의학물리. 제3권 2호 1992

A Study on Electron Dose Distribution of Cones for Intraoperative Radiation Therapy*

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Abstract

For intraoperative radiation therapy using electron beams, a cone system to deliver a large dose to the tumor during surgical operation and to save the surrounding normal tissue should be developed and dosimetry for the cone system is necessary to find proper X-ray collimator setting as well as to get useful data for clinical use.

We developed a docking type of a cone system consisting of two parts made of aluminum : holder and cone. The cones which range from 4cm to 9cm with 1cm step at 100cm SSD of photon beam are 28cm long circular tubular cylinders. The system has two 26cm long holders : one for the cones larger than or equal to 7cm diamter and another for the smaller ones than 7cm. On the side of the holder is an aperture for insertion of a lamp and mirror to observe treatment field.

Depth dose curve, dose profile and output factor at dept of dose maximum, and dose distribution in water for each cone size were measured with a p-type silicone detector controlled by a linear scanner for several extra opening of X-ray collimators.

For a combination of electron energy and cone size, the opening of the X-ray collimator was caused to the surface dose, depths of dose maximum and 80%, dose profile and output factor. The variation of the output factor was the most remarkable. The output factors of 9 MeV electron, as an example, range from 0.637 to 1.549.

The opening of X-ray collimators would cause the quantity of scattered electrons coming to the IORT cone system, which in turn would change the dose distribution as well as the output factor. Dosimetry for an IORT cone system is inevitable to minimize uncertainty in the clinical use.

Key word : IORT cone system, Electron, Extra X-ray collimator opening, Depth dose curve, Dose profile, Output factor

*This paper was supported by SNUH Research Fund-1987.

Introduction

Intraoperative radiation therapy (IORT) is a rapidly developing treatment modality in radiation therapy. IORT is comprised of a single, large dose fraction of radiation therapy delivered to the tumor or tumor bed during the surgical procedure. The rationale for the use of IORT is to maximize the radiation dose delivered to the neoplastic tissues and to minimize the radiation dose to surrounding normal tissues and thereby improve the therapeutic ratio. The use of electrons in IORT has been the most common to date.

Intraoperative treatments are commonly delivered by a linear accelerator which provides a range of electron energies. For the electron beam to be directed to the tumor, a cone which serves an additional purpose of keeping the normal tissue out of the treatment area is necessary. For IORT a cone system appropriate for hospital's specific treatment unit should be developed because it is not commercially available. Generally, two types of cones are now used over the world. One type is the docking system in which a cone made of plastic or brass is placed in the patient and rigidly attached to a collimation system attached on the machine head. The other type is a non-docking system in which a fixed air gap is maintained between the treatment machine head and the top of the cone placed in the patient.

We developed our own IORT cone system appropriate for Clinac-18 (Varian, USA) being used. Our cone system is of a docking type made of aluminum providing circular fields. The cone system is composed of two parts ; holder and cone. Diameter of cones ranges from 4cm to 9cm with 1cm step.

Even though the dose by electrons coming directly from scattering foils are of main part, electrons scattered on movable X-ray collimators and other field-defining cone would considerably contribute to the dose. The scattered electrons could be grouped three parts. The first group is scattered from the x-ray collimators only, the second from the cone system only, and the third from the cone system after scattered from the X-ray collimators. So, the quantity and properties of scattered electrons, including spectral and directional distributions depend on both the opening of the movable X-ray collimators and the material, dimension and shape of the IORT cone system. The quantity and properties of scattered electrons should also affect electron dose. Because the collimator opening and the cone system change the ratio of lower-energy electrons and the direction of scattered electrons differs from the direction of primary electron beam, they contribute to the change of dose, specifically in the region at swallow depth. Thus, they should affect the surface dose, depth of dose maximum, dose profile and output factor.

To apply a cone system to intraoperative radiation therapy, dosimetry related to the cone system is necessary for the selection of the appropriate electron beam energy and cone size to cover the target volume. Also, dosimetry is necessary for an X-ray collimator setting to get the acceptable dose profile and output factor. In IORT, generally, high output factor is desirable for reduction of treatment time. The acceptable dose profile and high output factor would not be coexistent.

