The Dosimetric Data of 10 MV Linear Accelerator Photon Beam for Total Body Irradiation

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Purpose : This study was to obtain the basic dosimetric data using the 10 MV X-ray for the total body irradiation.

Materials and Methods : A linear accelerator photon beam is planned to be used as a radiation source for total body irradiation (TBI) in Chonnam University Hospital. The planned distance from the target to the midplane of a patient is 360cm and the maximum geometric field size is 144cm x 144cm. Polystyrene phantom sized $30\times30\times30.2cm^3$ and consisted of several sheets with various thickness, and a parallel plate ionization chamber were used to measure surface dose and percent depth dose (PDD) at 345cm SSD, and dose profiles. To evaluate whether a beam modifier is necessary for TBI, dosimetry in build up region was made first with no modifier and next with an 1cm thick acryl plate 20cm far from the polystyrene phantom surface. For a fixed sourec-chamber distance, output factors were measured for various depth.

Results : As any beam modifier was not on the way of radiation of 10MV X-ray, the d_{max} and surface dose was 1.8cm and 61%, respectively, for 345cm SSD. When an 1cm thick acryl plate was put 20cm far from polystyrene phantom for the SSD, the d_{max} and surface dose were 0.8cm and 94%, respectively. With acryl as a beam spoiler, the PDD at 10cm depth was 78.4% and exit dose was a little higher than expected dose at interface of exit surface. For two-opposing fields for a 30cm phantom thick phantom, the surface dose and maximum dose relative to mid-depth dose in our experiments were 102.5% and 106.3%, respectively. The off-axis distance of that point of 95% of beam axis dose were 70cm on principal axis and 80cm on diagonal axis.

Conclusion:

1. To increase surface dose for TBI by 10MV X-ray at 360cm SAD, 1cm thick acrylic spoiler was sufficient when distance from phantom surface to spoiler was 20cm.
2. At 345cm SSD, 10MV X-ray beam of full field produced a satisfiable dose uniformity for TBI within 7% in the phantom of 30cm thickness by two-opposing irradiation technique.
3. The uniform dose distribution region was 67cm on principal axis of the beam and 80cm on diagonal axis from beam axis.
4. The output factors at mid-point of various thickness revealed linear relation

with depth, and it could be applicable to practical TBI.

Key Words : Total body irradiation, 10MV X-ray, Dosimetry, Spoiler

INTRODUCTION

Sometimes we need use of a very large unusual radiaiton field such as total body irradiaiton (TBI) for the preparation of bone marrow transplantation (BMT). For such total body treatments, it would seem to be best to use a large field enough to cover the total body of a patient.

Several methods have been proposed to make a large field for TBI by several authors. Some dedicated units having single, dual or multiple sources were specifically designed for treatment with large fields[1-5]. Many facilities designed for conventional radiation treatment were also modified to produce very large fields. Technique of sweeping beam[6] or patient translation[7] with small field were also introduced. Facilities for conventional treatment purposes were used with unconventional geometry to provide the large field desirable for TBI[8-11].

Because the radiotherapy facility is usually unique to each hospital and the technique for TBI should be affected by the facility, the technique associated with total body radiotherapy should be chosen appropriate to the condition of the each institute and the patient, and the irradiation time must be considered. Conventionally, one of the most common technique to obtain a sufficiently large field has been to increase the treatment distance[1-5]. The large field and treatment geometry used in TBI needs special dosimetry different from conventional radiotherapy. Even though data in similar situation are available, application of the data could introduce fatal results because the data necessary for TBI were obtained in different situaton. Therefore, a basic dosimetry necessary for the TBI has to be made[1].

The intents of this report are to find the appropriate procedures of producing the very large field needed for TBI and to obtain the basic dosimetric datas with 10MV X-ray of linear accelerator (CLINAC 1800, Varian Co., USA) unit in Department of Therapeutic Radiology, Chonnam University Hospital.

MATERIALS AND METHODS

A facility available for total body irradiation (TBI) at Department of Therapeutic Radiology, Chonnam University Hospital is a linear accelerator (CLINAC 1800, Varian Co., USA). At 100cm SAD, maximum field size and diameter of the circular field by the fixed primary collimator of the linear accelerator were $40\times40cm^2$ and 49cm, respectively. The radiation considered in this study was 10MV X-ray from the accelerator.

For dosimetry, polystyrene phantom, an ionization chamber and an electrometer were used. The polystyrene phantom was consisted of several sheet of $30\times30cm^2$ area and with various thickness from 0.1cm to 5.1cm, and its total thickness was 30.2cm, that would close to lateral thickness of adult waist. A parallel plate ionization chamber (PS-033, Capintec Inc, USA) held to a sheet of polystyrene 5.1cm thick was connected to an electrometer (Model 192, Capintec Inc, USA). For the purpose increasing surface dose, one sheet of acrylic plate of 1cm thickness, which could fully cover a entire field for TBI was used.

