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A Study on Effective Source-Skin Distance using Phantom in Electron Beam Therapy

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In this study, for 6-20 MeV electron beam energy occurring in a linear accelerator, the authors attempted to investigate the relation between the effective source-skin distance and the relation between the radiation field and the effective source-skin distance. The equipment used included a 6-20 MeV electron beam from a linear accelerator, and the distance was measured by a ionization chamber targeting the solid phantom. The measurement method for the effective source-skin distance according to the size of the radiation field changes the source-skin distance (100, 105, 110, 115 cm) for the electron beam energy (6, 9, 12, 16, 20 MeV). The effective source-skin distance was measured using the method proposed by Faiz Khan, measuring the dose according to each radiation field (6×6, 10×10, 15×15, 20×20 cm^2) at the maximum dose depth (1.3, 2.05, 2.7, 2.45, 1.8 cm, respectively) of each energy. In addition, the effective source-skin distance when cut-out blocks (6×6, 10×10, 15×15 cm^2) were used and the effective source-skin distance when they were not used, was measured and compared. The research results showed that the effective source-skin distance was increased according to the increase of the radiation field at the same amount of energy. In addition, the minimum distance was 60.4 cm when the 6 MeV electron beams were used with 6×6 cut-out blocks and the maximum distance was 87.2 cm when the 6 MeV electron beams were used with 20×20 cut-out blocks; thus, the largest difference between both of these was 26.8 cm. When comparing the before and after the using the 6×6 cut-out block, the difference between both was 8.2 cm in 6 MeV electron beam energy and was 2.1 cm in 20 MeV. Thus, the results showed that the difference was reduced according to an increase in the energy. In addition, in the comparative experiments performed by changing the size of the cut-out block at 6 MeV, the results showed that the source-skin distance was 8.2 cm when the size of the cut-out block was 6×6, 2.5 cm when the size of the cut-out block was 10×10, and 21.4 cm when the size of the cut-out block 15×15. In conclusion, it is recommended that the actual measurement is used for each energy and radiation field in the clinical dose measurement and for the measurement of the effective source-skin distance using cut-out blocks.

Keywords : electron beam, source-skin distance, energy

1. Introduction

The purpose of radiation therapy is to raise the maximal therapy effectiveness so that the maximum dose is delivered into the tumor and the minimum dose is delivered to the healthy organs [1]. Among the therapy methods, electron beam therapy in vitro using radiation is an efficient treatment of skin cancer, body skin cancer, breast cancer, and salivary gland tumors because the damage to the normal area can be minimized since its effectiveness rapidly decreases at deeper depths than the effective depth. However, in order to correctly treat the cancer without sequela, the dose distribution within the tissue according to the interaction between the electron beam and tissue should be exactly identified [2-4]. However, the source-skin distance (SSD) changes the dose distribution, and in the dose calculation of photon beam, the distance reverse square-root law using mechanically fixed SSD is applied as it is, but in the dose calculation of electron beam, the specified SSD cannot be applied as it is. This is due to the same phenomenon whereby the electron beam is dispersed from the virtual source owing to the scattering from the scattering foils and the collimator surface under the radiation of the electron beam.

In general, the physical properties of the electron beam emitted from a medical linear accelerator are determined

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depending on the scattering foil, the opening of the collimator, the structure of the electron cone, the size and shape of the irradiated field, and the density and thickness of the cut-out block or organizational composition material. These physical properties can occur due to the multiple scattering of the incident electrons, the lost energy in leading, or the displacement of the original motion direction while interacting with the atomic nucleus of the material or orbital electron when the electron beam passes through the material [5, 6]. In addition, the incident angle of radiation can be affected by whether or not the filter is used [7, 8].

As mentioned above, in order to solve the problem in the dose calculation, whereby the change in the source-skin distances is required, the effective SSD (which is the distance between the virtual source and the skin when the distance reverse square-root law can be applied) should be found. In this study, the authors attempted to measure the effective SSD, adopting the method proposed by Faiz Khan, among several methods used for measuring SSD. In addition, in order to protect the normal tissue according to the size and shape of the patient's tumor, this study was performed to compare the difference between the effective SSD when the cut-out block manufactured according to the size and shape of the tumor was used and the effective SSD when the cut-out block was not used under the same condition.