Materials and Method

Our cone system for intraoperative radiation therapy consists of two parts made of aluminum (Figure 1) : holder and cones. The holder attached on the head of a radiation treament unit has the functions to fix a cone for the head and to prevent the stray radiation from contributing to dose out of treatment field. The upper part of the holder is an aluminum disk of 40cm diameter and 1cm thickness and has an aperture for electron beam. Three nuts on the head of Clinac-18 (Varian, USA) are used to fix the disk with 3 holes coinciding the nuts. A 3cm thick block and a circular tubular cylinder are fixed to the disk. The aterture of the 3 parts is a single circular duct. Three bolts to hold a cone are on the lower part of the cylinder. An aperture for the purpose of insertion of a lamp and mirror for observation of treatment field is on the wall of the holder. Our system has two 26cm long holders of different aperture diameter : one for the cones larger than or equal to 7cm diamter and one for the cones smaller than 7cm diameter.

The aluminum cones were 28cm long circular tubular cylinders. The size of field by cones ranger from 4cm to 9cm with 1cm step. At the upper end of each cone is a 3cm long ring-shaped adaptor with unifrom thickness. The adaptor fills up a gap between a cone and tubular holder to stop leakage electrons through the gap. The adaptor is fitted to the holder to minimize lateral shift and leaning of the cone. However, before the cone is not tightened by the bolts, the cone can freely move up and down through the holder duct. The lower tip of the cones is on the gantry axis.

A p-type diode (Therados, Sweden) controlled by a semi-automatic linear scanner (LSC-2, Therados, Sweden) was used to measure depth dose curve, dose profile and dose distribution in a water phantom. Farmer type ionization chamber (PR-06C, Capintec, USA) connected to an electrometer (35616, Keithley, USA) was used to measure the output factor in a water phantom.

Dosimetries for electron beams with nominal energy 9, 12 and 15 MeV of Clinac-18 (Varian, USA) were made for several combinations of cone size and movable X-ray collimator setting. The smallest collimator settings were by 1 or 2cm larger than cone diameter at 100cm SAD from X-ray target : 2cm for 4 to 6cm cones and 1cm for 7 to 9cm cones. The larger collimator settings were by 6, 11 and 16cm larger than cone diameter for whole cones.

