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Wooden K.K., Hogstrom K.R., Blum P., Gastorf R.J., and Cox J.D. Whole-limb irradiation of the lower calf using a six-field electron technique. *Medical Dosimetry*, 21:211-218, 1996.

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## WHOLE-LIMB IRRADIATION OF THE LOWER CALF USING A SIX-FIELD ELECTRON TECHNIQUE

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**Abstract**—The present work demonstrates utilization of electron beam irradiation for the treatment of Kaposi's sarcoma when the full circumference of the lower calf is involved, and when the deep lymphatics are negative for disease. The finite penetration of the electron beam spares deep tissue, preventing the edema associated with photon total limb irradiation. The number of fields with fall-off required to produce a uniform dose to a cylindrical anatomic structure was studied by calculating dose distributions resulting from two-, four-, and six-field techniques for a 5-MeV electron beam and a 9 cm diameter cylinder. The dosimetry and set-up for the six-field technique is demonstrated by a case study. Results show that a six-field electron technique produced a sufficiently uniform dose while remaining relatively easy to set up and use to deliver patient treatment. For the patient case study, dose distributions for the six-field technique showed that (1) the penetration of the 90% dose decreased from 1.5 cm for a single field to approximately 1.0 cm for a 5-MeV beam; (2) the surface dose increased from approximately 70% to 100%, (3) the dose around the circumference of the leg at the depth of 1 cm or less varied from approximately 90% to 120% of the prescribed dose; and (4) the prescribed dose was 2.5 times the maximum central-axis dose from a single field. The six-field treatment was relatively simple to apply and produced an acceptable dose distribution for treatment of Kaposi's sarcoma of the lower calf. This treatment should be applicable to other sites such as the thigh and arms and for other cutaneous diseases such as melanoma.

**Key Words:** Kaposi's sarcoma, Lower leg irradiation, Electron treatment planning.

### INTRODUCTION

Kaposi's sarcoma (KS) is the most common neoplastic manifestation of acquired immunodeficiency syndrome (AIDS).<sup>1</sup> The type of KS associated with AIDS is known as epidemic Kaposi's sarcoma (EKS). Up to 25% of all patients with AIDS have been reported to have EKS. The etiology of EKS is unknown. While cytomegalovirus is frequently present in AIDS patients, it does not seem to be causally related to EKS, but may play a cofactorial role.<sup>2</sup> EKS is rarely seen in females. It is usually not the primary cause of death in AIDS patients, however, EKS causes many problems for patients who are in the relatively early stage of AIDS. Some of these complications are cosmetic problems, pain, and compressive disorders secondary to tumor growth, which dramatically increase the patient's physical and mental discomfort.<sup>3</sup>

In 75% of cases, the first site of clinical involvement of this sarcoma is the lower extremities. The lesions tend to grow by local extension, and coalesce as they grow, forming irregular-shaped clusters. The size and shape of individual lesions vary, and their color ranges from light pink to dark purple.<sup>1</sup> Small

single lesions can be surgically removed or frozen by liquid nitrogen. Systemic treatment should be considered if the disease is overtly widespread. The response to systemic treatment is often partial and temporary, and tolerance is variable, particularly with regard to hematological toxicity.<sup>3</sup> Vinblastine was reported to "control" EKS in approximately 30% of patients and to arrest tumor progression temporarily in another 50%. Combination of vinblastine with vincristine or other agents produces some degree of response in 75% of patients treated.<sup>1</sup>

Since KS is a radioresponsive disease, radiotherapy is considered the treatment of choice for localized or regionalized disease involving cutaneous tissue. Radiotherapy ranges from localized field irradiation (LFI) for one or two single-lesion areas to large extended field irradiation (EFI) to treat an entire extremity where disease is overtly widespread.<sup>1,2</sup> The conventional approach is to treat an area with EFI by using photons, e.g., <sup>60</sup>Co or 6 MV x-rays. Treatment is delivered by using two parallel-opposed fields with a 1 cm bolus placed around the limb to provide dose build-up.<sup>3</sup> The use of photons can cause unnecessary dose to the underlying area. Also, treating with only two

photon fields will produce a non-uniform dose between the lateral aspects of the extremity and the inferior and superior portions of the leg. While one reason for irradiation of EKS is to alleviate edema associated with this disease, the use of photons can cause chronic edema of the limb. The edema results when a strip of tissue is not spared for the integrity of the lymphatic system. The potential for this complication could make photon irradiation unacceptable when the deep lymphatics are negative for disease. In these cases, electrons may be more beneficial. Electrons do not penetrate as deep as photons, so the deep lymphatics can be salvaged. Also, the electron beams can be arranged to allow dose uniformity throughout the extremity while keeping the surface dose high enough without the use of bolus.