For the linear accelerator to provide a large field for TBI, the gantry was set in order that direction of phantom beam axis was horizontal (Fig. 1). It is planned that the distance from X-ray target to a point put on the sagittal mid-plane of a patient to be treated by TBI would be 360cm. At the distance geometric field size of the accelerator and diameter of the circular field by its fixed primary collimator were $144\times144cm^2$ and 176cm, respectively.

The polystyrene plates were put on a wooden table. Height of the phantom was adjusted using an acrylic plate, 1cm thick, and several sheets of styrofoam plate. The polystyrene plate holding the parallel plate ionization chamber was vertically set up for the window of the ionization chamber to face the radiation source. For measurement of dose at exit surface and in the region close to the surface, the front window of the parallel plate chamber faced to a wall near the phantom. Some thin plates such as 0.1cm to 0.5cm thickness were put in vicinity of the sheet holding the ionization chamber. The other sheets were set next to the thin plates. To verify the fixed SSD, a piece of green cloth tape was adhered on the acrylic plate at the front of the phantom. Percent depth dose (PDD) for a full field at 345cm SSD were measured in a polystyrene phantom of a cross section of $30 \times 30cm^2$ smaller than radiation field.

Depth dose on beam axis relative to mid-point dose of a 30cm thick phantom with spoiler for two parallel opposing field technique would be evaluated.

For the purpose changing depth of measured point, the sheet of polystyrene plate holding the parallel plate chamber was exchanged with some sheets of thin plate. The thickness of this plates was equal to the change of depth of measurement point. Position of remaining sheets of plystyrene was fixed.

To evaluate whether spoiler is necessary or not for TBI, the depth doses in buildup region, at first, were measured without spoiler. To increase the surface dose, a sheet of acrylic plate of 1cm thickness was vertically set up 20cm apart from the surface of the polystyrene phantom. It was assumed that this separation between the phantom and spoiler would be close to actual situation of TBI because a patient would be shifted inwards from the lateral edge of a couch.

When dose profiles at depth of dose maximum for 360cm SAD were measured, the collimator angle was set in order that the principal axis or diagonal axis of radiation field was horizon. The shift of measurement point was made by translation of the phantom and/or the table. At 360cm SAD, the output factors per monitor unit (MU), in situation including spoiler were measured at several depths.

RESULTS

The percent depth curves on buildup region of fields without and with spoiler are compared in Fig. 2. In case without spoiler, the depth of dose maximum and surface dose are 1.8cm and 61%, respectively. In other case with spoiler, the depth of dose maximum and surface dose are 0.

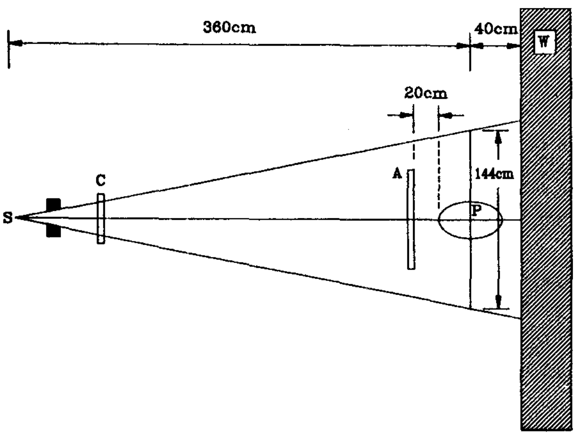

Fig 1. Schematic diagram of beam alignment for total body technique. Abbreviations used are:A, 1cm thick acrylic plate; C, compensator tray; P, patient; S, radiation source; W, treatment room wall

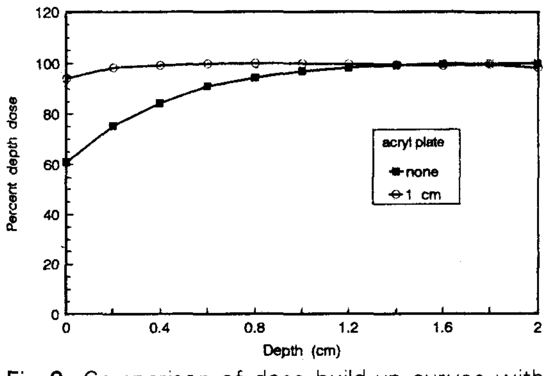

Fig 2. Comparison of dose build-up curves with or without 1cm thick acrylic plate as spoiler separated by 20cm from the phantom surface.

