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Dose Distribution of Co-60 Photon Beam in Total Body Irradiation*

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Abstract. Total body irradiation is operated to irradicate malignant cells of bone marrow of patients to be treated with bone marrow transplantation. Field size of a linear accelerator or cobalt teletherapy unit with normal geometry for routine technique is too small to cover whole body of a patient. So, any special method to cover patient whole body must be developed. Because such environments as room conditions and machine design are not universal, some characteristic method of TBI for each hospital could be developed. At Seoul National University Hospital, at present, only a cobalt unit is available for TBI because source head of the unit could be tilted. When the head is tilted outward by 90°, beam direction is horizontal and perpendicular to opposite wall. Then, the distance from cobalt source to the wall was 319 ㎝. Provided that the distance from the wall to midsagittal plane of a patient is 40㎝, nominal field size at the plane(SCD 279㎝) is 122㎝×122㎝ but field size by measurement of exposure profile was 130㎝×129㎝ and vertical profile was not symmetric. That field size is large enough to cover total body of a patient when he rests on a couch in a squatting posture. Assuming that average lateral width of patients is 30㎝, percent depth dose for SSD 264㎝ and nominal field size 115.5㎝× 115.5㎝ was measured with a plane-parallel chamber in a polystyrene phantom and was linear over depth range 10~20㎝. An anthropomorphic phantom of size 25㎝ wide and 30㎝ deep. Depth of dose maximum, surface dose and depth of 50% dose were 0.3㎝, 82% and 16.9㎝, respectively. A dose profile on beam axis for two opposing beams was uniform within 10% for mid-depth dose. Tissue phantom ratio with reference depth 15㎝ for maximum field size at SCD 279㎝ was measured in a small polystyrene phantom and was linear over depth range 10~20㎝. An anthropomorphic phantom with TLD chips inserted in holes on the largest coronal plane was bilaterally irradiated by 15 minute in each direction by cobalt beam aixs in line with the cross line of the coronal plane and contact surface of sections No. 27 and 28. When doses were normalized with dose at mid-depth on beam axis, doses in head/neck, abdomen and lower lung region were close to reference dose within ± 10% but doses in upper lung, shoulder and pelvis region were lower than 10% from reference dose. Particulaly, doses in shoulder region were lower than 30%. On this result, the conclusion such that under a geometric condition for TBI with cobalt beam as SNUH radiotherapy departement, compensators for head/neck and lung shielding are not required but boost irradiation to shoulder is required could be induced.

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Introduction

Total body irradiation (TBI) with megavoltage photon beams is frequently used to destroy the bone marrow and leukemic cells, to immunosuppress patient prior to receive a bone marrow transplant[1-5] (BMT), or both.

TBI is also made complex by the fact that the maximum field size for most treatment units, is too small to encompass the patient's full length on the patient support system. The ability to provide these very large fields and the corresponding delivery of a specified dose have been challenging for the medical radiation physicists.[6-18] Because of the constraints of radiotherapy apparatus and treatment room, the techniques associated with total body radiotherapy have been as varied as the number of radiation oncologists using them. The diversity in the production of large fields to be used for TBI techniques means that the dosimetric data required would vary from one institution to another. These mean that standard calculation routines could not be applied to TBI.

Numerous methods have been introduced to make large field for TBI. Some dedicated facilities having single, dual or multiple sources were specifically designed for treatment with large fields.[6-10] Many facilities designed for conventional radiation treatment were also modified to produce very large fields.[9-12] Facilities for conventional treatment purposes were used with unconventional geometry to provide the large field desirable for TBI.[9,10,13-18]

Co-60 gamma ray or megavoltage x-ray beams are generally used to get a large field for TBI. Some compensators for thin parts and lung, low density tissue, are used to meet the uniform dose distribution over the whole body of patients. In Seoul National University Hospital a cobalt unit is the only facility available for total body irradiation in both room condition and mechanical design. Even the cobalt unit should be modified because of a beam stopper mounted to the unit. The authors will describe a specific geometry for TBI proper to their own real situation and present dosimetric results of TBI field of cobalt beam for such geometry.