In this report, we describe a six-field irradiation technique that is effective in treating the superficial tissues around the circumference of an extremity, and thus may be useful in treatment of KS. This technique was applied for treatment of the lower calf of a patient with KS. The treatment planning dosimetry and treatment technique will be discussed.

## MATERIALS AND METHODS

### *Treatment planning dosimetry*

The treatment planning dose calculations were performed on a treatment planning system—TPS (General Electric Target, General Electric Medical Systems, Buc, France) that calculates electron beam dose distributions by using a two-dimensional pencil-beam algorithm.<sup>4</sup> The TPS is capable of calculating the dose in multiple parallel planes, and for the case described here, dose was calculated in transverse planes perpendicular to the isocentric axis of the accelerator, which approximately coincided with the long axis of the lower leg. Although the system is capable of accepting computed tomographic (CT) scans for the patient description and calculating dose in the presence of bone, for this study the patient contour was input by using the TPS digitizer. Thus the dose calculation ignored bone (tibia and malleoli), whose effect on the dose distribution is unknown for this geometry. It is believed to be less than 10%. The dose to the surrounding soft tissue most likely increased rather than decreased. The plan output consisted of life-size isodose plots with user-specified dose normalization and values of plotted isodose contours.

To appreciate the effect of circular anatomic structure on the electron beam dose distribution, a single-field dose distribution was calculated first. To determine the simplest multiple field technique, treatment plans were calculated for two, four, and six fields. The multiple field techniques did not abut field edges around the patient's leg, as this would not only have been too complicated for set-up, but also would have

resulted in the problem of large volumes of high dose at the abutted field edges. Rather, each field was made substantially wider than the maximum width of the leg (approximately 2 cm or more fall-off), so that it irradiated one-half of the leg. This technique's use of broad fields with fall-off is similar to that used for total skin electron therapy.

The TPS was also used to verify the dose at the junction of abutment between the dorsum of the foot field and the inferior border of the lower calf field. The abutment dosimetry was calculated in a mid-sagittal plane of the leg. The dorsum of the foot field required 0.5 cm of bolus for surface dose build-up. Because the TPS required the bolus to be entered as part of the patient, and because only one of the two abutted fields had bolus, it was necessary to calculate the dose distributions of the two fields separately and to manually sum their dose distributions. Also, the junction dosimetry was calculated using only the anterior field of the six-field technique. To utilize all six fields would have required a three-dimensional TPS. A flat phantom was used in lieu of the true shape of the foot, as we were interested only in the dosimetry in the abutment region, where the anatomical surface is approximately flat.

### *Simulation*

Patient simulation was performed on an Oldelft Simulix MC simulator. (Nucletron-Oldelft Corporation, Columbia, MD) As shown later, a six-field technique was utilized, and the objective of simulation was to establish patient positions which would place the patient's lower leg such that it would be approximately centered on a line parallel to the gantry's isocentric axis. The leg was treated with a technique referred to as iso-SSD, in which all fields had a SSD of 105 cm and were directed toward a common point in the patient. With the patient in the supine position, one anterior (gantry angle = 0°) and two oblique (gantry angles = ±60°) fields were irradiated. With the patient in the prone position, one posterior (gantry angle = 0°) and two oblique (gantry angles = ±60°) fields were irradiated.

The inferior and superior borders of the calf were established during simulation. Anterior, posterior, and lateral laser lines were marked on the calf to assure that the set-up would be reproducible every day. Two other fields were demarcated during simulation, one an extension of the disease to the dorsum of the foot and one to the posterior knee (popliteal fossa). For treatment planning dose calculations, three contours were taken by using plaster of paris strips. Contours were taken with the patient supine, and changes in the contour for the patient prone were ignored. Contours in transverse planes were taken at the central leg and at 11 cm above and 9 cm below the central leg. The mean diameters of the leg in these areas were 9 cm, 11 cm, and 8 cm, respectively.