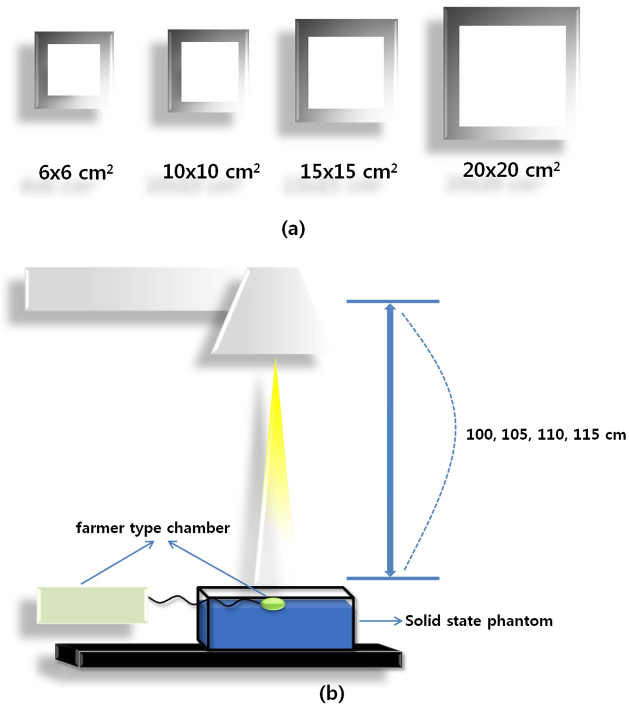

Fig. 1. (Color online) Every energy (6, 9, 12, 16, 20 MeV) was set in the radiation fields of 6 × 6, 10 × 10, 15 × 15, 20 × 20 cm^2, and (a) changing the distance between the bottom of an applicator and the skin surface into 100, 105, 110, 115 cm in every radiation fields, (b) the effective source-skin distances were measured by measuring each dose.

2. Subjects and Methods

2.1. Measurement Comparison of Effective SSD

For the experimental equipment, a 6-20 MeV electron beam of a linear accelerator iX (Varian Co., USA) was used, and the experiments of the distance measurement targeting the solid state phantom (RW3, IBA Co., Germany) were performed using the Farmer type chamber (ionization chamber, FC 65-G, IBA Co., Germany).

Each energy of 6, 9, 12, 16, and 20 MeV was set up to the radiation fields of 6 × 6, 10 × 10, 15 × 15, and 20 × 20 cm^2, respectively, and the effective SSDs were measured by measuring each dose, while changing the distance between the bottom of the applicator and the skin surface to 100, 105, 110, and 115 cm in each radiation field (Fig. 1). The depths of the measuring points of each energy and the radiation fields are the maximum dose depths (dm); that is, 6 MeV was measured at 1.3 cm depth, 9 MeV at 2.05 cm, 12 MeV at 2.7 cm, 16 MeV at 2.4 cm, and 20 MeV at 1.8 cm depth. Also, in order to obtain the effective SSD, the ion chamber is placed at the maximum dose depth (dm) within the solid phantom, and the effective SSDs were measured by radiating 100 monitor unit (MU) while changing the distance of 5 cm from the bottom of the applicator to the skin surface, to 0 cm to 20 cm. In addition, if I_0 is the measured value when the gap between the bottom of the applicator and skin is 0 cm, and I_0 is the measured value when the gap between the bottom of the applicator and skin is g cm, and the electron beams is met, the distance reverse square-root law,

$$\frac{I_0}{I_g} = \left(\frac{f + d_m + g}{f + d_m}\right) \quad (1)$$

$$\text{or} \quad \sqrt{\frac{I}{I_g}} = \frac{g}{f + d_m} + 1 \quad (2)$$

is established [9].

If the graph is drawn by obtaining the value of $\sqrt{I/I_g}$ as the function of Gap$_g$, it becomes a straight line, of which the slope is the function,

$$f = \frac{1}{\text{Slope}} - d_m \quad (3)$$

which can be used to obtain the effective SSD.

