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Electron Beam Therapy with Linear Accelerator
Physical Considerations for Total Skin Irradiation Therapy

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リニアアクセラレータによる電子線治療
全身表面照射についての物理的考察

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Varian 6 MeV リニアアクセラレータの電子線を用いて全身表面照射を行う場合の物理的条件について検討した．

1．体表面に比較的均等照射を行うには，直角4方向から照射することが望ましい．この際オーバーラップした部位は線量が180%に達するが，全照射量が1,000～1,500Rなので臨床上は差支えない．

2．電子線のエネルギーを落すには種々の厚みのアクリル板を電子線の出口部に設けることによつて可能である．この際，X線による汚染が多くなる．一方 Beam Bending Magnet の電流を調節することによつて4MeV までエネルギーを下げうる．

3．X線汚染量は，焦点ファントーム間距離420cmで水ファントーム内5cmの位置で電子線量の0.7%である．しかし0.5cm，1cm厚みのアクリル板により電子線のエネルギーを減弱せしめるとX線量はそれぞれ2.2%，4.6%に増加する．この量は電子線全身照射に際しては無視し得ない．

Malignant skin invasion such as mycosis fungoides or lymphoma cutis is radiosensitive, but the total skin irradiation is required for its therapy. High energy electrons are considered to be most suitable for this treatment modalities. The high energy electrons produced by linear accelerator[5] or Van de Graaf accelerator[4] were used successfully because of their high output for the purpose of total skin surface irradiation at a long distance.

C.J. Karzmark[1] reported the physical properties of the medical linear accelerator at Stanford University, and two field technique were applied to obtain the uniform distribution of electrons. L. Szar[3] interposed a carbon deccelerator of a various thickness outside of the end-window of the accelerator to reduce the eletron energy. J.H. Grollman, Jr.[2] reported that homogenity of the dose distribution in a field of 6 feet in diameter at 6 meters from the unit was only ± 6 per cent for Varian linear accelerator. Patients were irradiated anteriorly and posteriorly and sometimes lateral projections were added.

J.H. Grollman, Jr.[2] reported 37 cases with exfoliative erythroderma, mycosis fungoides, lymphosarcoma treated by this method with complete control or satisfactory palliation.

In this report some physical measurements were performed for which we consider to be necessary

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from the clinical observations of the total skin irradiation therapy.

Treatment Techniques

A patient was kept standing against the wall. Entire body except head and face which were protected with a lead helmet was exposed to the electron beam produced by Varian linear accelerator.

Three physical conditions must be considered.

1) Homogeneous dose distribution over the total skin area. J.H. Grollman, Jr.[2] used anterior and posterior irradiation, but the lack of the electron at the lateral surfaces could not be neglected according to our experiences.

2) The energy range of electrons produced by linear accelerator is fixed in the normal operating conditions. There are two ways to reduce the energy of available electrons. The one is to change the current of the electron bending magnet (beam bending method), a flux of the energy lower than 6 MeV can be obtained. The other is to use of deccelerator such as acrylate plate of various thickness at the end-window of linear accelerator (absorber method).

3) X-ray contamination should be negligibly low. Total dose of x-ray absorbed by the patient during the electron exposure must be estimated.

Homogenity of dose in electron flux

At the focus-wall distance of 450 cm, the maximum dimension of radiation field is about 120 cm X 144 cm for lateral and longitudinal dimensions. Dose distribution within this field was isocentric and the 80 per cent range of the maximim dose was 120 cm in diameter.

Homogenity of dose measured on the surface of the body section phantom

Anterior and posterior projections result the lack of dose at the lateral surface of the body. In order to compensate this lack of dose, lateral projections should be added. Comparing the Fig. 1 and 2, anterior

Fig. 1 Radiography exposed to electrons from Linac(6MeV, no absorber) in the body section phantom. F.F.D. 440cm, Field size 70×150cm

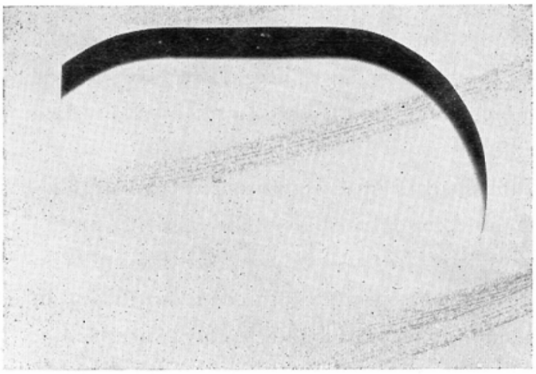
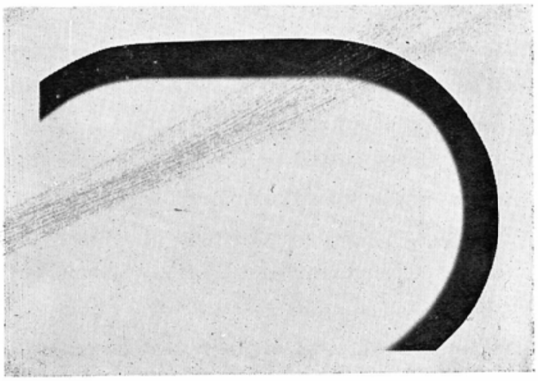