*Patient treatment set-up*

The patient was treated on a Siemens Mevatron 6740 (Siemens Medical Systems, Inc.-OCS, Concord, CA) equipped with variable trimmers that have a maximum field size of  $25 \times 30 \text{ cm}^2$  at isocenter.<sup>5</sup> Using the variable trimmers allowed the field length to be as long as needed, and the field width to be adjusted to have appropriate fall-off. The six-field technique was delivered by one anterior and two anterior oblique fields (supine position) and by one posterior and two posterior oblique fields (prone position). The dorsum of the foot and posterior knee fields were treated with the patient in the supine and prone positions, respectively. Patient set-up followed a specified procedure developed from the geometry of the treatment plan. That procedure was facilitated by the table being equipped with a digital readout of the table height.

**RESULTS***Superficial treatment of circular anatomic structure with electrons*

A single electron beam irradiating a circular cross-sectional anatomic structure is significantly affected by the non-perpendicular incidence. This is illustrated in Fig. 1, which shows the dose distribution for a cylindrical

cal anatomic structure (diameter = 9 cm) irradiated by a single 5-MeV electron beam, which was 17 cm wide by 31 cm long at the treatment SSD of 105 cm. The lateral fall-off, approximately 4 cm, placed the anatomic structure well inside the penumbra, so the beam incident on the circular anatomy at the 105 cm SSD was uniform. On the central axis, the beam was of normal incidence, and the surface dose,  $D_s$ , was about 70%;  $R_{100}$ ,  $R_{90}$ , and  $R_{20}$  were 1.1 cm, 1.5 cm, and 2.3 cm, respectively. Approximately 1 cm from the lateral and medial anatomic extent, the angle of incidence varied rapidly, being about  $45^\circ$ . At  $R_{100}$  the dose decreased by approximately 4% because of a greater SSD and increased because of electron scatter,<sup>6</sup> resulting in a net hot spot of just over 100%. The surface dose clearly increased. More significantly, the therapeutic depth,  $R_{90}$ , decreased to approximately 1 cm.  $R_{20}$  increased to approximately 2.4 cm.

The minimal number of fields, equally spaced at angles around the circular atomic structure, was determined to be six. Figs. 2–4 illustrate the dose distribution resulting from two, four, and six equally spaced fields. When the two-field technique was used (Fig. 2),  $R_{90}$  varied from 1.5 cm to 0.2 cm, being unacceptable. When the four-field technique was used (Fig. 3),

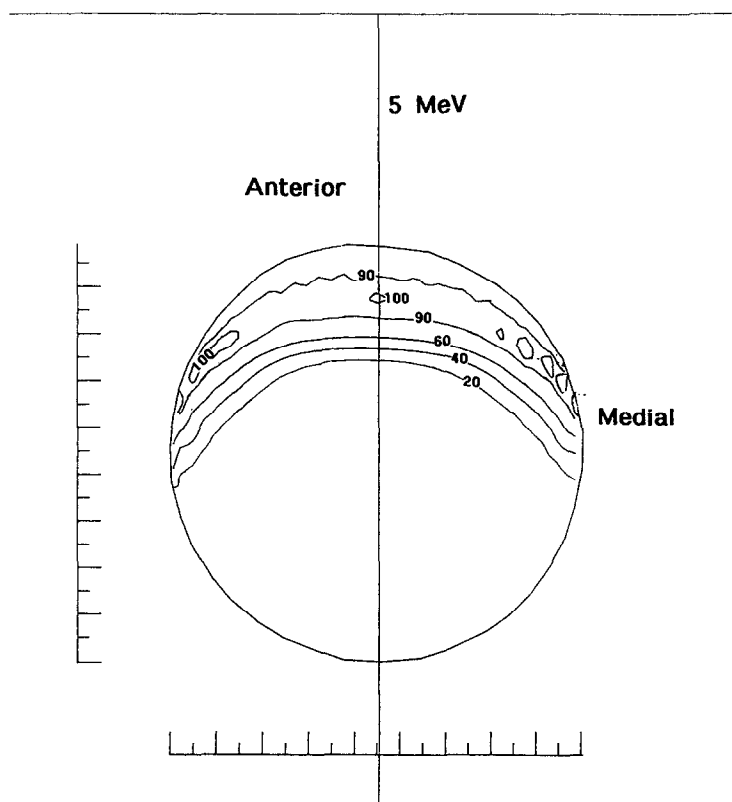


Fig. 1. Isodose contours plotted for an anterior 5-MeV electron field irradiating a mid-transverse plane of a 9-cm diameter cylinder simulating the lower leg. (100% = maximum central-axis dose for beam incidence perpendicular to flat surface.)