Whether the compensators are required to get a uniform dose distribution over the whole body of a patient or not should be discussed with a base on data measured in a phantom similar to human body under the condition without any compensator. On such a purpose, dose distribution on the largest coronal plane of an anthropomorphic phantom was measured using TLD.

Meterial and Methods

A maximum field size of a cobalt unit(Picker C-9, USA) at Seoul National University Hospital is 35cm×35cm at isocenter (SAD=80cm). A fixed beam stopper is attached to the unit and imposes restrictions on the extention of SSD and, as the result, on the expansion of the maximum field size. So a unconventional geometry is required to get a large field size adequate for TBI. Fortunately, the cobalt unit has a very useful mechanical function for TBI such as tilting the head containing a radioactive source. The tilting angle of the head is greater than 90° outward. When the head is tilted by 90°, the direction of radiation beam is perpendicular to the opposite wall. Then, the distance from the cobalt sorce to the opposite wall is 319cm(Fig. 1) and the maximum field size is 140cm×140cm on the wall surface. Even though other tilting angle can be set to get a more large field, 90° as head tilting angle is

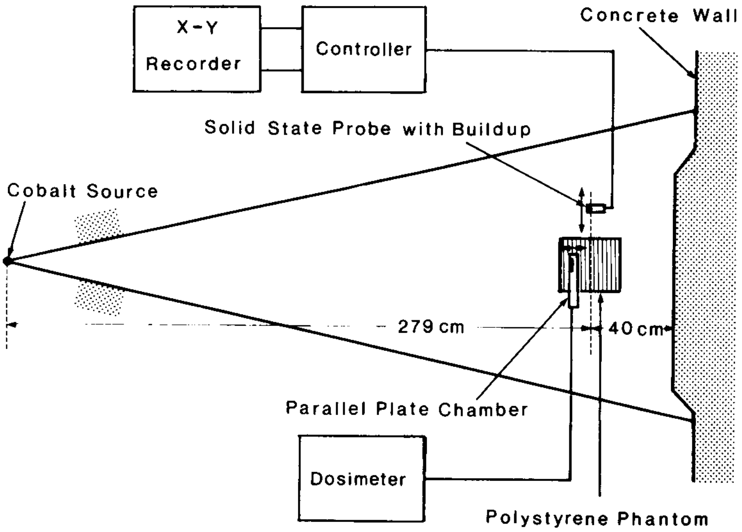

Fig. 1 Geometry for total body irradiation and dosimetry setup. Field size was of maximum. PDD was Measured for 264cm(279−15) SSD and TPR was measured for reference depth 15cm. Exposure profile was scanned at SCD 279cm.

preferable to get a TBI geometry because there is no reference plane helpful to set the position of a patient for a tilting angle different from 90°. The wall surface is not flat and parts of the wall at both lateral sides of the field are caved backward by 10cm.

A patient to be treated by TBI should be put at a some distance from an wall opposite to a radiation source and irradiated in a squatting posture with two lateral fields with equal weight. By considering the patient-to-wall distance, it would be desirable that a variation of the distance be small. So, the fixed distance from the sagittal plane to cobalt source or to the opposite wall could be preferred to the fixed SSD. It was assumed that the mid-sagittal plane of a TBI patient should be set at 40cm from the wall surface and the patient should be bilaterally irradiated. Then, the distance from the source to the sagittal plane of a patient is 279cm, and the geometric maximum field size at the sagittal plane is 122cm×122cm and diagonals 172cm.

Under the above described geometric condition, the dosimetry for cobalt beam was made. For total body irradiation, a patient treated should be encompassed by a uniform radiation field. Exposure distribution in air on a plane 40cm far from the wall was scanned using a solid state detector (Therados, Sweden) with a mix-DP buildup on a servo arm controlled by the control unit of 1 dimensional water phantom(Therados LSC-2, Sweden). The scanning range of the servo arm is 50cm that is too short to cover a side of the TBI field. To get an off-axis ratio of exposure in air, scan was made dividing 3 parts on a horizontal line. For such purpose the servo arm was laterally shifted by a scanning range, 50cm. The profile was recored on a paper by XY recorder. After scanning on a horizontal line, the servo arm was shifted up or down by 10cm to cover full field and some out-field.