Fig. 2 Radiogrophy exposed to electrons from Linac(6MeV, no absorber) in the body section phantom. Front and lateral exposures. F.F.D. 440cm, Field size 70×150cm



and lateral projections give the relatively homogeneous in the blackning of the films respective to the density and penetration of the electrons. Dose distributions measured by filmmetry interposed in the body phantom are shown in Fig. 3 and 4 which correspond to Fig. 1 and 2. Densities of the films at the distances of 0.5 cm, 1.0 cm, 1.5 cm and 2.0 cm from the surface were measured with a film scanner. From

Fig. 3 Dose distributioon of Electron from 6MeV Linear Accelerator. (measured with films of Fig 1)

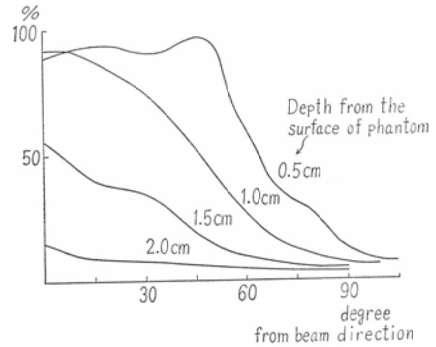
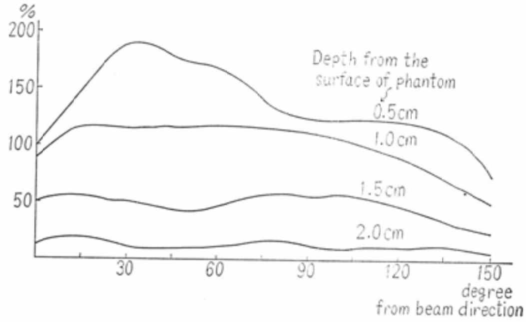


Fig. 4 Dose distribution of Electron from 6MeV Linear Accelerator. (measured with films of Fig. 2)



the standard curve obtained by the exposre to 6 MeV electron, density curves of the films were converted to the radiation dose and the per cent to the frontal, 0.5 cm depth dose was calculated. The abscissa was taken for the angles from the directions of the electron beam. Over 45 degrees the dose was sharply decreased for anterior projection in Fig. 3, at 90 degrees the dose at the 0.5 cm from the surface was 8 per cent of the maximum, so that even when anterior and posterior projections are added, it weighs only to 16 per cent. Furthermore the lack of the penetrations of the electrons can not be neglected. Fig. 4 shows the dose distributions of the anterior and lateral projections, here around 45 degrees the dose resulted the highest level and it weighs 180 per cent of the dose at 0.5 cm from the surface at the point of 0 degree. But the penetration of the electron are satisfied.

Method of Reducing Elctron Energy

Reducing the current of the beam bending magnet to 22 A, the electron energy was reduced to about 4 MeV as shown in Fig. 5. Usually the current of the beam bending magnet was set to 58 A but it is

Fig. 5 Depth dose curve of Electrons from 6 MeV Linear Accelerator

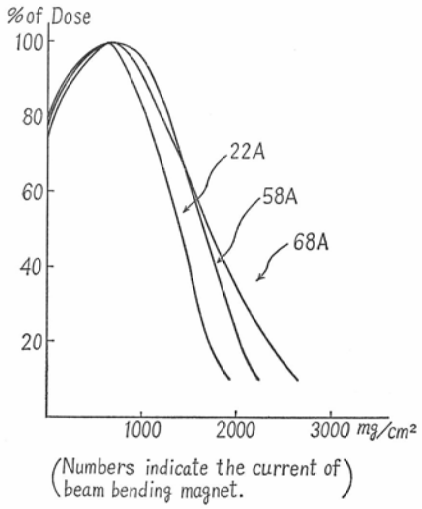
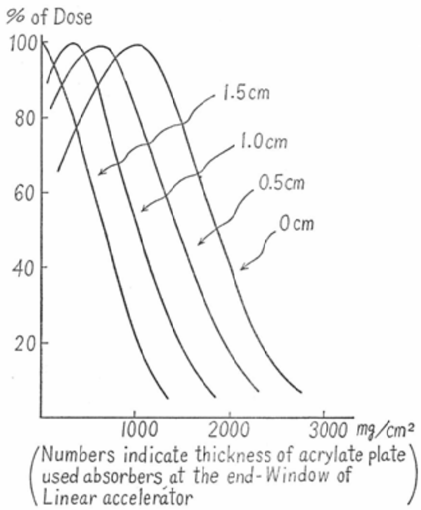