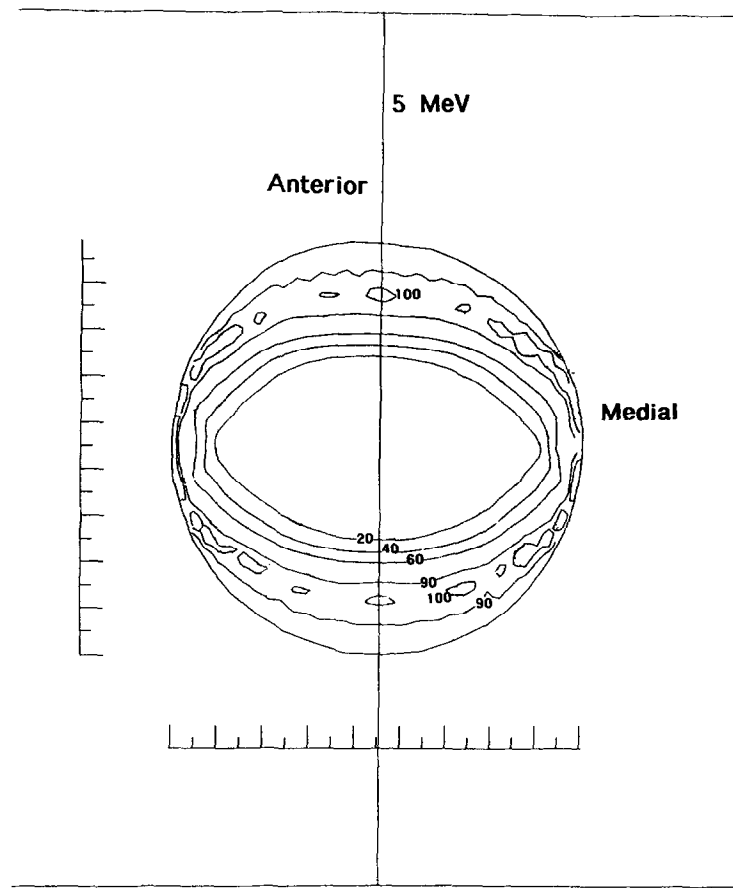


Fig. 2. Isodose contours for parallel-opposed 5-MeV electron fields described in Fig. 1. (100% = maximum central-axis dose for single beam incidence perpendicular to flat surface.)

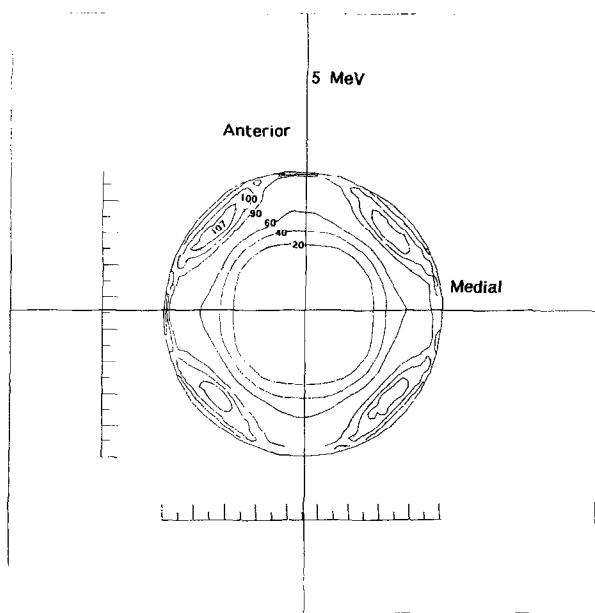


Fig. 3. Isodose contours for four 90° spaced, 5-MeV electron fields described in Fig. 1. (100% = 1.8 times maximum central-axis dose for single beam incidence perpendicular to flat surface.)

the maximum dose was just over 107%.  $R_{90}$  varied from 1.2 cm to 0.2 cm, again being unacceptable. When the six-field technique was used, we finally achieved an acceptable dose distribution,  $R_{90}$  varying between 1.0 cm and 0.8 cm and the maximum dose varying from approximately 100% to just over 108% (Fig. 4). Also note that the surface dose was 90% or greater. It should also be understood that the dose distribution in Fig. 4 was normalized such that the 100% isodose line corresponded to 2.55 times the given dose (maximum central axis dose to a flat water phantom at the 105 cm treatment SSD) of a single field. Therefore, for a dose prescription ( $D$ ) to the  $X\%$  isodose contour, the monitor units (MU) for each of the six fields is given by:

$$MU = \frac{D/X\%}{2.55 \cdot (D/MU)_s} \quad (1)$$

where  $(D/MU)_s$  is the dose per monitor unit for the single 5-MeV,  $17 \times 31\text{-cm}^2$  beam incident on a flat water phantom at 105 cm SSD.