For calculation of exposure time, the exposure rate in air or dose rate in tissue at a given point should be known. Above described TBI technique is not of fixed SSD but of fixed source-to-sagittal plane distance. To get a dose rate at the sagittal plane of a patient, TPR or TMR value is required. Because the thickness of the part of patient body on or near beam axis is generally greater than 20cm, TPR with reference depth 15cm was measured using a parallel plate chamber(Capintec PS-033, U.S.A.) and an electrometer(Keithley 35616, U.S.A.). To select the size of a phantom replacing a patient, however, is very confusing because the patient should be fully covered by the field size and body dimension depends on the patient. A polystyrene phantom with a dimension 25cm×25cm×30cm was used for dosimetry, even though the size is not large enough to replace a patient. Lateral thickness of the most patient is very close to 30cm, anterior-posterior thickness is less than 25cm and height is far longer than 25cm. Even though the phantom dimension is less than the patient dimension, it could be replaced as a patient, because scatter radiation from the part of body far from measuring point would not significantly contribute to dose.

Percent depth dose(PDD) for SSD=264cm that is 15cm upward from the reference plane to be on mid-sagittal plane of a patient was measured using the parallel plate chamber and electrometer described above. The polystyrene phantom described above was also used for measurement of PDD.

Dosimetry in an anthropomorphic phantom(Humanoid, U.S.A.) on total body irradiation geometry specific to Seoul National University Hospital was made using $CaF_2 \cdot M_n$ chips(Victoreen, U.S.A.). The Humanoid phantom has made of several sections, 2.55cm thick and each section has a number of holes of 0.48cm diameter able to put a measuring probe into. On the largest coronal plane of the phantom, including rods to fix several sections into one, there exist 296 holes separated by 2.98cm space. At the center of each rod which fills up a hole and has radiological properties similar to surrounding material, a TLD chip was loaded. At once, 100 annealed TLD chips or so were loaded on some consecutive sections and on the coronal plane. The anthropomorphic phantom containing TLD chips was vertically set under the condition that distance from the mid-sagittal plane to the wall opposite to source was 40cm, and the beam axis, horizontal, was in line with the cross line of the largest coronal plane and the contact surface of sections, No. 27 and 28, at which lateral thickness was 28.5cm. Then, distance from Co-60 source to the mid-sagittal plane was 40cm and the geometric field size on the sagittal plane was 122cm×122cm. One diagonal axis of the field was on the body axis of the phantom. The anthropomorphic phantom containing TLD chips was bilaterally irradiated for 15 minute for each field. Dose rate at mid-point on beam axis was 384.0 cGy/h. Exposed TLD chips were read by a TLD reader(Harshow/Filtrol TLD System 4000, Holland).

Results

Percent depth dose(PDD) for SSD=264cm(nominal field size 115.5cm×115.5cm) was measured using the parallel plate chamber and electrometer described above. Fig. 2 shows PDD in polystyrene phantom with a dimension 25cm×25cm that is much smaller than field size. Depth of dose maximum was about 0.3cm that is shallower than depth of dose maximum for 80cm SSD, 0.5cm. Surface dose was 82% that is much greater than surface dose for 80cm SSD. Exit dose at depth 30cm increased rather than to decrease compared with dose at a point with a little underlying layer. Depth of 50% was 16.9cm. The increase of surface dose is deemed to be caused by electrons recoiled from air between cobalt source and phantom surface. The increase of exit dose is deemed to be caused by electrons backscattered from the adjacent wall.