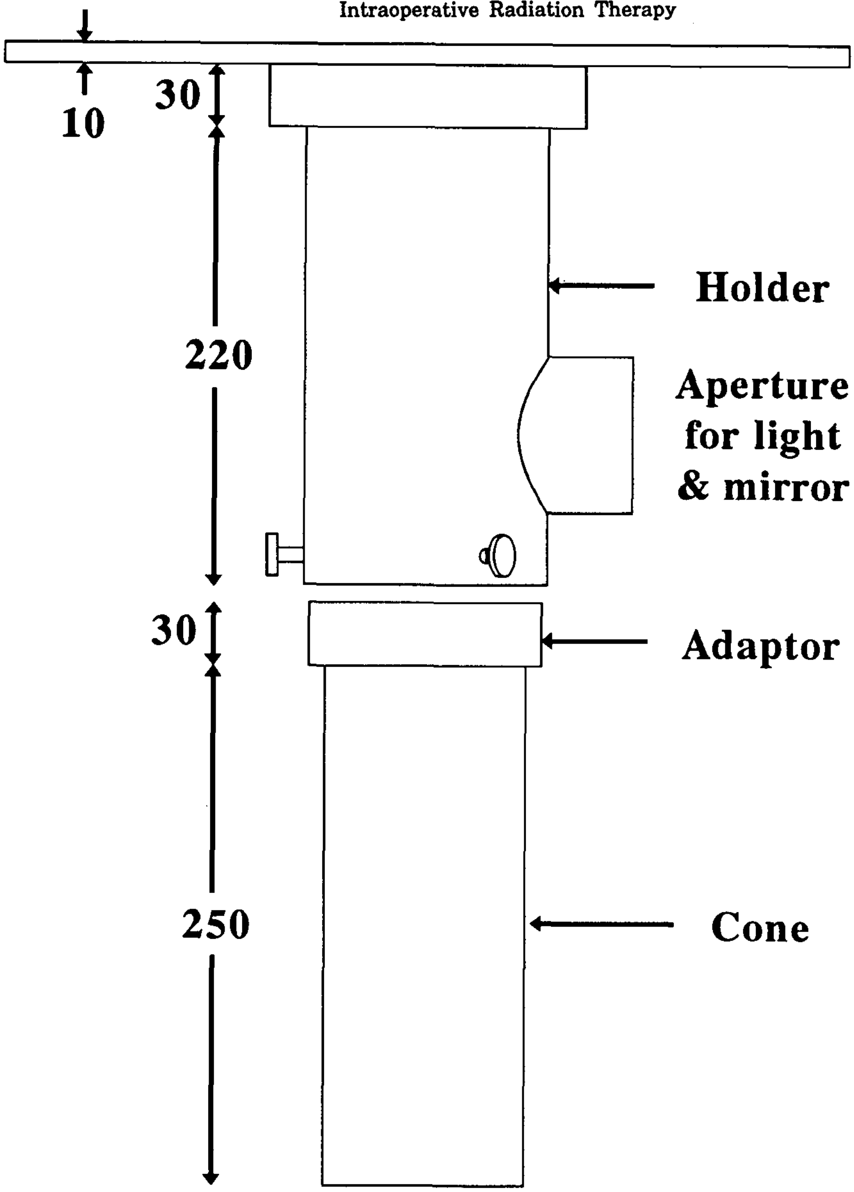

Figure 1. Schematic diagram of our cone system for intraoperative radiation therapy. The cone system comprises two parts ; holder and cones. The field size by cones ranges from 4cm to 9cm with 1cm step. The unit of dimension is mm.

The depth dose cunes measured on the beam axis were used to analyse surface dose, the depth (d_{max})of dose maximum and treatment depth (d_{80}) for each combination of a cone size and X-ray collimator setting. The dose profile measured at the depth of dose maximum was used to analyse dose flatness for the combination of a cone size and X-ray collimator setting. The dose distribution was made integrating dose profiles measured at 7 different depths. The output factor was defined by the ratio of the ouput at d_{max} to monitor unit (MU).

Result

The depth dose curves of 9, 12 and 15 MeV electron beams for 4cm and 9cm aluminum cones for different X-ray collimator settings are compared in Figure 2.