Using beams at 60° intervals and the 105 cm SSD allowed the treatment to be set-up without the trimmer bars of the variable electron collimator hitting the couch. Extension to an eight-field technique would not

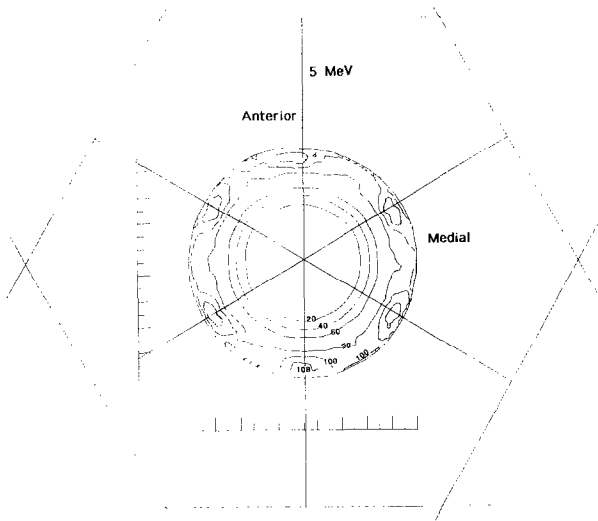


Fig. 4. Isodose contours for six 60° spaced, 5-MeV electron fields described in Fig. 1. (100% = 2.55 times maximum central axis dose for single beam incidence perpendicular to flat surface.)

only have increased the treatment set-up time, but clearance between the couch and variable collimator would have been unlikely, and problems with grazing electron radiation scattering off the table would have become a concern. Hence, the six-field electron treatment is presently our treatment technique of choice for superficial circular atomic structures.

#### Case study

A 31-year-old Hispanic male was diagnosed HIV positive in 1992. In May 1995, the patient noticed lesions developing on his right calf. The lesions were biopsied and confirmed to be KS. Initially, the patient was given velban and vincristine, but he showed minimal response to systemic therapy. At that time the patient was referred to M. D. Anderson Cancer Center for radiotherapy. The physical examination revealed multiple lesions on the right calf. The lesions extended from the popliteal fossa to the dorsum of the foot. Most of the lesions were flat, but a few were as thick as 0.5 cm. The calf and foot were edematous. An MRI revealed that the lesions were confined to the skin and subcutaneous tissue and that there was no deep extension into the muscle.

Because the numerous lesions encompassed the circumference of the lower leg, they would have to be treated by extended field irradiation. However, using this technique with photons would create several problems discussed previously. Therefore, the physician prescribed the use of electrons. The aim was to treat the circumference of the leg as uniformly as possible. The depth of  $R_{90}$  should be at least 0.3 cm greater than the depth of the thickest lesions, 0.5 cm, and the  $R_{20}$

should be less than the depth of the deep lymphatics. It was decided to treat the lower calf with a six-field electron technique. There was an additional dorsum of the foot field which abutted the inferior border of the lower calf field, and there was an additional popliteal fossa field that was gapped approximately 2 cm superior to the lower calf treatment volume.

Upon review of various energy plans, the physician prescribed a 5-MeV beam and a dose of 25 Gy in 10 fractions to a specified isodose contour of the six-field technique. The dorsum of the foot and the popliteal fossa fields also received 25 Gy (to  $R_{100}$ ) in 10 fractions. Fig. 5 shows the treatment areas with the patient in the supine and prone positions.