Assessing adequacy of Co-60 as quality for TBI, depth dose curve for parallel fields is

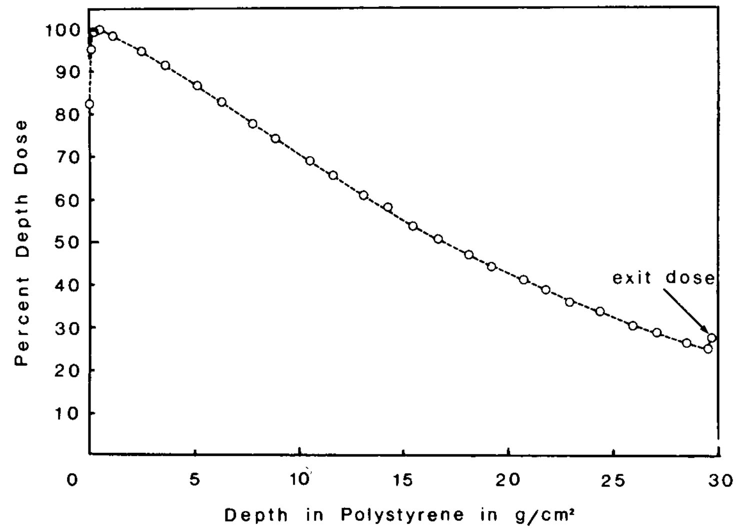

Fig. 2 Percent depth dose in small polystyrene phantom. Nominal field size and phnatom size at phnatom surface are 115.5cm×115.5cm and 25cm×25cm, respectively.

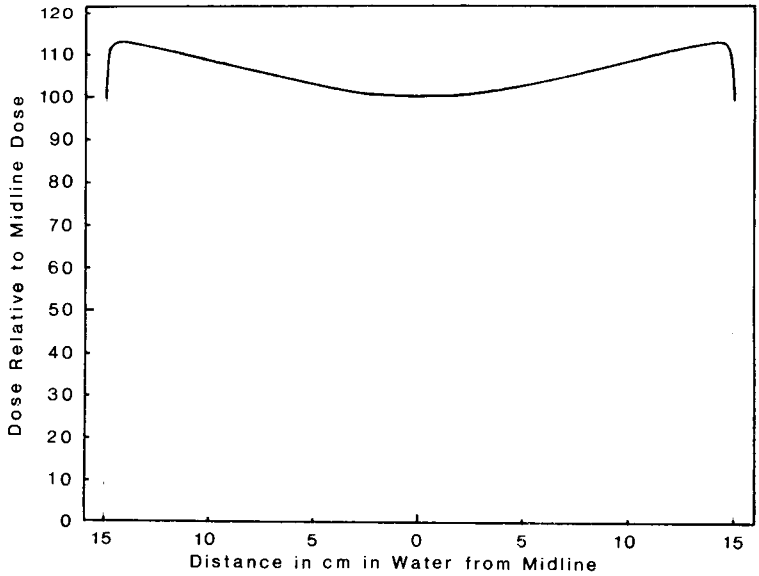

Fig. 3 Depth dose curve for parallel opposed fields normalized to midpoint value. Nominal field size and phantom size at phantom surface are 115.5cm×115.5cm and 25cm×25cm, respectively. Dose uniformity is good for 30cm thickness.

more apparent than that for single field. Fig. 3. shows a depth dose curve for parallel opposed fields with phantom of thickness 30cm. Ratio of maximum peripheral dose to the midpoint dose was 1.13, that is deemed to be uniform.

Horizontal and vertical off-axis ratio of exposure at 279cm SCD are shown in Fig. 4. Field size that is width between two points of 50% level of the exposure on beam axis was 130cm in horizontal direction(longitudinal in normal position) and 129cm in vertical direction (transverse in normal psoition) that are all larger than geometric field width 122cm. The reason that dosimetric field size is different from geometric field size is that source size, source-diaphram distance and scatter rays from collimating system and air between cobalt source and phantom surface affect radiation field size.