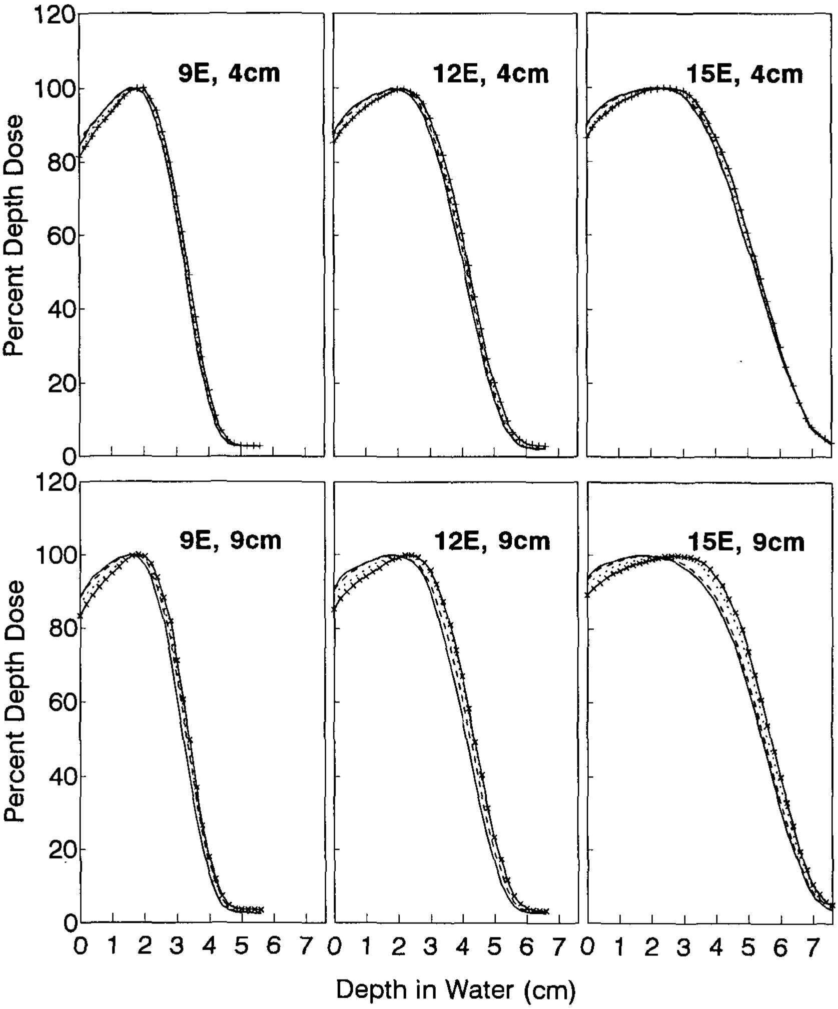

Figure 2. Comparison of depth dose curves of electron beams for same cone with different X-ray collimator setting. The cone sizes are 4cm for upper and 9cm for lower. The extra openings of X-ray collimtors are depicted like as: 1cm, 2cm, 6cm, 11cm and : 16cm.

Each depth dose curve was normalized to its maximum dose. As the opening of X-ray collimators increased, the depth of maximum dose was shifted to surface. The shift was larger for the larger cone size. For low energy electron beam like 9 MeV, the shift was negligible, while for higher energy electron beams, the higher the electron beam energy and the larger the cone size, the more significant the shift.

For 15 MeV electron beam of cone size 9cm, the shift of dose maximum point for X-ray collimator setting 25×25cm from that for small setting like as 10×10cm was approximately 1.1cm toward the surface. The shift of depth (d_{80}) of 80% dose relative to the maximum, generally accepted as treatment depth, showed the same phenomena as that of depth of dose maximum as shown in Figure 2. As the X-ray collimator setting increased, the surface dose for the same electron energy and same cone size increased. The higher the electron energy and the larger the cone size, the increase of the surface dose was the more significant. In the sharp fall-off region of dose, dose gradient was decreased as the collimator setting increased for the same cone size. However, the change of practical range was negligible for the change of the cone size and collimator setting.

The depth dose curves of 9, 12 and 15 MeV electron beams for 3 different aluminum cone sizes, 4, 6 and 9cm, are shown in Figure 3. The extra opening of X-ray jaws, a side of field over cone diameter, was simplified as 6cm for different size of cones. For each electron energy, the depth dose curves were nearly independent of the cone size.

