Dose Effect of Tissue Compensator for 6 MV X-Ray

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It is ideal thing to compensate tissue deficit without skin contamination in curvatured irradiation field of high energy photon beam. The 3-dimensional compensating technique utilizing tissue equivalent materials to ensure an adequate dose distribution and skin sparing effect was described. This compensator was made of paraffin (70%) and stearin wax (30%) compound. The parameters for evaluation of the effect on skin dose in application of compensator were considered in the size of the field, the thickness of the compensator and the source-to-axis distance.

The results are as follows; the skin doses were not changed even though application of the compensator, but depended on the field size and the source-to-axis distance, and the skin doses were only slightly changed within 1% relative errors as increasing the thickness of the compensator in these experiments.

Key Words: 3-dimensional compensator, Tissue equivalent material, Skin dose

INTRODUCTION

The absorption dose in tissue is determined by calibrating the attenuation dose in water phantom or polystyrene solid phatom. Dose distribtuion in high energy photon beam is relatively even in deep tissues but, a radiation beam on an irregular or sloping surface causes skewing of the isodose curves. The surface irregularity gives rise to unacceptable nonuniformity of the dose distribution within the target volume and results in excessive irradiation of sensitive structures such as spinal cord. Many techniques have been devised to overcome this problem, including the use of wedged filter, multiple fields, addition of bolus material or compensating filter. Especially in head and neck irradiation, it is important to compensate the tissue deficit because of its marked surface irregularity. In Fig. 1, a) showes isodose curves skewed by the patient's surface, therefore higher dose is delivered to the isocenter of relatively thinner tissue[1]. To

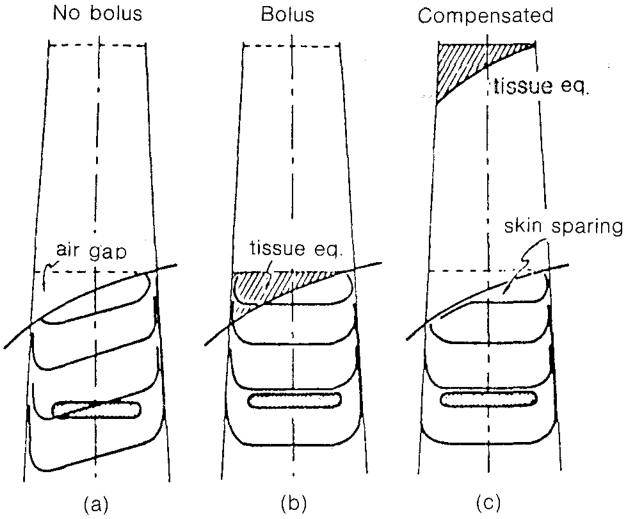

Fig. 1. Schematic diagrams to illustrate the use of bolus and copensating filters.

correct this difference the use of tissue equivalent material at the tissue deficit portion makes even dose distribution at the isocenter of the patient (Fig. 1-b). These materials to obtain even dose distribution at the isocenter of the tissue are called "bolus". But the purpose of above bolus should be distinguished from that of a bolus layer, which is thick enough to provide adequate dose buildup over the skin surface. The later should be termed as the buildup bolus which is commonly used at the time of neck node irradiation or skin invasion by cancer.

Perhaps the simplest form of the bolus is small cloth bags containing a mixture of 60% rice fiour and 40% of sodium bicarbonate. Paraffin wax mixed with approximately an equal amount of beeswax is also very useful. A very thorough discussion of tissue substitute materials is given by White[2]. The use of bolus material for high energy radiation has some disadvantages such as losing skin sparing effect because the buildup region occur near the skin surface. In order to preserve the skin sparing effect and to obtain even dose distribution at the isocenter, the compensating filter should be placed some distance away from the patient's surface (Fig. 1-c). The principles and techniques for constructing compensating filters had been discussed by Hall and Oliver[3], Van de Geijn[4], and Sundbom[5]. A semiautomatic machine for cutting filters is described by Cunningham et al[6], and a simple device for making compensating filters for large field irradiations is described by Leung et al[7]. Recently, Kim et al[8] report clinical application of the 3-dimensional tissue equivalent compensator.