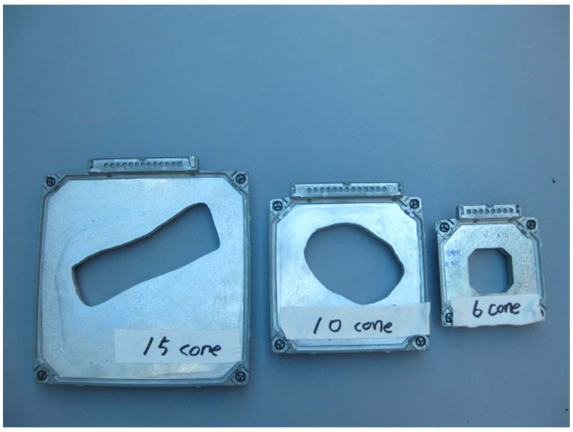

Fig. 2. (Color online) Effective source-skin distance when used each cut-out blocks (6 × 6, 10 × 10, 15 × 15 cm) were measured at 6 MeV.

2.2. Measurement Comparison of Effective SSDs when Cut-out block was used and when Cut-out block was not used

The experimental method used to measure the effective SSD using cut-out blocks with different sizes and shapes was a comparison between the effective SSD at each electron beam energy (6, 9, 12, 16, and 20 MeV) when 6 × 6 cut-out blocks were used and when they were not used. In addition, the effective SSD obtained using the method used in experiment 1 as shown in Fig. 2 when each cut-out block (6 × 6, 10 × 10, 15 × 15) was used, was compared with the effective SSD when the cut-out block was not used at 6 MeV.

3. Results

3.1. Measurement Comparison of Effective SSD

The electron beam energies of 6, 9, 12, 16, and 20 MeV were selected, and the square-root value ($\sqrt{I_0/I_g}$) of I_0/I_g at the maximum dose depth within the solid phantom was obtained while varying Gap g to 0, 5, 10, 15, and 20 cm for each radiating field of 6 × 6, 10 × 10, 15 × 15, and 20 × 20 cm^2, etc, respectively, as shown in Table 1. The graph was drawn by indicating the gap on the x-axis, and I_0/I_g on the y-axis using the results shown in Table 1, and the effective SSD was obtained from equation 3. From the measurement results, the effective SSD was 60.4 cm in the radiating field of 6 × 6 cm^2 and 87.2 cm in 20 × 20 cm^2 at 6 MeV electron beam energy. The effective SSD was 73.2 cm in the radiating field of 6 × 6 cm^2 at 9 MeV electron beam energy, and 85.0 cm in 20 × 20 cm^2 at 6 MeV electron beam energy. The effective SSD was 74.7 cm in the radiation field of 6 × 6 cm^2 at 12 MeV electron beam energy, and 81.2 cm in 20 × 20 cm^2 at 12 MeV electron beam energy. The effective SSD was 75.1 cm in the radiating field of 6 × 6 cm^2 at 15 MeV electron beam energy, and 83.5 cm in 20 × 20 cm^2 at 15 MeV electron beam energy. The effective SSD was 72.8 cm in the radiating field of 6 × 6 cm^2 at 20 MeV electron beam energy, and 83.7 cm in 20 × 20 cm^2 at 20 MeV electron beam energy (Table 2). These results indicate that, as the size of the radiation field reduces in the same energy, the difference between the effective SSD and the normal SSD increased (Fig. 3).

Table 1. Square-root value ($\sqrt{I_0/I_g}$) of I_0/I_g at depth of maximum dose by each Energy.

Energy	distance	Field size			
		6 × 6 cm^2	10 × 10 cm^2	15 × 15 cm^2	20 × 20 cm^2
6 MeV	5 cm	1.069	1.057	1.054	1.053
	10 cm	1.15	1.12	1.115	1.111
	15 cm	1.231	1.182	1.172	1.166
9 MeV	5 cm	1.062	1.058	1.055	1.054
	10 cm	1.13	1.121	1.116	1.113
	15 cm	1.195	1.179	1.173	1.169
12 MeV	5 cm	1.061	1.059	1.056	1.054
	10 cm	1.129	1.124	1.118	1.115
	15 cm	1.19	1.182	1.176	1.173
16 MeV	5 cm	1.063	1.059	1.055	1.053
	10 cm	1.131	1.124	1.117	1.114
	15 cm	1.192	1.184	1.175	1.17
20 MeV	5 cm	1.066	1.06	1.053	1.052
	10 cm	1.137	1.127	1.117	1.112
	15 cm	1.2	1.189	1.175	1.169

Table 2. Effective source-skin distance according to electron beam energy and size of radiation field. Unit: cm