#### Patient dosimetry

The patient dose distribution through the calf was calculated in three transverse planes. The dose distribution was normalized in accordance with the physician's prescription. The plotted isodose contours can be viewed as the fraction dose in cGy or the total dose in deciGy. The first planar dose distribution, which contained the central axis of the beams and was midway between the inferior and superior borders of the calf treatment volume, is shown in Fig. 6. The dose delivered at a depth of 1 cm was approximately 25 Gy. The dose between the surface and 1 cm depth varied from approximately 25 to 30 Gy. The dose at 1.5 cm depth was approximately 22 Gy. The dose at a depth of 3.0 cm was approximately 5.6 Gy (22% of prescribed dose). Also of interest is the dose distribution in off-axis transverse planes where the shape and the mean diameter of the calf varied. Fig. 7 shows the dose distribution in the transverse plane 11 cm superior to the central axis, where the mean diameter had increased from 9 cm to 11 cm. Here the 22 Gy contour varied from a depth of approximately 1.0 cm to 1.5 cm, and the 5.6 Gy contour varied from a depth of 2.7 cm to 3.5 cm. Fig. 8 shows the dose distribution in

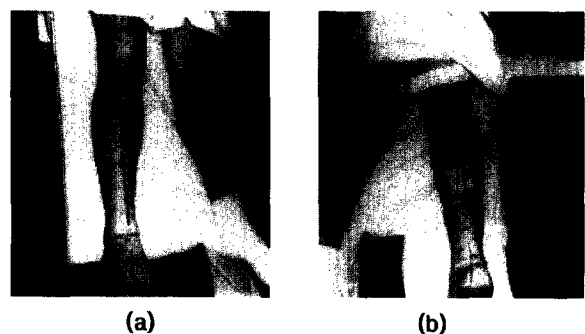


Fig. 5. (A) Anterior view of lower calf irradiated by six-field technique and dorsum of foot field. (B) Posterior view of lower calf irradiated by six-field technique and popliteal fossa field.

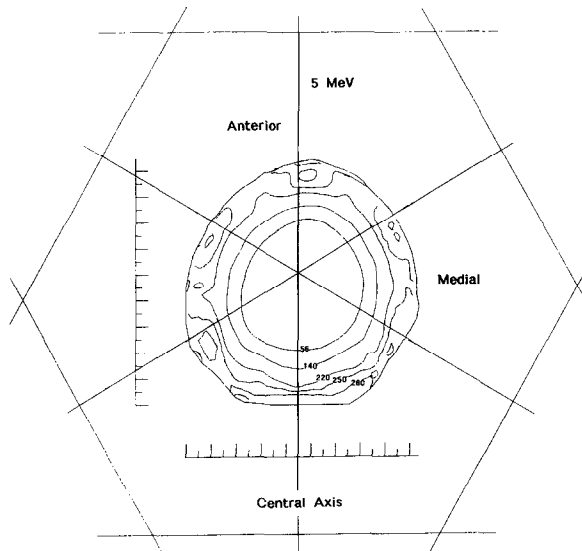


Fig. 6. Isodose contours in central transverse plane of lower calf resulting from six-field technique (mean diameter = 9 cm). Each field is a 5-MeV,  $17 \times 31$  cm<sup>2</sup> electron field at 105-cm SSD. The resulting dose distribution shows the fraction dose in cGy for a dose of 100 cGy from each of the six fields.

the transverse plane 9 cm inferior to the central axis, where the mean diameter had decreased from 9 cm to 8 cm. The 25 Gy contour varied from the surface to a depth of 2.0 cm, and the 22 Gy contour varied from a depth of approximately 1.2 to 2.2 cm. The dose between the surface and a depth of 1 cm varied from approximately 22 to 30 Gy. The 5.6 Gy contour was at a depth of approximately 3.0 to 3.5 cm.

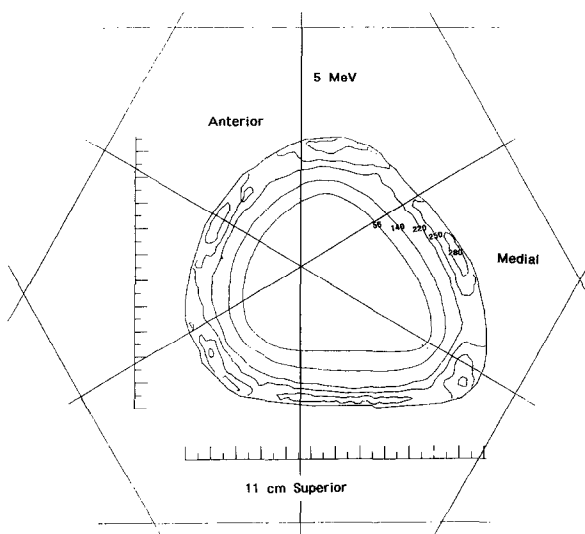


Fig. 7. Isodose contours for six-field technique in a transverse plane located 11 cm superior to the central plane (mean diameter = 11 cm).