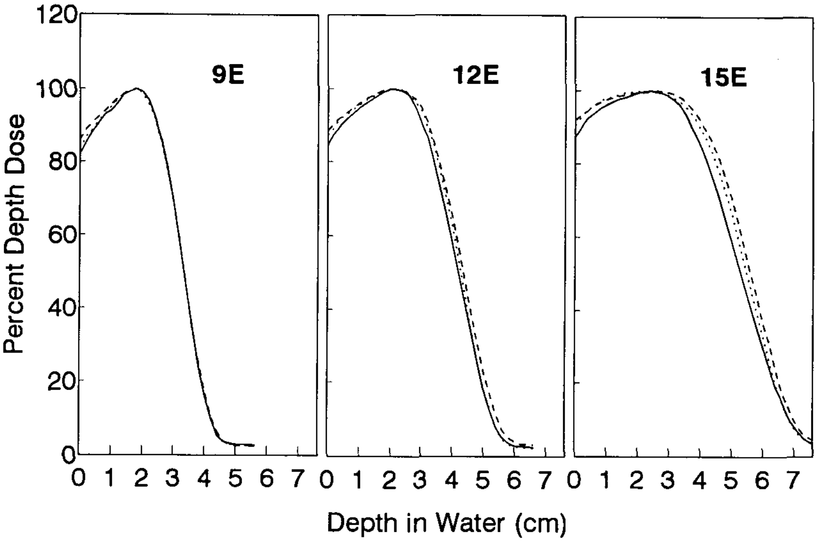

Figure 3. Comparison of depth dose curves of electron beams for 3 different aluminum cone sizes with the same extra opening of X-ray collimator. The extra opening of X-ray collimators was 6cm. The cone size are depicted as:—;4cm ···;6cm and —;9cm.

Some dose profiles of 9, 12 and 15 MeV electron beams for 2 aluminum cone sizes, 5 and 9cm, are shown in Figure 4. They are compared for different extra opening of X-ray collimators. They were measured at the depth of dose maximum of the field with the smallest extra opening of the X-ray collimators. For a cone size 5cm, the shape of dose profiles for each electron energy was changed but nearly independent of the extra opening of the X-ray collimators. For a cone size 9cm without regard of electron beam energy, in contrast to the smaller cone size,

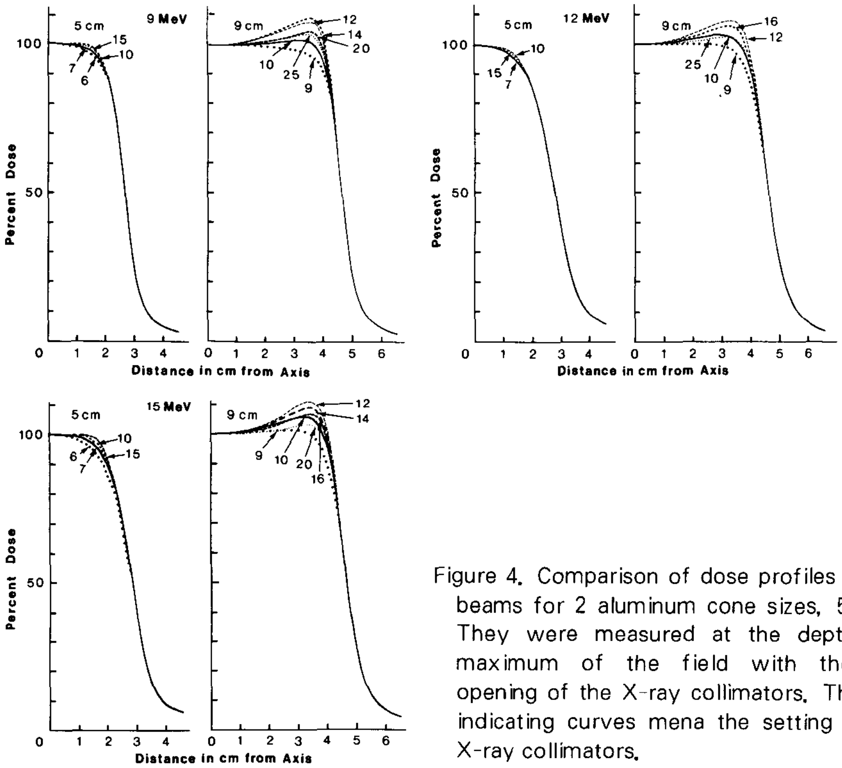

Figure 4. Comparison of dose profiles of electron beams for 2 aluminum cone sizes, 5 and 9cm. They were measured at the depth of dose maximum of the field with the smallest opening of the X-ray collimators. The numbers indicating curves mena the setting (in cm) of X-ray collimators.

the shape of dose profile changed with the extra opening of the X-ray collimators, specifically with a horn in the inner region close to field margin. As an extra opening of x-ray collimators was increased, the horn increased for the extra opening smaller than a specific one and next decreased. Then, the extra opening was a measure of 3 or 4cm, dependent on the electron energy. For 15 MeV electron with 9cm cone, the horn was 113% for 3cm extra opening of X-ray collimators. As the extra opening of the X-ray collimators was increased, the dose profile was more flattened.