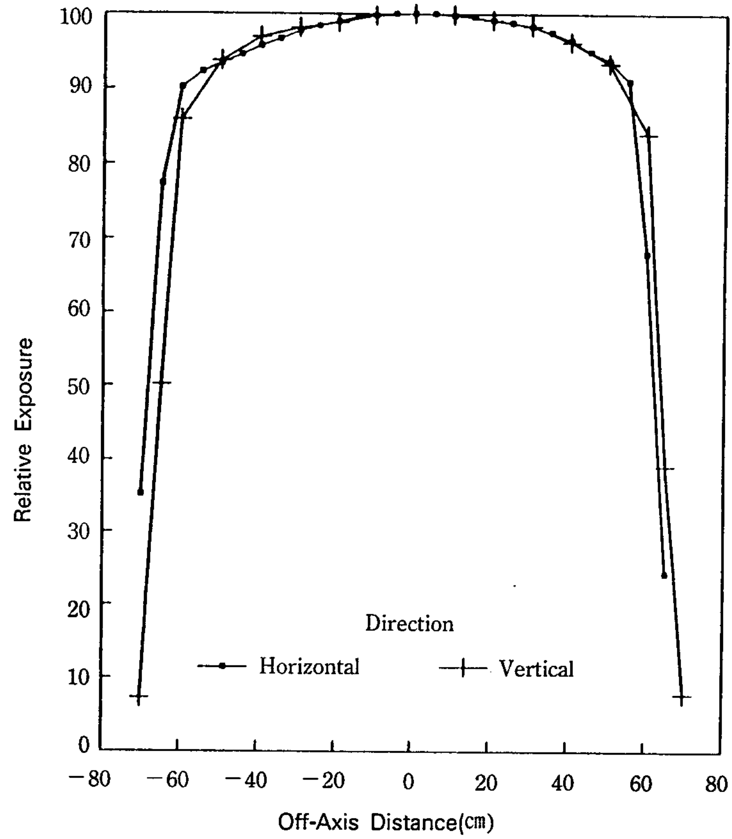

Fig. 4 Off-axis ratio of exposure in air for maximum field size at SCD 279cm. Field width was 130cm in horizontal and 129cm in vertical but geometric field size is 122cm×122cm. Width of 90% or more for beam center was 115cm in horizontal and 114cm in vertical.

Exposure distribution in air in and around the field 122cm×122cm at SCD 279cm is shown in Fig. 5. Exposure distribution is not symmetric about horizontal line through field center, and high dose area such as 95% is biased to upper side. This could be explained that beam direction would not be horizontal due to a little bit inclined axes of C-arm and york.

Tissue phantom ratio(TPR) with field 122cm×122cm and phantom size 25cm×25cm with reference depth 15cm is shown over the depth range 10cm to 20cm in Fig. 6. TPR values are linear over the range.

Fig. 7 shows dose distribution of Co-60 beam, SAD 279cm on the largest coronal plane of anthropomorphic phantom. Fig. 8 shows dose profile on body axis on the coronal plane. The dose values were normalized for the dose at midpoint on beam axis. Dose is the lowest in shoulder area and the highest in neck area. Fig. 8 shows that dose in shoulder area is

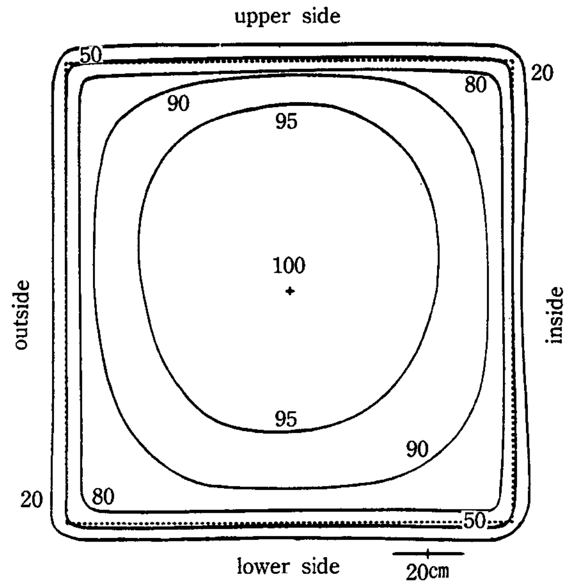

Fig. 5 Relative exposure distribution of Co-60 at SCD 279cm. "+" represents center of field. The distribution was symmetric about vertical axis but asymmetric about horizontal axis.