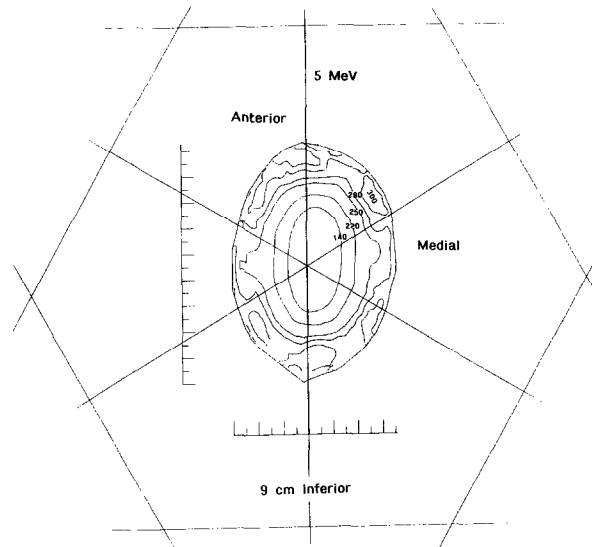


Fig. 8. Isodose contours for six-field technique in a transverse plane located 9 cm inferior to the central plane (mean diameter = 8 cm).

Illustrated in Fig. 9 are the results of the junction dosimetry from the abutment of the anterior calf field with the dorsum of the foot field. The dorsum of the foot field was angled so as to have as nearly as possible perpendicular incidence to the surface of the foot. It can be seen that the beam edges diverged from each other due to the angulation of the dorsum of the foot field. The fields were overlapped by 2.5 mm (width of match line included in both fields), and the junction

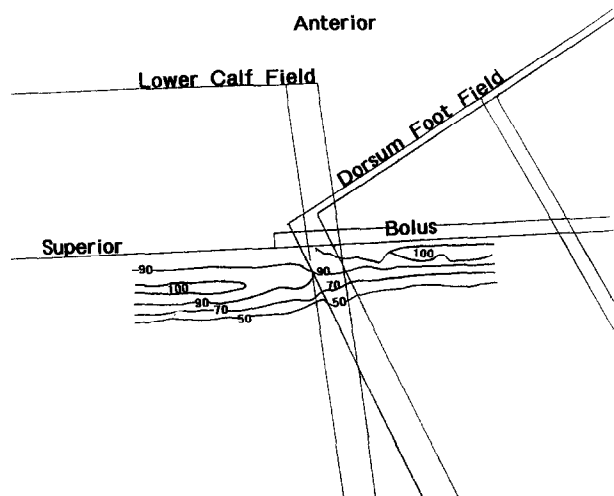


Fig. 9. Isodose contours for abutment dosimetry. Simulation of anterior 5-MeV electron field of six-field technique abutting single appositional 5-MeV electron field used to irradiate the dorsum of foot. The 2.5-mm-wide skin line demarcating the border was treated by both fields, and the junction was shifted 1.0 cm midway through treatment.

was shifted 1 cm halfway through treatment, generating a uniform dose in the abutment regions.

#### Patient treatment set-up

The objectives of patient treatment set-up were:

1. to mimic the simulated set-up;
2. to ensure that the opposite leg was not irradiated;
3. to ensure that the gantry and electron collimators cleared the patient and treatment couch; and
4. to be rapid and efficient.

There were two treatment positions, supine and prone, each receiving three of the six calf fields and one patched field.

In both positions the right calf was aligned such that a skin line that equally splits the calf matched the sagittal laser. Soft padding was placed between the surface of the treatment couch and the calf so that the irradiated surface was about 2 cm off the couch and its lateral simulation lines could be matched by the lateral lasers. In both positions the opposite leg was spread away from the table. For the supine position the leg was allowed to dangle off the table. For the prone position the patient had to cooperate by bending the knee to withdraw the leg, which was then immobilized by a Velcro strap. In both positions, a small board placed under the patient was used to support the upper leg to just above the knee joint.