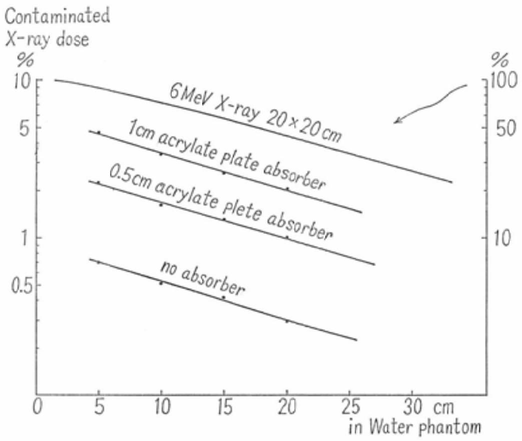
Fig. 6 Depth dose curve of Electrons from 6 MeV Linear Accelerator



possible to raise up to 68 A. Differences in depth dose of electrons obtained by these magnet currents are not so remarkable.

By the absorber method, depth dose curves were obtained as shown in Fig. 6. Electron energy at the distance of 440 cm in air was about 6 MeV. Eighty per cent range of the maximum dose were 1500 mg, 1000 mg, 700 mg and 300 mg per square cm respectively to the thickness of the acrylate absorber 0 cm, 0.5 cm, 1.0 cm and 1.5 cm. This method was rather easier than the beam bending method, but resulted the higher x-ray contaminations.

Fig. 7 Contaminated x-ray dose



X-ray Contaminations

Experiments were designed as follows: Focus-chamber distance was taken 420 cm, field size was 150 × 120 cm. Radocon ionization chamber (No. 606) was moved from 5 cm to 20 cm from the surface of the phantom parallel to the electron beam directions. Dose of electrons were measured by Smplex ionization chamber (for soft Radiation, shallow type). Dose of x-rays measured by Radocon ionization chamber were shown in per cent dose of electrons. As shown in Fig. 7, when 0.5 and 1.0 cm of acrylate absorbers were placed at the end-window of linear accelerator, the amount of x-ray contaminations were raised to 2.2 and 4.6 per cent respectively at the 5 cm in water phantom. Without absorber, x-ray contamination was only 0.7 per cent. Three depth dose curves of contaminated x-rays were shown in Fig. 7. As a reference the depth dose curve for 6 MeV x-rays of 20 × 20 cm field size was shown, where the almost same depth dose could be obtained between these 4 curves.

Discussion

One of the profit of the linear accelerator is the electron therapy for large field, even including the total body surface. Experiments have shown that the 4 directional irradiations are desired to cover the total body surface.

Reducing the electron energy be acrylate absorbers results high x-ray contamination, which is produced by collimating system and acrylate absorber. Suppose that 1000 rad is delivered to the skin by 4 directional method and that 1 cm thickness of acrylate plate is used to reduce electron energy. About 200 rad of x-ray will be delivered to the total body. This will result the hematopoietic damage of patients[2]. As fully discussed by J.H. Grollman, Jr.[7][2], X-ray contaminations was reduced to 0.3 per cent by adjustment of the magnetic field, which results in a lowering of electron energy to 3 MeV.

We can expect about 4 MeV electrons by the beam bending method. Selection of the energy of 6 MeV or 4 MeV seems to be not critical in the clinical practice. But 2 or 3 MeV electrons might have definite clinical indication. So easy controllable equippment for this purposes might be desired.

Another requirement is directed to higher enrgy. Some sort of skin involvement needs more penetration of electrons than the range of 6 MeV of electron.

Homogenities of dose distribution on the toal body surface is hardly achieved. Overlapping of dose arised from frontal and lateral projections results more than 150 per cent of dose at the width of 30 degrees, but usually 1000 rad to 1500 rad are delivered for treatment so that this inhomogenities does not result serious conditions. Hidden areas such as axillary area, internal surfaces of both thigh, perineal area are difficult for surface irradiation. Therefore, additional irradiations using small fields might be desired.

Summary

A physical design for total skin irradiation therapy with a linear accelerator was presented. Homogenity of the dose distribution over the total skin area was achieved by four directional irradiations.

Reduction of the electron energy was obtained by using acrylate absorber attached at the end-window of the linear accelerator, but about 5 per cent of x-ray contamination was resulted, which is not negligible amount for total body injury. By the beam bending method, the electron energy could be reduced to 4 MeV from 6 MeV.

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