Output factors of 3 electron energies for different aluminum cone sizes and extra X-ray collimator opening are shown in Figure 5. The dependence of the output factors on the cone size and the extra opening of X-ray collimators is remarkable. The variation of output factors reduced as the electron energy increased. One example of the most remarkable dependence of output factor on the extra collimator opening is 9 MeV electron with 4cm cone. The minimum and maximum of the output factors are 0.637 for 2cm extra collimator opening and 1.135 for 16cm extra collimator opening (Figure 5 and Table 1). The output factor generally increased with the extra collimator opening but for some cone sizes showed a tendency to decrease for large extra collimator opening like as 16cm. For each group of cone sizes, the small and the large which are classified by the

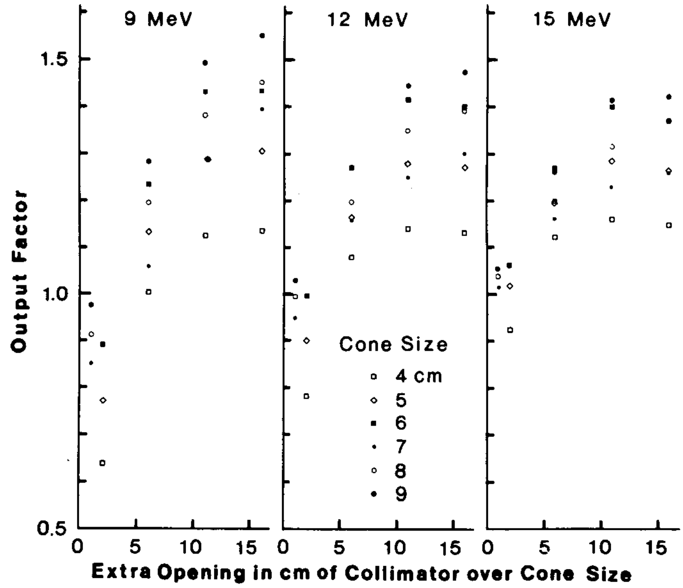

Figure 5. Output factors of 3 electron energies for different aluminum cone sizes and extra X-ray collimator opening. Both the cone size and the extra opening of X-ray collimators are the most important factors to affect to the output factors of IORT cone system.

Table 1. Output factors of electron beams with IORT cone. The values of electron energies are nominal.

Energy	Cone Size	Extra opening of X-ray collimator over cone size				
		1cm	2cm	6cm	11cm	16cm
9MeV	4cm		·637	1.003	1.126	1.135
	5		·771	1.133	1.287	1.304
	6		·891	1.235	1.430	1.434
	7	·850		1.159	1.287	1.395
	8	·911		1.195	1.382	1.451
	9	·974		1.285	1.492	1.549
12MeV	4cm		·781	1.079	1.139	1.134
	5		·900	1.166	1.280	1.271
	6		·996	1.274	1.412	1.401
	7	·949		1.167	1.250	1.299
	8	·993		1.197	1.348	1.394
	9	1.029		1.270	1.450	1.474
15MeV	4cm		·924	1.123	1.162	1.147
	5		1.107	1.193	1.285	1.265
	6		1.061	1.270	1.401	1.371
	7	·1.014		1.162	1.229	1.261
	8	·1.036		1.179	1.316	1.343
	9	·1.056		1.262	1.417	1.422

adaptation to cone holder, the output factor increased with the cone size. The variation of output factor by the cone size increased with the extra collimator opening but was less remarkable than the output factor variation by the extra collimator opening.

The size of the holder also affected to output factor. For larger extra opening of X-ray collimators than 6cm, the output factors of 6cm cone attached to the small size holder were higher that those of 7cm cone attached to the large holder (Table 1).