Dose distribution of high energy radiation is characterized by abrupt increment of absorption dose within a few millimeter depth beneath the skin surface, maximum dose at the reference depth (denote d_{max}), and gradual decrease at further depth. D_{max} is deeper as higher as the radiation energy, and the buildup region stands for the region between the skin surface and d_{max}.

When a primary beam traverse through an interacting substance such as a compensating filter, generally it is well known that it creates scattered beam during this interaction which may cause loss of the skin sparing effect of megavoltage radiation beam[9]. Therefore, we considered it is necessory to evaluate the correct dose at the buildup region in the instance of using this kind of a tissue compensator like ours. Although Ellis F. et al[10,11] reported the use of a tissue compensator to compensate the tissue deficit with various material, there was no report about the skin dose when this type of the 3-dimensional tissue compensator was applicated to the patient yet.

The skin dose was analyzed in various field size, compensator thickness and source-to-detector distance in the 6 MV photon beam with the 3-dimensional tissue equivalent compensator.

METHODS AND MATERIALS

To preserve the skin sparing effect of megavoltage radiation beam, the compensator must be located away from the patient's surface. When the compensating filter is inserted into the primary beam, the primary and secondary radiation can be altered in beam quality. In general the required thickness of the compensating filter is thinner than

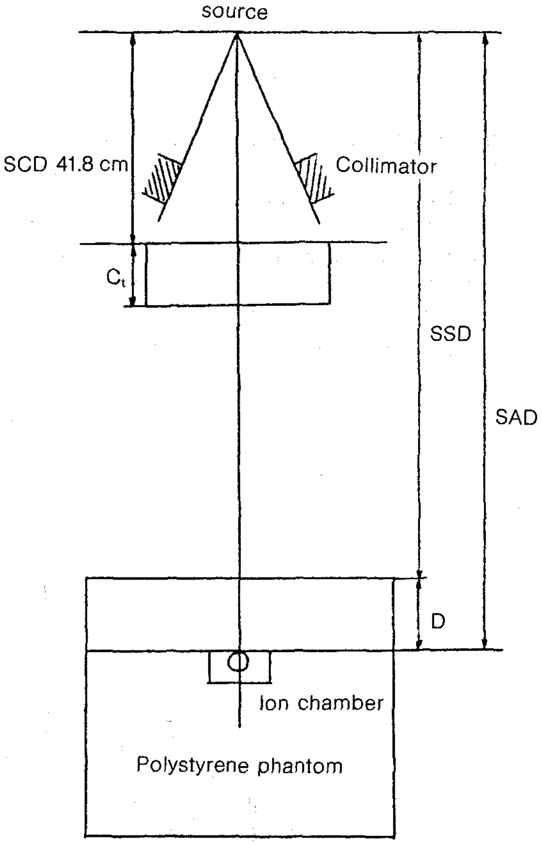

Fig. 2. Diagram of experimental setup.
C_t; compensator thickness
SCD; source-compensator distance
SSD; source-surface distance
SAD; source-axis distance
D; depth

the actual tissue deficit[8,12].

In these experiments, we analysed the skin dose at the different field size, compensator thickness, and source-to-detector distance.

The depth of dose estimation was performed from the skin surface to 40 mm of depth. Fig. 2 showed the schematic diagram of experimental setup. To compare the skin doses applied with the compensator to those applied without the compensator, both instances of absorption doses at 0.0, 0. 74, 1.43, 7, 03, 10.0, 15.0, 26.3, 40.2 mm depth in each field size of 5×5, 10×10, 15×15, 20×20 cm^2 were estimated.

The physical components of the 3-dimensional compensator were a mixture of paraffin 70% and stearin wax 30% which had the low atomic number of materials. And this material had equivalent density to human tissue in the high energy photon beam. The size of the compensating filter was limited to 15×15 cm^2 and the thickness was various from 9.5 mm to 103 mm. The absorption dose at each depth was estimated with parallel-plate ionization chamber (PS-033 Capintec Co.) and Farmer 2570 electrometer using polystyrene solid phantom (physical density; 1.045 g/cc, electron density ratio; 1.015 to water).