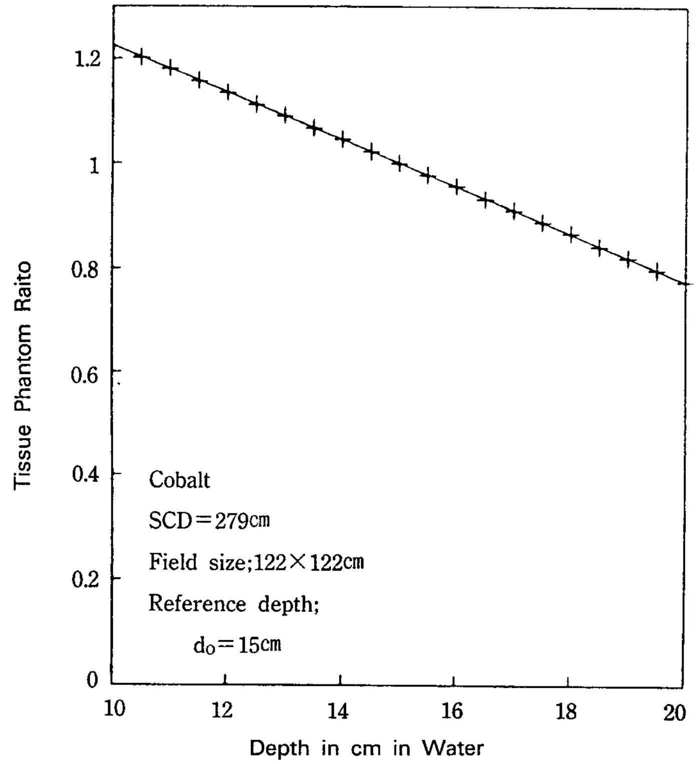

Fig. 6 TPR of Co-60 with field size 122cm×122cm and phantom size 25cm×25cm for reference depth 15cm.

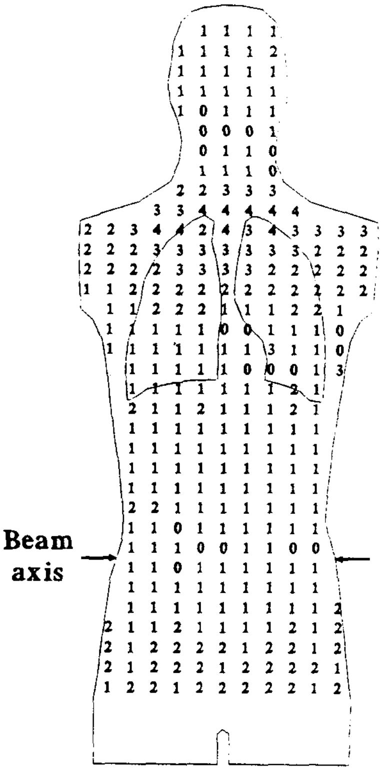

Fig. 7 Dose distribution of Co-60 beam, SAD 279cm on the largest coronal plane of Humanoid phantom. The dose values were normalized for the dose at midpoint on beam axis. The figures represent dose range : 0 : 100~110%, 1 ; 90~100%, 2 ; 80~90%, 3 : 70~80%, 4 ; 60~70%.