8cm and 94%, respectively. The surface dose of no-spoiler field was too low to use such field for TBI while that of spoiler field was high enough for TBI.

The percent depth dose gradually decreased with increasing depth under the depth of dose maximum, and measured as 78.4% at 10cm depth, 56.2% at 20cm depth, 42.9% at 30cm depth (Fig. 3). The dose in the interface region of exit surface increased with depth contrary to general property of depth dose curves. The increase of exit dose is seemed to be caused by backscatter from the adjacent wall.

Fig. 4 shows a dose profile curve in a 30cm thickness of phantom for parallel opposed fields normalized to midpoint value. The surface dose and maximum dose are 102.5% and 106.3%, respectively. Those values imply that dose distribution of 10MV X-ray for thickness of 30cm or less for TBI at 360cm SAD would be uniform in whole field. Even though the thickness is increased by a little, the the dose uniformity would be kept at large.

The dose distribution in beam profiles along the principal and diagonal axis at the 1cm depth revealed that 100% isodose line was within 67cm from central axis in principal plane and 80cm in diagonal axis, respectively(Fig. 5).

The output factor measured at mid-point of variable thickness showed linear relation with depth ranged from 6 to 15cm (Fig. 6). The out put factor expressed by dose per monitor unit

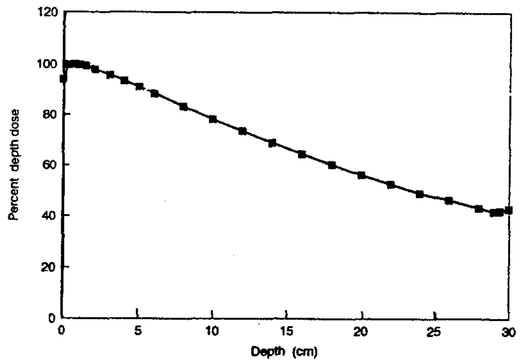

Fig 3. Percent depth dose curve along the central axis at 345cm SSD and 144×144cm^2 field size.

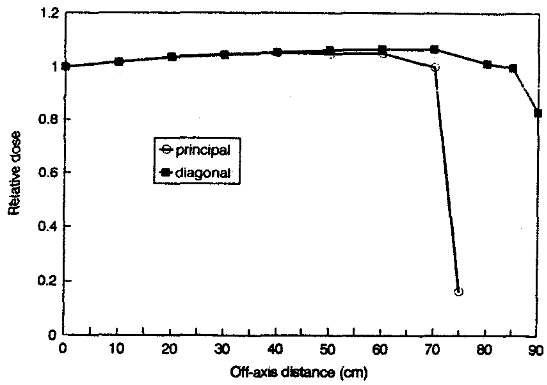

Fig 5. Beam profiles along the principal and diagonal axis at 360cm SAD.

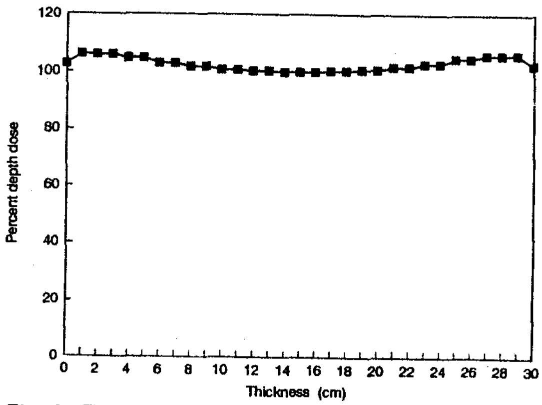

Fig 4. The relative absorbed dose to that of the midpoint of 30cm phantom thickness for bilateral opposing fields.

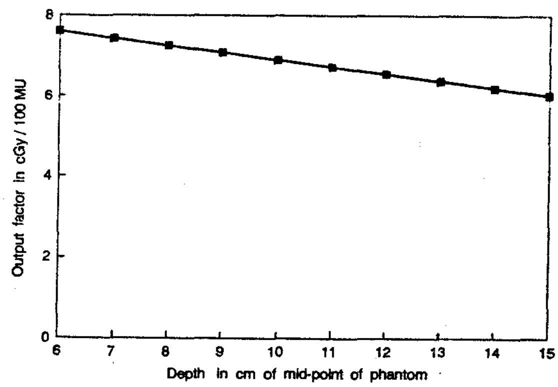

Fig 6. Output factors measured at mid-depth of various phantom thickness at 360cm SAD.