RESULTS

In this experimental measurement of depth dose, the depth of maximum dose (d_{max}) in given field size showed the 15 mm of depth in 6 MV photon beams of dual energy photon beams of linear accelerator (Mevatron, Siemens, German). And the absorption dose at a given depth was normalized to the d_{max}.

The relative surface dose to d_{max} of 6 MV photon beam in reference source-to-axis distance (SAD=100 cm) in open beam has showed 16.3% for 10×10 cm^2 and 25.5% for 20×20 cm^2. And it showed that the dose of buildup region were increase as field size increased, as shown on Table 1 and Fig. 3. It showed a typical depth dose curves of 6 MV photon beam. The magnitude of dose increment regard to increasing the field size was decreased as deepening the depth.

Table 1. Percent Depth Dose in the Buildup Region of 6 MV Photon beam at Given Field Size and Reference Source Axis Distance (SAD=100 cm) in Open Beam

Field size / Depth (mm)	5×5	10×10	15×15	20×20
	(cm×cm)			
0.00	11.6	16.3	21.8	25.5
0.74	32.1	36.6	41.7	43.4
1.43	32.4	48.2	53.0	53.6
7.03	87.0	87.8	90.2	90.5
10.00	98.1	99.0	99.0	99.2
15.00	100.0	100.0	100.0	100.0
26.30	94.2	94.5	94.9	95.2
40.20	84.9	86.4	87.1	88.0

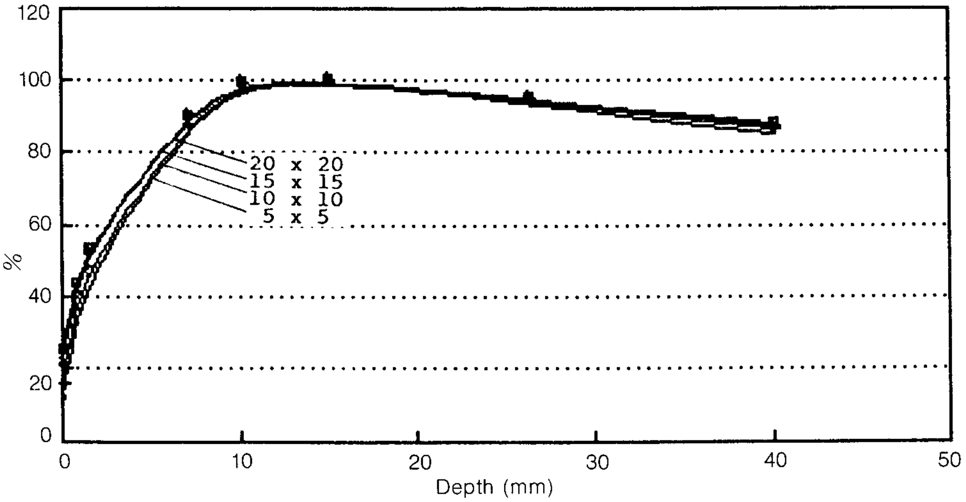

Fig. 3. Percent depth dose in the buildup region of 6 MV photon beam at given field size and source axis distance without using compensator.

In different field size, absorption dose at a given depth was abruptly increased within a few millimeter beneath the skin surface, maximized at 15 mm of depth, but gradually decreased at further depth.

