition. L BCD = Φ, hinge angle. Therefore,

$$L A + LABC + L ADC + LBCD = 360^\circ$$

Or $$\theta_1 + \theta_2 + 90 + 90 + \Phi = 360^\circ$$

Or $$\Phi = 180^\circ - (\theta_1 + \theta_2).$$

This is the condition for uniform distribution for two wedge fields.

If $\theta_1 = \theta_2 = 0^\circ$ for open or normal field, $\Phi = 180^\circ$ and is a parallel pair. If $\theta_1 = \theta_2 = \theta$, then the conditions for uniform distribution is

$$\Phi = 180^\circ - 2\theta$$

Or otherwise,

$$\text{Wedge angle,} \quad \theta = (180 - \Phi)/2$$

$$\text{i.e.,} \quad \theta = 90 - \Phi/2$$

The above equation even though helpful in treatment planning, may not yield an optimum plan for a given patient contour. The relationship assumes that the wedge

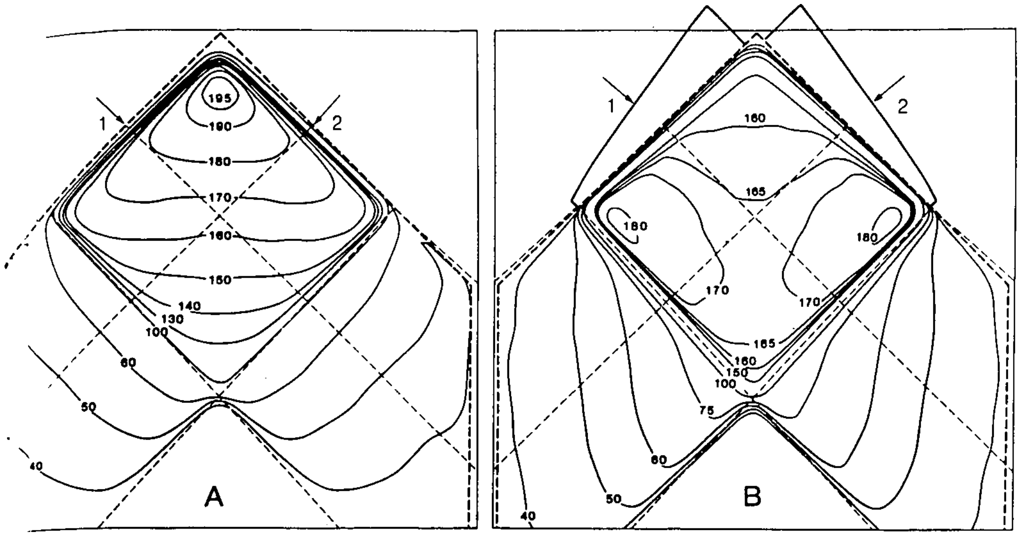

Figure 2.3. Isodose distribution for two angle beams. A, Without wedges; B, with wedges; MV, field size =10X10 cm, SSD = 100 cm, wedge angle = 45^0.

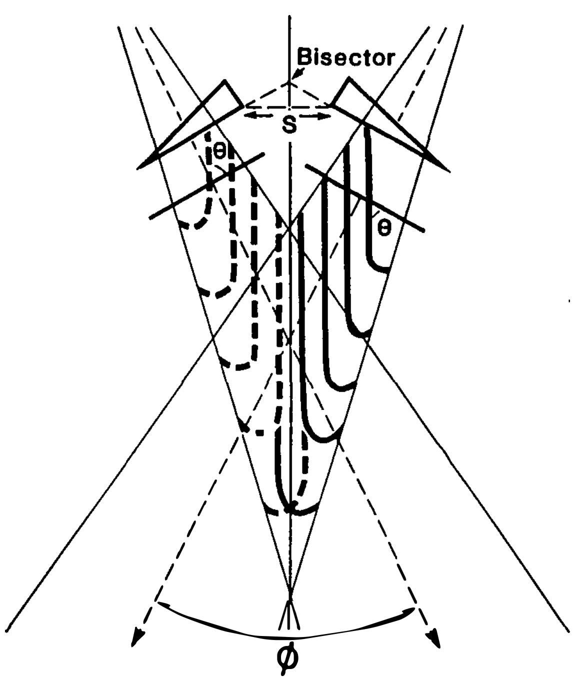

Figure 2.4. Parameters of the wedge beams, θ is wedge angle, ϕ is hinge angle, and s is separation. Isodose curves for each wedge field are parellel to the bisector.