Dose distributions for 7cm aluminum cone with 1cm extra X-ray collimator opening are shown in Figure 6. For 12 and 15 MeV electron beams, there are some high dose areas in off-axis region and buildup region. This is closely related to the horn in the off-axis region.

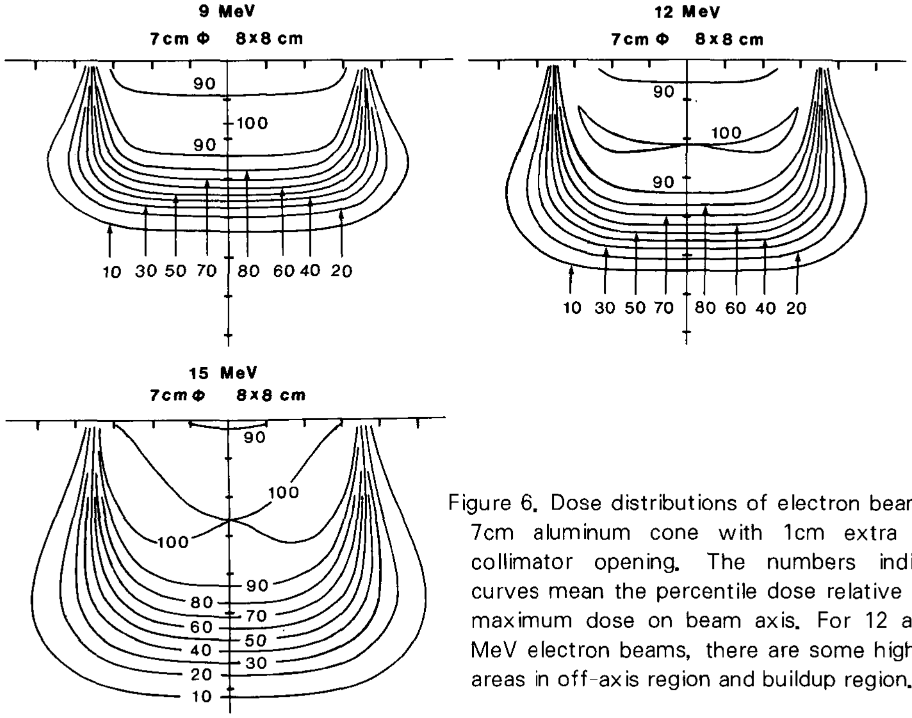

Figure 6. Dose distributions of electron beams for 7cm aluminum cone with 1cm extra X-ray collimator opening. The numbers indicating curves mean the percentile dose relative to the maximum dose on beam axis. For 12 and 15 MeV electron beams, there are some high dose areas in off-axis region and buildup region.

Discussion

In our study, the surface dose monotonously increased with the extra opening of X-ray collimators and the cone size, but the changes were negligible. McCullough[5], Biggs[11] and Fraass[13] using a docking type cone system reported that the surface dose was nearly independent of the setting of X-ray collimator. Their results are similar to ours. In the analysis of the relation between the surface dose and the cone size, McCullough[5] reported that the surface dose had a minimum value for certain cone size dependent on the electron energy, but Biggs [11] report did not show any regularity. This disagreemnet in the dependence of surface dose on the cone size would be related to measuring method. For measurement of surface dose, we used a p-type silicone detector in water, McCullough⁵⁾ used film in polystyrene and Biggs¹¹⁾used a parallel-plate ionization chamber in solid.

As the opening of X-ray collimators increased, the depths of maximum dose and d_{80} were shifted to surface, particularly, for higher energy electron beam, 12 and 15 MeV. The shifts were larger for the larger cone size. The results of Fraass¹³⁾ and McCullough⁵⁾ were similar to ours. Nyerick⁹⁾ reported that when the cone size increased the depth of 90% dose was nearly constant for low energy such like 6 MeV but increased for the higher energy. In his early report, Biggs⁶⁾ reported that for small intra-oral cone the cone size larger the deeper the depths of dose maximum and d_{80} were for 15 MeV electron. In other report¹¹⁾, on the other hand, he reported that the depths of dose maximum and d_{80} shifted to surface for low energy such like 9 MeV but were constant for high energy such like 29 MeV.