To investigate the skin dose applied the compensating filter to the equipment, all thickness of compensating filter was attached to the equipment from 9.5 mm to 103 mm. The relative percent dose at the surface, 1.43 mm, 7.03 mm of depth has shown on Table 2 and Fig. 4. In the same field size, the surface dose was not changed significantly even though the thickness of filter was changed. The percent depth dose curve showed initial steep increment to the maximum dose point, 15 mm from the skin surface, and then gradual decrease at the further depth. The compensating filter did not cause any change in shape of percent depth dose curve. And in the same depth, the depth dose was increased as increasing the field size, similar to open beam. However the skin dose was nearly not changed, only within 1% relative discrepancy, regardless of the change of the compensator thickness at the same field size and depth. As shown on Table 2, when the compensator thickness was increased from 0.0 mm to 103 mm in the same field size of 10×10 cm^2, the absorption dose at 0.0 mm depth, skin surface, was changed merely as 16.3%, 16.7%, 16.6%, 16.4%, 16.1%, 16.1% for each compensator thickness respectively. And the same findings of dose was observed at the 1.43 and 7.03 mm of depth.

The surface dose was also estimated in different source-to-detector distance, 110 cm and 90 cm, using the different thickness of compensating filter in 10×10 cm^2 field size. The results were showed that the percent depth dose was not changed regardless of the change of the compensator thickness at the same depth, even though the source-to-detector distance was changed from 100 cm to

Table 2. Relative Percent Dose to Maximum Dose at the Skin as a Function of Compensator thickness in 6 MV Photon Beam at Reference Source Axis Distance (SAD=100 cm)

	Compensator thickness (mm)																	
Depth (mm)	0.0 mm			9.5 mm			22 mm			53 mm			81 mm			103 mm		
F.S	0.0	1.43	7.03	0.0	1.43	7.03	0.0	1.43	7.03	0.0	1.43	7.03	0.0	1.43	7.03	0.0	1.43	7.03
5×5	11.6	45.3	87.0	11.9	45.5	87.6	11.9	44.9	87.2	11.6	44.0	87.1	11.2	42.8	86.4	11.1	41.8	85.8
10×10	16.3	48.2	87.8	16.7	48.5	88.2	16.6	48.1	88.2	16.4	47.3	88.0	16.1	46.1	87.3	16.1	45.6	87.2
15×15	21.8	53.0	90.2	22.4	53.4	90.5	22.6	53.4	90.9	22.8	53.0	90.9	22.6	52.3	90.1	22.7	51.9	89.9
20×20	25.5	55.2	90.6	26.9	56.4	91.0	27.0	56.4	91.6	27.3	56.3	91.6	27.7	56.1	91.6	28.0	56.0	91.5

(F.S; field size, cm^2)

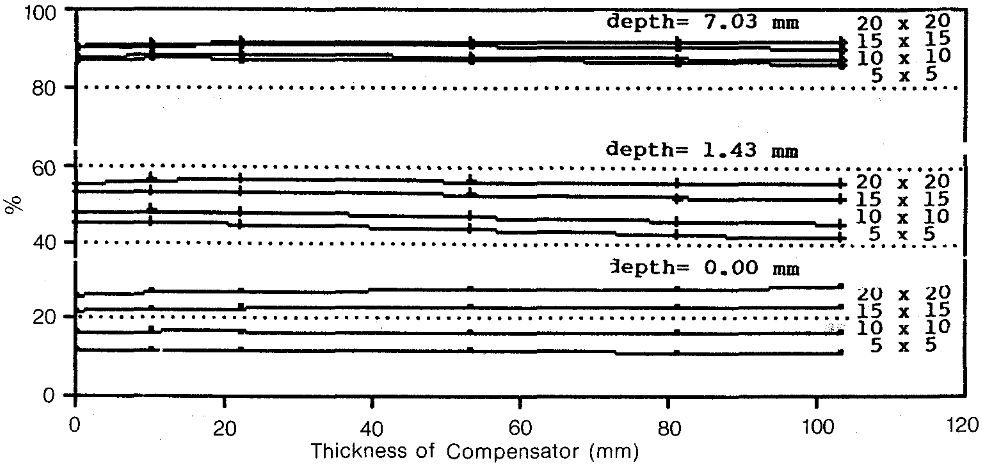

Fig. 4. Relative percent dose to maximum dose at the skin as a function of compensator thickness in 6 MV photon beam at reference source axis distance (SAD=100 cm).