MeV	6	9	12	15	20
6 × 6 cm^2	60.4	73.2	74.7	75.1	72.8
10 × 10 cm^2	78.7	80.6	78.5	77.6	75.7
15 × 15 cm^2	83.4	82.7	80.5	80.9	80.2
20 × 20 cm^2	87.2	85.0	81.2	83.5	83.7

3.2. Measurement Comparison of Effective SSDs when the Cut-out block was used and when the Cut-out block was not used

From the results of comparing both the effective SSDs when a 6 × 6 cm^2 cut-out block was used and when it was not used, the effective SSDs were measured as 60.4 cm and 52.2 cm in the case when the cut-out block was used and in the case when it was not used, respectively, at 6 MeV electron beam energy. In the case of 12 MeV electron beam energy, the effective SSD was measured as 74.7 cm when the cut-out block was used, and the effec-

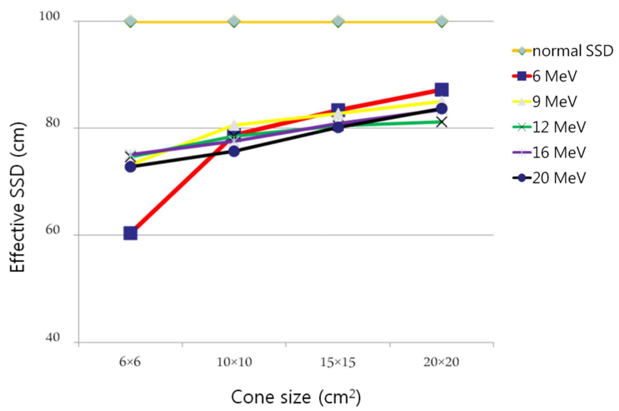

Fig. 3. (Color online) Measurement comparison of effective source-skin distance according to various amounts of energy.

Table 3. Effective Source-Skin Distance for Electron Beam Energy when used 6 × 6 Cut-out Block and when did not use the Cut-out Block, respectively. Unit: cm

	Field size	MeV				
		6	9	12	15	20
Cut-out block	6 × 6 cm^2	60.4	73.2	74.7	75.1	72.8
Non Cut-out block	6 × 6 cm^2	52.2	67.6	73.6	73.3	70.7

tive SSD was 73.6 cm when it was not used. In the case of 20 MeV electron beam energy, the effective SSD was measured as 72.8 cm when the cut-out block was used, and the effective SSD was 70.7 cm when it was not used (Table 3). These results showed that the difference between both effective SSDs was 8.2 cm in the case of 6 MeV, and the difference was 2.1 cm in the case of 20 MeV. It is thus considered that as the electron beam energy decreases, the difference between the effective SSDs increases (Fig. 4).

From the results of comparing the effective SSD according to the size of the cut-out block with the effective SSD

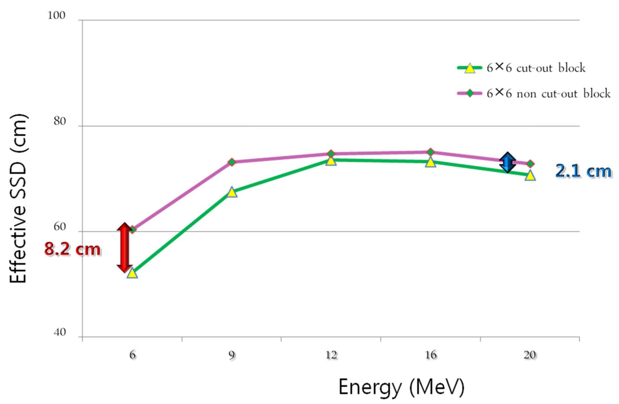

Fig. 4. (Color online) Measurement comparison of each effective source-skin distance when cut-out block was and was not used.

Table 4. Effective source-skin distance for cut-out block size at 6 MeV. Unit: cm^2

	Field size	6 MeV
Cut-out block	6 × 6	60.4
	10 × 10	78.7
	15 × 15	83.4
Non Cut-out block	6 × 6	52.2
	10 × 10	76.2
	15 × 15	62