(MU) was related to the thickness T as follow ; $D/MU = -0.00178 \times (T/2) + 0.08676$

DISCUSSION

The large field irradiation technique is needed for the total body irradiation (TBI) preparing the bone marrow transplantation (BMT) or half-body irradiation which can be indicated for the palliation of widespread metatatic bone pain[12]. The conventional method can not be used directly and must be modified according to the individual institute and treatment equipments. For the ideal therapy some physical parameters such as the beam energy, treatment distance, dose rates and treatment ports should be considered and optimized for each individual institution[4]. Kim et al[13]. also emphasized the need for a system of uniform dose reporting and for uniform dose prescription in TBI through a survey of TBI techniques.

The large field size can be obtained by the long treatment distance using conventional treatment units. A typical TBI treatment uses a horizontal beam with the patient placed at an extended distance, usually 3-4m, in order to cover his entire body with the usual radiation ports. According to the report No. 17 of task group 29 (TG 29)of AAPM (American Association of Physicist in Medicine)[4], the needed physical parameters to make the ratio of peak dose to midplane dose on the central ray at the 30cm patient thickness within the 15% range, were the high energy above 6 MV and the long distance above 300cm SSD. The parameters, 10 MV energy and 360cm SAD of geometric alignment in this study, were verified to be appropriate to obtain the dose uniformity within 7%.

The Minnesota group have obtained satisfactory BMT results after conditioning their patients with high dose rate and low-total-dose radiation in conjunction with high dose cyclophosphamide[14]. At present, no consensus has been reached as to which TBI regimen is the most effective in reducing the target cells and decreasing the incidence of acute and late effects of treatment[15].

Determination of absorbed dose in TBI by photons requires the same type of data as used in regular radiotherapy techniques but may require specific corrections to long-distance beam geometry. Since the treatment field extends beyond the edge of the patient when treating total body, the effective field is smaller than the overall field. In this case, the phantom dimensions, rather than collimator field size, determine the effective field size used to determine the appropriate TAR's or other depth dose data[16]. Faw and Glenn[17] have shown that the dose distribution is a function of the field size or the phantom size, whichever smaller.

The phantom should be approximately equivalent in size to a typical patient to provide the same scatter at the point of measurement as the patient. For low energy megavoltage beams different sizes of phantoms may have to be used since scatter will depend on the patient's dimension and shape to a significant degree. A single phantom that is equivalent to an average patient may be used for 10MV or higher-energy X-rays, since with higher energies change in scatter with field size is relatively less important[18]. The TG 29 rcommended that the minimum phantom size of $30 \times 30 cm^2$ was required for the large field dosimetry. According to this recommendation we used the $30 \times 30 \times 30.2 cm^3$ polystyrene phantom for this study.

Some dose ratio parameters, such as tissue air ratio (TAR), tissue maximum ratio (TMR), tissue phantom ratio (TPR), are normally considered to be distance independent. However, there is evidence that extreme deviations from conventional treatment distance results in distance dependent changes in these quantities[20]. Furthermore, the conversion of percentage depth dose data from one distance to another using the Mayneord factor may also be in error by 2 to 6%[19]. Therefore central ray measurement should be performed for the large field treatment geometry[4,20]. The authors performed dosimetry at 360cm SAD and geometrical field size $144 \times 144 cm^2$. In this study percent depth dose gradually decreased with increasing depth. For the builateral total body technique we obtained mid-point dose of phantom according to the thickness, and revealed that the uniformity of dose distribution was within 7% at the prescription point.

If high energy X-rays from a linear accelerator are used, some consideration should be given to the effects of the low dose in the build-up region. The dose in the build-up region is strongly dependent on the treatment geometry (field size, SSD) and any intervening materials. The dose in the build-up region can be increased by the addition of a beam spoiler such as a plate of plastic near the skin surface, hence, measurements should be made under these conditions[4]. In this study the surface dose was increased from 61% to 94% and d_{max} point shallowed from 1.8cm to 0.8cm in depth by the appliction of 1cm acrylic plate which was placed at 20cm in front of phantom. There are presently no data indicating clinical problems because of this effect[4].

Khan et al[18] compared beam profiles at a normal distance and at the TBI distance, and showed that the beam profile is more or less unchanged except for geometric magnification. When linear accelerators are used with the collimator rotated such that the patient lies along the field diagonal, there may be a large dose decrease toward the field corners since the beam flattening filters usually have circular symmetry and are often designed to flatten the field along the two principal planes but not along the diagonals[11]. For such situations, it may be necessary to design special filters to achieve an adequate flatness or give a special attention to the set-up position of the patients to fit within the uniform dose region of the beam[11]. Ideally, dose profile should be measured at the treatment distance in a full water phantom[4]. But we had the limitation in the dosimetry system we checked the beam profile using the polystyrene phantom. The safe area for the uniform dose distribution (within 100% dose point) was within 67 cm in the principal axis and 80cm in the diagonal axis from the central axis, respectively.