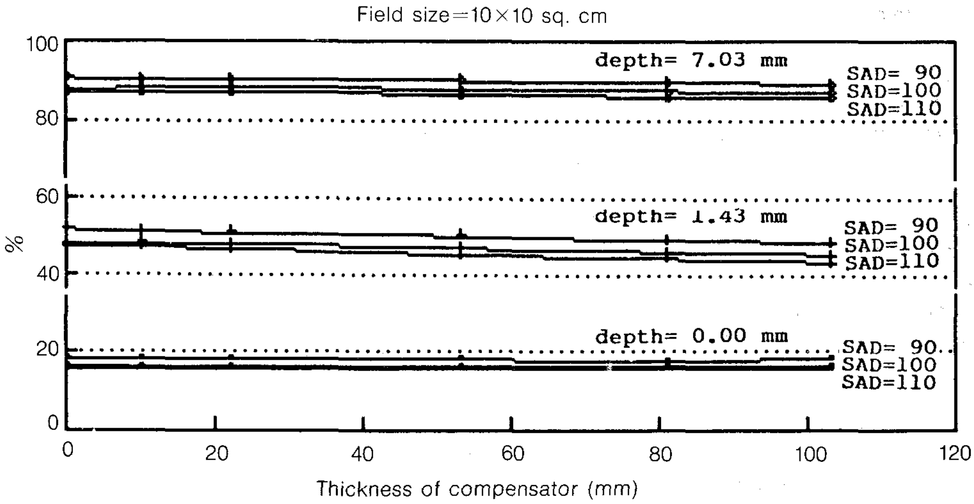

Fig. 5. Relative percent dose to maximum dose at the skin at different source axis distance (SAD) in 6 MV photon beam at reference field size (10×10 cm^2).

Table 3. Relative Percent Dose in the Buildup Region at Different Source Axis Distance in 6 MV Photon Beam at reference field size, 10×10 cm^2

	Source axis distance (SAD)								
	90 cm			100 cm			110 cm		
Depth (mm) / Ct	0.0	1.43	7.03	0.0	1.43	7.03	0.0	1.43	7.03
0.0	18.2	51.8	90.8	16.3	48.2	87.8	15.9	47.3	86.8
9.5	18.1	51.1	90.1	16.5	48.5	88.2	16.0	47.3	87.1
22	18.1	51.0	90.4	16.4	48.1	88.2	15.8	46.9	87.1
53	18.0	50.4	90.1	16.4	47.3	88.0	15.5	45.2	86.5
81	17.8	49.1	89.4	16.1	46.1	87.3	15.3	44.6	85.8
103	18.0	48.9	89.3	16.1	45.6	87.2	15.3	43.5	85.6

(C_t; compensator thickness, mm)

110 cm or 90 cm as shown in Fig. 5. But, the absolute absorption dose was increased a little as shortening of the source-to-detector distance from 110 cm to 90 cm at a given thickness of compensating filter and depth. Regarding to Table 3, the absorption dose at the depth 0 mm and 9.5 mm thickness of compensating filter was increased 16.0% to 18.1% in different source-to-detector distance of 110 cm and 90 cm, respectively.

DISCUSSION

The 3-dimensional tissue equivalent compensator using on this study is a mixture of paraffin and stearin wax. This mixture resembles a human tissue radiologically, and has benefit of easy handling because a major component of this mixture is paraffin. Parallel-plate ionization chamber as a detector using on this study has the electrode spacing of 2.4 mm, therefore it is most popularly useful for dose calibration in buildup region and skin surface. And this chamber may differentiate a little dose difference between two region with narrow depth difference, and has high accuracy. In these experiments, we use 6 MV photon beam which is popularly useful recently in head and neck irradiation, and the field size is limited within 20×20 cm^2 because the field size for head and neck irrdiation is mostly within above size except for lymphoma. The experimental setup and dose calibration is achived by SAD method. Since the compensator ratio in 6 MV linear accelerator is about 0.6, the compensator thickness is limited to 103 mm which is equivalent to 150 mm of tissue deficit in head and neck irradation.