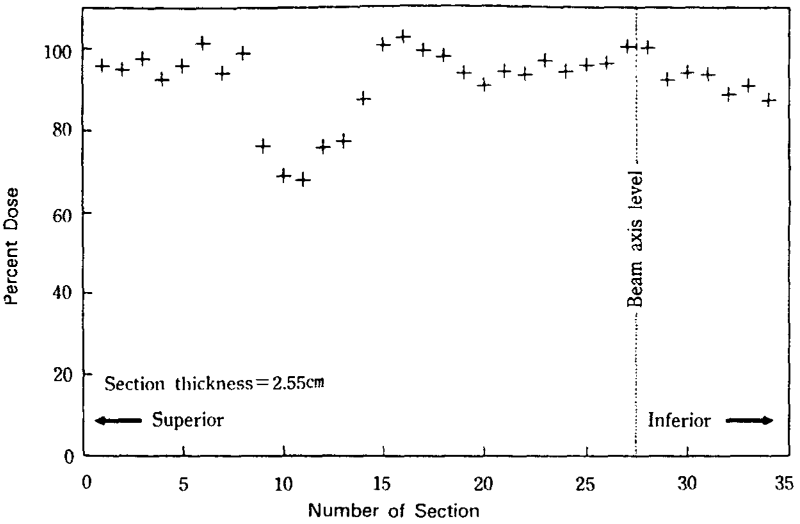

Fig. 8 Dose profile of Co-60 beam, SAD 279cm on body axis on the largest coronal plane of Humanoid phantom. The dose values were normalized for the dose at midpoint on beam axis.

excessively low. Even though dose in neck area is high, the dose does not exceed 110%, In upper lung area and pelvic area, dose is generally lower than 90%. Dose in lower and abdoman area and head area ranges from 90% to 100%.

Discussion

Even though several techniques for total body irradiation have been reported[19], there could not exist a universal technique because a treatment room and/or machine could be specific to hospital. Even though a specific technique could be also selected, it should be modified to suit the actual condition of a treament unit and/or room. So, it is not easy to compare dosimetric data. However, several techniques could have similarities and differences in dose distribution.

In this study on dosimetry of cobalt beam at long distance, comparing those for SSD 80cm, the dose maximum point came more close to surface and surface dose increased. It could be supposed that main source of remarkable change in dose distribution in buildup region would be electrons from air between treatment unit and phantom surface, that are recoiled through interaction with photons.

Quality of a photon beam affects dose uniformity on beam axis. If cobalt gamma beam does not meet the requirement of dose uniformity on our specific geometry for TBI, our cobalt unit could not be used for TBI. The variation of dose at horn relative to midline dose was a little bit higher than 10%, that is sufficiently uniform for TBI. So, cobalt beam could be used as a source for TBI at SAD 279cm that is specific in our hospital.

The our results of study on TBI dosimetry in an anthropomorphic phantom irradiated bilaterally by cobalt beam do not verify the general knowledge again, but in the contrary, force medical physicists to recognize that boost irradiation to some thick parts such as shoulder, upper lung and pelvis should be required. Doses, particularly, in shoulder area that are the most thick in lateral dimension were extremely low. Doses in head and neck area, that wrer expected to be excessively high because of thin lateral thickness of head and neck were close to doses in central beam area. It is considered that such a dose distribution is closely related to remarkable reduction of off-axis ratio of exposure in air from 1.

Uniform dose distribution over whole body of a patient under TBI is very important. It is generally accepted that for the purpose it would be natural to use compensator for thin parts such as head, neck and foot, and low density part such as lung. Findley, et al[18] and Khan, et al[23] using 10 MV X-ray, Svensson, et al[17] using 4 MV X-ray, Galvin, et al[27] using 6 MV X-ray and Engler[24] using 16 MV X-ray have advocated that compensation is required for head and neck, lung, leg and foot. Because they used different quality of radiation from ours, Co-60, our results relevant to compensation might be different from their results. Lam, et al[14] reported the dosimetric results of cobalt beam at 500cm treatment distance and Glasgow, et al[15, 25] did the dosimetric results of cobalt beam at 220cm treatment distance. Lam, et al reported that dose distribution was uniform over the whole body. Glasgow, et al reported that dose was high in head and heart area but low in shoulder. Dose at heart was close to prescribed dose in our result but high in Glasgow's result. Even though they used cobalt as a radiation source, none of them are close to ours because our geometry for irradiation such as treatment distance 279cm is different from theirs.