We measured output factors at the mid-depth of phantom at 360cm SAD and geometrical field size $144 \times 144 cm^2$ in polystyrene phantom. The output factor measured at mid-depth of variable thickness revealed linear equation.

CONCLUSION

1. The 10MV X-ray produced the dose uniformity within 7% in the phantom thickness of 30cm by the bilateral total body technique.
2. With the application of beam spoiler(20cm in front of phantom), D_{max} point was shallowed from 1.8cm to 0.8cm and surface dose increased from 61% to 94%, respectively. Therefore it is recommnended to apply beam spoiler in TBI.
3. In beam profile the off-axis distance of 100% isodose curve was 67cm in principal axis and 80cm in diagonal axis from the center, respectively. This difference of dose distribution should be considered in practical TBI.
4. The dose distribution in TBI is affected by various factors, so we checked the absolute dose rate directly. The output factors at mid-point of various thickness revealed linear equation, and it could be applicable to practical TBI.

The basic beam dosimetric data for TBI in this study was compatible with the physical parameters of AAPM No. 17, and authors think that these basic dosimetric data could be applicable to practical TBI.

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=국문 초록=

전신 방사선조사를 위한 10MV 선형가속기의 선량측정

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연구목적 : 전남대학교병원 치료방사선과에서 가동중인 10MV X-ray를 이용하여 전신 방사선 조사에 필요한 기본적인 선량측정자료를 얻고자 하였다.

대상 및 방법 : 환자 전신이 포함될 수 있는 대형조사면을 얻기 위하여 collimator를 완전히 개방하여 조사방향이 수평이 되게 gantry각을 맞추었다. 방사선 선원에서 환자 중심축까지의 거리가 360cm일 때 최대 기하학적 조사면은 144cm×144cm이었다. Polystyrene팬텀과 평행평판형 전리함을 이용하여 깊이선량율과 principal 및 diagonal axis에서 측방선량분포를 측정하였다. 또한 1cm두께의 아크릴판을 팬텀의 전면에서 20cm 떨어진 위치에 놓고 표면 선량의 증가와 최대선량점(d_{max})의 변화를 측정하였다. SAD 360cm에서 팬텀의 중심에 측정기 위치를 고정시키고 팬텀의 두께를 12cm에서 30cm까지 변화시키면서 MU당 선량율을 측정하였다.

결 과 : SSD 345cm, 조사면 크기 144cm×144cm의 조건에서 깊이선량율은 10cm 깊이에서 78.4%였고, dmax점은 1.8cm이었다. 1cm두께의 아크릴판을 spoiler로 팬텀에서 20cm 띄우고 사용했을 때 dmax점은 1.8cm에서 0.8cm으로 이동하였고, 표면선량은 61%에서 94%로 증가하였다. 평행 2문 조사시 30cm두께의 팬텀에서 선축상 선량분포의 차이는 7%이내였다. 100% 선량점의 선축이탈거리는 principal axis에서 67cm, diagonal axis에서 80cm이었다. 팬텀의 중심에서 측정된 출력계수로 MU당 선량은, (Dose/MU)=−0.00178×(T/2)+0.08676 (T:팬텀 두께(cm))로 표현되는 직선의 관계식을 나타내었다.

결 론 : 1) 좌우 대향 2문조사 방법으로 30cm두께의 팬텀에 10MV X-ray를 조사하였을 때 선량분포의 차이는 7%이내로 만족스러운 결과를 보였다. 2) 고에너지 광자선으로 전신방사선 조사시 표면선량 증가를 위하여 beam spoiler의 사용이 필요할 것으로 사료된다 3) 측방선량분포곡선에서 principal 및 diagonal axis에 따른 선량분포의 차이가 있어 환자 치료시 고려되어야 할 것으로 생각된다 4) 전신방사선조사시 선량분포는 여러 가지 요인에의하여 달라질 수 있기 때문에 직접적인 방법에 의해 측정된 MU당 선량은 깊이와 직선의 관계식을 보여 실제 치료에 적용될 수 있을 것으로 생각된다.

본 연구에서 얻어진 전신 방사선조사에 관한 기본적 선량측정자료는 AAPM보고서 No. 17에서 권장된 범주에 들었으며 향후 임상에 이용될 수 있을 것으로 생각된다.

주요어 : 전신 방사선조사, 10MV X-ray, Dosimetry, Spoiler