In an open beam, absorption dose at same depth was increased according to increment in field size. It may be due to increasing scatters of primary beam on the collimator surface by the change of the collimator size, i.e. as the field size is increased, collimator surface is also incrreased. And the effect of scattered beam by collimator is decreased as increasing the tissue depth to be estimated in the same field size, as shown on Table 1.

The experimental group showed that the change of skin dose was very little even though the compensator thickness is changed at each field size as shown on Table 2. By the report of Khan et al[9], as the collimator materials, the lighter in atomic number such as lucite, the more scatter beam on skin were irradiated, and it was maximal when the distance between the skin and the compensator was within 15 cm and the field size was larger. But if the distance between the skin and the compensating filter is more than 30 cm, the effect of scattered beam by the compensator is much little. In our experiments, the effect of skin dose by the compensator is nearly negligible because the distance between the compensator and skin surface was more than 44 cm in our experimental setup.

In the other experimental setup, when the distance of the radiation source to detector was decreased, the skin doses were increased as in Table 3. This results may be interpreted as that scatter beams from the collimator surface has been mainly contributed to the skin doses and additionally scatters from the compensator in small portion by decreasing the distance of collimator and compensator to skin. But as in Table 2, effect on skin doses in reducing the source-to-detector distance is almostly caused by collimator scatters because the effect of compensator on skin doses is nearly absent in these experiments. Generally, it is well known that skin doses are increased when the distance beween skin and source or collimator is decreased, so our results are acceptable reasonably.

CONCLUSION

Tissue compensators had been used to ensure an adequate dose distribution and skin sparing effect, ususally on the head and neck or other tissue defict area.

It is the trial to evaluate the effect of compensator on skin when 3-dimensional compensator utilizing tissue equivalent material was applicated on the head and neck area. This compensator was made of paraffin (70%) and stearin wax (30%). The parameters for evaluation were the size of the field, the thickness of the compensator and the source-to-detector distance. The results were as follows;

The skin doses were nearly not changed even though application of the compensator, but it depended on the field size and the source to detector distance. It had minimal role for tissue compensator on skin doses in the wide ranges of compensator thickness, but the skin doses were changed mainly according to field size and source to detector distance in these experiments. By these results, it is allowable that this 3-dimensional, tissue equivalent, compensator can be used safely

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국문초록 =

두경부 방사선조사시 3차원조직보상체에 의한 피부선량

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인체의 굴곡이 심한 부위에 방사선 조사시 조직결손을 보상하여 조직의 중심에 균등한 선량분포를 얻기 위해 조직보상체를 사용하게 된다. 그러나, Ellis F.등이 1960년대에 고에너지 방사선치료에서 조직결손에 따른 조직보상체의 사용을 발표한 이후로 여러 종류의 조직보상체를 사용하여 왔음에도 불구하고 보상체를 사용하였을 때의 피부선량 변화에 대한 연구는 아직까지 없었다. 이에 본 연구에서는 파라핀과 스테아린왁스가 혼합된 3차원 조직등가보상체를 사용하였을 때, 조사면적의 변화, 보상체의 두께변화, 방사선원과 검출기 사이의 거리변화에 따른 피부선량을 실험측정하였다. 실험에 이용된 방사선 에너지는 두경부조사에 많이 사용되는 6 MV광자선이며, 조사면적은 5×5 cm^{2}에서 20×20 cm^{2}까지 이며, 조직보상체 두께는 9.5 mm에서 103 mm까지 이며, 선량측정은 폴리스티렌 고체팬톰을 사용하여 평행 평판형 전리함(Parallel-plate ionization chamber)으로 피부표면인 0.0 mm에서 40.2 mm 깊이까지 측정하여 다음과 같은 결과를 얻었다.

일정한 조사면적과 일정한 선원-검출기 간 거리의 경우에는 보상체의 두께가 증가하여도 피부선량의 변화는 거의 없었다. 피부선량 변화는 보상체의 사용과는 무관하게 조사면적이 커짐에 따라 상대적으로 증가하였고, 방사선원과 검출기사이의 거리가 짧을수록 증가하였다