Conclusion

A special geometry for TBI using a cobalt teletherapy unit has been considered to be, proper to room and machine. Under such a geometry, PDD and TPR in a polystyrene phantom smaller than radiation field were measured with a plane-parallel chamber. Dosimetry by TLD on the largest coronal section of an anthropomorphic phantom was made. The conclusions are as follows ;

1. The geometric condition such that the available distance and nominal maximum field size were 279cm and 122cm×122cm respectively, was eligible for TBI.
2. The dosimetric condition such that depth dose profile on beam axis for two opposing fields was uniform within 10% for the mid-point dose, was also eligible for TBI.
3. Doses in head/neck, lower lung and abdomen regions were uniform but doses in shoulder, upper lung and pelvis area were not uniform. Compensators for head/neck and lung regions should not be required but boost irradiation over shoulder area would be rather desirable.

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Co-60에 의한 전신조사시 선량분포

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골수이식을 받게 될 환자의 이상 골수를 완전히 죽이기 위해 MV 정도의 선질의 광자선에 의한 전신방사선요법이 시행되고 있다. 국소방사선요법에 이용되고 있는 방사선치료장치에 의한 일상적인 방법으로 환자의 전신에 걸쳐 방사선을 조사하기에는 조사면의 크기가 훨씬 미치지 못한다. 그래서 환자의 전신에 걸쳐 방사선을 조사할 수 있는 방법이 개발되어야 한다. 방사선 전신조사를 위한 여건이 병원에 따라 다를 것이기 때문에 병원에 따라 독특한 방법이 개발될 수 있다. 서울대학교병원에서는 코발트치료기 만이 두부를 기울일 수 있어서 전신조사에 이용될 수 있다. 코발트치료기의 두부를 밖으로 90° 기울일 때 선축은 수평이고 또한 맞은편 벽과 직각이 된다. 이 때 선원에서 맞은편 벽가지 거리는 319cm이였다. 벽에서 환자의 중앙시상면까지 간격을 40cm라고 가정할 때, 중앙시상면에서 명목상 최대 조사면 크기가 122cm×122cm이였고, 조사선량분포를 측정한 결과로는 130cm×129cm이였으며 상하방향에서는 대칭이 아니였다. 환자가 쭈그리고 앉은 자세를 취한다면 조사면의 크기는 전신조사를 시행할 수 있을 정도로 충분히 크다. 환자 좌우폭의 평균을 30cm라고 가정하고, 중앙시상면에서 선원쪽 15cm위치에 기준표면(SSD는 264cm, 명목상 조사면 크기 115.5cm×155.5cm)을 두고 단면의 크기가 25cm×25cm이고 두께가 30cm인 폴리스티렌 팬톰에서 평판형 전리함으로 PDD를 측정하였다. 최대선량점의 깊이는 0.3cm이였고 표면선량율은 82%, 50% 깊이는 16.9cm였다. 대향조사시 선축상 선량분포는 중점의 선량에서 10%이내로 일치하였다. SCD를 279cm, 최대 조사면, 기준깊이 15cm에 대한 TPR을 폴리스티렌 팬톰에서 깊이 10cm에서 20cm에 걸처 측정하였다. 측정범위에서 TPR은 직선성을 보였다. 인체팬톰의 최대 전단면(coronal plane)에 있는 각 구멍에 TLD 조각을 넣고, 코발트선원에서 팬톰의 시상면까지 거리를 279cm되게 하고 선축은 팬톰의 27번 절편과 28번 절편의 접면과 최대 전단면의 교차선과 일치시켜 양방향에서 15분씩 조사하여 전단면에서 선량을 측정하였다. 팬톰내 선축상 중앙점의 선량을 기준으로 다른 부위의 선량을 비교하였다. 두경부와 복부, 폐의 하반에서 선량의 차이는 ±10% 이내였고, 폐의 상반과 어깨와 골반 부위에서 선량은 10%이상 저선량을 보였다. 특히 어깨부위에는 30%이상 저선량을 보였다. 이로부터 서울대병원과 유사한 조건에서 코발트로 전신조사하는 경우에는 폐나 두경부에 대응하는 조직보상체를 이용하기보다는 어깨부위에 선량을 추가하는 것이 바람직할 것이라고 생각한다.