The calf fields were rapidly set up using geometry. For the anterior fields, shown in Fig. 10, the table

height was adjusted to give 105 cm SSD on the central axis. The fields at  $\pm 60^\circ$  were set rapidly by rotating the gantry and translating the couch so as to place the isocenter in the proper location relative to the patient. As seen in Fig. 10, the couch was moved 8.2 cm laterally and raised 4.6 cm to properly position the patient for the left anterior oblique field. These set-ups were achieved rapidly as the couch position was zeroed after setting up the anterior field. The procedure was then repeated for the posterior field.

The dorsum of the foot was treated with the patient in the anterior position. The couch was rotated from  $0^\circ$  to  $290^\circ$ , almost lateral, and the gantry was rotated toward the patient to an angle of  $30^\circ$ . This ensured the best distribution to the dorsum of the foot by providing nearly perpendicular incidence and good junction dosimetry (already described). The posterior knee field was treated with the patient in the prone position, using standard single field techniques.

#### Patient follow-up

The patient completed the prescribed dose of 25 Gy in 10 fractions without complications. After 5 days of treatment, the patient was seen in the clinic for evaluation. Examination of the raised and discolored area from the popliteal fossa to the dorsum of the foot revealed minimal change, perhaps a slight flattening of the lesions. The patient has not been seen for a follow-up examination.

## CONCLUSION

Electron beam irradiation has been demonstrated to be a useful technique for treatment of KS of the lower leg when it is not necessary to treat the deep lymphatics. A technique with six low-energy electron fields spaced at equal angles provided a satisfactory dose distribution. Each of the six fields had fall-off, so abutment was not an issue; this and the circular anatomic structure resulted in a portion of each electron beam striking the patient at a steep angle. For a single electron beam incident on the lower leg, the angled incidence, which occurred only near the edges to the circular anatomy, increased surface and superficial dose and decreased depth of  $R_{90}$ . To evenly distribute these effects, a six-field irradiation technique was necessary. This technique increased the surface dose from approximately 70% for the single beam with normal incidence to almost 100% for the six-field technique and decreased the  $R_{90}$  from 1.5 cm for the single beam to a range of 0.7–1.6 cm for the six-field technique. Because of the increased surface dose, the six-field technique required no bolus. Each point on the circular anatomic structure was directly irradiated by three of the six beams, and the mean maximum dose, averaged azimuthally, was approximately 2.5 times the maximum central-axis dose for a single beam with normal incidence.

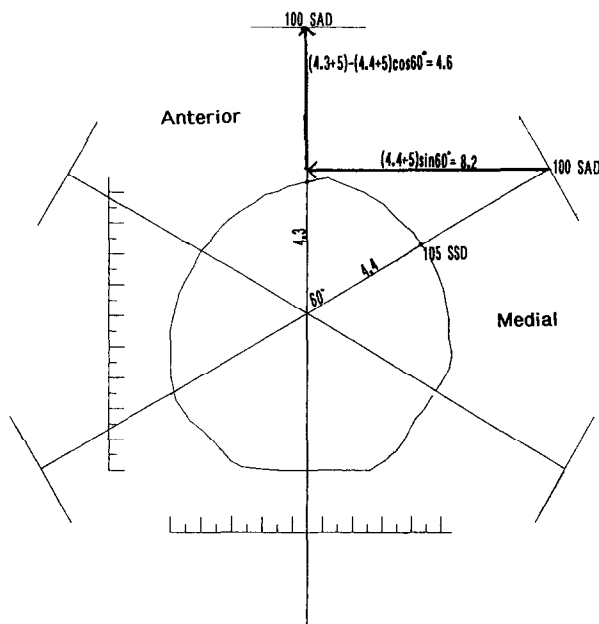


Fig. 10. Geometry of the central transverse plane through the lower leg. The relative locations of the 100-cm isocenters for the anterior and the left anterior oblique field are shown. The calculated displacement between the two provides the couch translations necessary to rapidly set up the oblique field after treating the anterior field.

A clinical case of KS demonstrated how the 5-MeV electron beam provided a dose distribution acceptable to the radiation oncologist using the six-field technique. The treatment plan was generated in a transverse plane about midway through the lower leg. The leg at that location had a mean diameter of 9 cm and was close to cylindrical. Superior and inferior transverse planes with substantially different mean diameters, 11 cm and 8 cm, respectively, also had acceptable dose distributions. The patient's treatment set-up was quick and relatively simple, as the technique required no abutment of the six fields.

The use of the six-field electron technique set-up for treatment of KS can prevent the edema associated with photon irradiation. This technique could be utilized in other whole-limb cancers in which cutaneous tissue is involved.

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