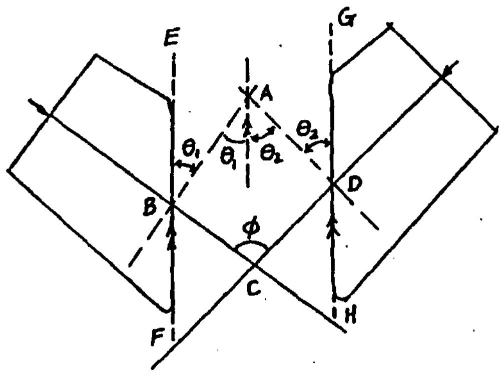

Figure 2.5.

isodose curves are not modified by the surface contour. In practice, contours are usually curved or irregular in shape and thus modify the isodose distribution for the wedged beams. As a result, the isodose curves for the individual fields are no longer parallel to the bisector of the hinge angle, thus giving rise to a non-uniform distribution in the overlap region. This problem can be overcome by using compensators which make the skin surface effectively flat and perpendicular to each beam. An alternative method is to modify the wedge angle so that a part of the wedge angle acts as a compensator and the rest as a true wedge filter. The main objective is to make the isodose curves parallel to the hinge angle bisector. Although the latter approach obviates the need for a compensator, the determination of an optimum wedge angle may not be easy if planning is done manually. The former method, on other hand, is well suited for manual calculations. This method becomes technically difficult to implement if complicated secondary blocking is required in addition to the compensator and the wedge filter[(4)]. The above equation suggests that for each hinge angle one should use a different wedge angle.

Another mode of application of wedge filters is in the form of a point wedge[(33)]. The technique uses three fields, with the wedging of each field toward a point at which the three fields meet at one of the corners of a cube. By this means it is possible to achieve maximum uniformity in the target volume when it can be irradiated from three directions at right angles. i.e., adjacent sides of a cube. Such sites are the head and the shoulder. The disadvantage of this technique is that extra care needs to be taken, with the use of special jigs, to ensure that the three fields are accurately related to each other in space.

2.8. DOSIMETRY OF WEDGED FIELDS

In Wedge pair treatments, superficial small lesions are treated where a high dose region or hot spot of up to +10% within the treatment volume is usually accepted[4]. These hot spots can occur under the thin ends of the wedges and their magnitude increases with field size and wedge angle. This effect is related to the differential attenuation of the beam under the thick end relative to the thin end. The most desirable feature of this technique is the dose fall off beyond the region of overlap. This fall off can be exploited to protect a critical organ such as the spinal cord. Though, wedge filters are invaluable in radiotherapy, some of these techniques are being replaced by electron beam techniques[4].

Utmost care must be taken to avoid any mistake in placing the wedge filter. Since wedged fields are combined with each other and with other fields, precision in direction, distance and position both during planning and delivery of treatment are essential. It can be shown that with a 5cm wedge an error of only 5mm in positioning can result in a 5% error in dosage at 5cm depth. A direction error of 10^0 can result in a 10% error at 5cm[11].

2.9. OBJECTIVES OF THE PRESENT WORK

The treatment of tumours under irregular body contour causes some problem for the practice of radiotherapy. This discrepancy may be overcome by suitably designing some beam modifying devices. When radiation beam falls on an irregular body surface produce tilting of isodose curves with respect to the central axis of the beam. This results in non-uniform dose delivery to the tumour volume. Under such situations special filters or absorbing blocks are placed in the path of the beam to modify the dose distribution. The most commonly used beam modifying device is a wedge shaped absorber which produces a progressive decrease in the intensity across the beam conforming with the varying thickness of the filter. When such filters are used to treat tumours under varying body surface, the change in isodose value resulted by virtue of the beam modifying device may compliment the body surface irregularity resulting in a uniform dose distribution within the tumour.

The present work aims at the design and fabrication of wedge filters of various clinical wedge angles both conventional and non-conventional values and hence for different thicknesses. Wedges with non-conventional angles were tried primarily because with these filters only uniform dose distributions are achieved in some head and neck malignancies which is described in chapter 6. Also, design and fabrication of wedge filters for two materials such as lead and lipowitz was carried out so that these beam modifying gadgets can be custom made within the department itself . The design and fabrication was done for cobalt-60 gamma rays and for 4 MV x-rays. A total of twenty three wedges were fabricated and all the twenty three filters fabricated were dosimetrically evaluated by using small volume ion-chamber. Dosimetry was done with water phantom system which has a large scanning volume with motorised movement of detectors and treatment planning computer. Dosimetric data analysis was done with water phantom measurement software and treatment planning software.

Hence, the aims of the work can be given as:

1. To design wedge filters to modify radiation beam from a teletherapy unit used for Radiotherapy.

2. To fabricate wedge filters to modify isodose curves of a radiotherapy equipment using different materials.
3. To evaluate the dosimetric aspects of each wedge filter using small volume ion chamber and water phantom system and hence make it suitable for routine patient care.
4. To fabricate wedge filters in conventional and non-conventional clinical wedge angles.
5. To dosimetrically evaluate the wedge filters for both cobalt-60 gamma radiations and megavoltage radiations from a 4MV medical linear accelerator.

2.10. CONCLUSION

The isodose distribution for a given radiation field is often altered purposely with special absorbing device inserted into the beam to suit some special situation. The most commonly used beam modifier in radiotherapy is a wedge filter. The use of wedge fields in radiation treatment planning is numerous. The main goal is to achieve uniform dose in the tumour volume in cases where the use of normal fields is hard to achieve for one reason or others.

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