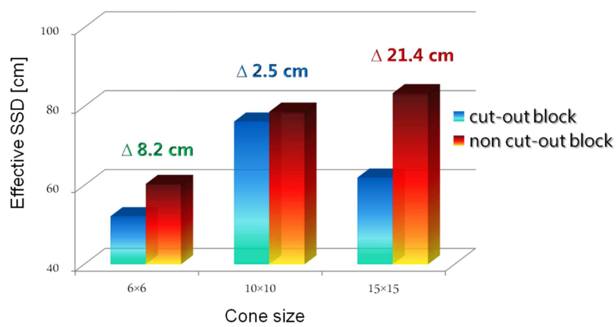

Fig. 5. (Color online) Comparison of effective source-skin distance when each cut-out block was used at 6 MeV.

when the cut-out block was not used at 6 MeV electron beam energy, the effective SSD was measured as 60.4 cm when the size of the cut-out block was 6 × 6 cm, and the effective SSD was 83.4 cm in the case of 15 × 15 cm. When varying the size of the radiation field without using the cut-out block at 6 MeV electron beam energy, the effective SSD was measured as 52.2 cm when the size of the radiation field was 6 × 6 cm^2, and was 62.0 cm in the case of 15 × 15 cm^2 (Table 4). From the result of comparing the effective SSD according to the size of the cut-out block with the effective SSD without using the cut-out block, the difference was 8.2 cm in the case of 6 × 6 cm^2, 2.5 cm in 10 × 10, and 21.4 cm in 15 × 15; the greatest difference was therefore shown in 15 × 15 cm^2 (Fig. 5).

4. Discussion

While the electron beam to be accelerated in a linear accelerator makes up a single energy distribution until it is emitted from the exit, its energy was lost due to the random collision and radiation while passing through the scattering coil, the monitor ion chamber, the two pairs of collimators, the electron cone, the inserted cut-out block, and the tissue composition material; it will also undergo multiple scattering by changing the first direction of movement [5, 6, 10]. Hence, because the dose distribution can be changed due to the multiple scattering of electrons, studies on the multiple scattering have been carried out [11-13]. Lee *et al.* studied the dose distribution of the electron beam according to the manufactured form of the cut-out block in the electron beam therapy. Their results showed that the cut-out block considering the beam diffusion phenomenon made up a uniform dose distribution at the depth of the reference points by more significantly reducing the lateral scattering effect of the thickness of the cut-out block than the cut-out block in which the beam diffusion phenomenon was not considered. As above, a change of the dose distribution occurred due to the multiple scattering in the electron beam therapy. In particular, the electron beam is scattered by the scattering foils, collimator, and applicator, etc.; therefore, in the dose calculation, the distance reverse square-root law was not established and, unlike the photon beam, the dosimetry error will occur if the dose is calculated directly using SSD.

Therefore, in order to solve this problem, the effective SSD should be obtained; this study was thus performed to investigate the importance of using actual measurements of the effective SSD in each electron energy and each radiation field.

From the result, the maximum value of the effective SSD was 87.2 cm and the minimum value was 60.4 cm; the difference was thus about 26.8 cm. Therefore, in the calculation of the electron dose, the effective SSD should be treated as a very important factor. In addition, if the radiation field is increased, the effective SSD is increased in the case of the same energy. In the case of the same radiation field, the effective SSD is increased to a middle energy, and if the energy is increased, the effective SSD is decreased again. Therefore, it is considered that the effective SSD should be used by actually measurement at each electron beam energy and each radiation field.

From the experimental results of the electron beam energy, the difference between the effective SSD when the 6×6 cut-out block was used and the effective SSD when the 6×6 cut-out block was not used was 8.2 cm at 6 MeV and 2.1 cm at 20 MeV; it is therefore considered that as the electron beam energy is reduced, the difference increases.

From the experimental results of the effective SSD for the size of cut-out block at 6 MeV electron beam energy, the difference between this effective SSD and the effective SSD without using the cut-out block was 8.2 cm in the case of 6×6 cm^2, 2.5 cm in the case of 10×10, and 21.4 cm in the case of 15×15; the greatest difference was therefore in the case of 15×15 cm^2.

It is considered that the greatest difference occurred in the case of 15×15 because of the manufactured form of the cut-out block. Therefore, the effective SSD should be actually measured by considering the manufactured form of the cut-out block.

5. Conclusions

The experimental results of this study showed the differences between the effective SSDs in each electron beam energy and radiation field as well as the difference in the effective SSDs according to the use of the cut-out block and the manufactured form. Therefore, for treatment by clinical electron beam, each electron beam energy and radiation field needs to be actually measured, and the use and form of the cut-out block should be actually measured through the dose calculations for the patients.

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