In our study, the dose profile was seen for 3 to 4cm extra X-ray collimator opening. For the larger extra collimator opening than 3 to 4cm, as the extra opening increased the horns were lowered and the flatness bettered. Fraass¹³⁾ also reported similar results. Bagne¹²⁾ showed results, similar to us, that the horn increased with the extra opening of X-ray collimator for small extra opening like as 1cm or less. Biggs¹¹⁾ result that when the opening of X-ray collimators increased, the in-field dose near field margin decreased was similar to us. His result, however, showed that there did not exist any horn on dose profile of 9 and 21 MeV electrons for 7cm cone and the flatness was rather lowered as the opening of X-ray collimators increased. Maybe Biggs results could be related to the secondary collimator adapted from a cobalt unit.

The output factor for each electron beam energy was closely related to both the cone size and the extra opening of X-ray collimators. In our study, the output increased with the cone size. And there is a certain extra collimator opening with maximum output fator. The extra opening over cone size was about 10cm. So, we could recommend 10cm as "optimal"extra opening of X-ray collimators because of the high output factor and the reasonable flatness. Biggs¹¹⁾ recommended 15× 15cm as the "optimal"X-ray collimator opening.

Conclusion

We made an IORT cone system made of aluminum for Clinac-18. On dosimetry with our IORT cone, we analyzed several dosimetric parameters with the variation of cone size and the opening of X-ray collimators. In this study we could get some conclusions like as followings:

1. Dosimetric changes are closely related to the electrons scattered from the cone system.

2. Output factor is a parameter with the most remarkable change related to the

setting of X-ray collimators.

3. Extra opening 10cm of X-ray collimators over cone size would be "optimal" for both high output factor and flat dose profile.
4. Dosimetry on IORT cone system is necessary for reduction of uncertainty in clinical use.

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수술중 전자선치료에 있어서 선량분포에 관한 연구

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전자선을 이용한 수술중 방사선치료를 위해서는 수술중에 드러내 놓은 종양에 고선량의 방사선을 조사하되 주변 정상 조직을 보존하기 위하여 cone 장치를 개발할 필요가 있으며, 임상에 필요한 자료를 얻는 것 뿐만아니라 콜리메이터에 의한 적정 X-선 창 크기도 정할 필요가 있다.

holder와 cone으로 이루어진 알루미늄제 결합형 cone장치를 개발하였다. 광자선의 SSD 100cm에서 조사면 크기가 직경 4~9cm이면서 1cm씩 차이가 있는 28cm길이의 원통형 cone을 만들었으며, holder는 cone의 직경이 7cm이상인 것과 미만인을 것을 접속시키기 위해 따로 두 개를 만들었다. holder의 측면에는 조사부위를 관찰하기 위한 거울과 조명등을 삽입할 수 있는 개구부를 두었다.

cone에 의한 조사면 크기와 콜리메이터에 의한 X선 창의 크기의 여러 가지 결합에 대하여 수중의 전자선의 깊이선량분포곡선 및 측방선량분포곡선, 선량분포를 1차원 물팬톰 장치로 조종하는 p-형 실리콘 검출기로 측정하였다. 출력계수도 p-형 실리콘 검출기로 수중에서 측정하였다.

전자선의 에너지와 cone의 크기의 결합이 일정할지라도 콜리메이터에 의한 X-선 창의 크기는 표면선량 및 최대신량점의 깊이, 80% 선량점의 깊이, 측방선량분포, 출력계수에 영향을 미쳤다. 그중, 출력계수의 변화가 가장 현저하였다. 예로서 9 MeV 전자선의 출력계수는 0.637과 1.549의 범위에 있었다.

콜리메이터에 의한 X-선 창의 크기는 수술중 전자선치료용 cone 장치의 벽으로 향하는 산란전자의 양에 영향을 미치고, cone장치에서 다시 산란된 전자는 출력계수 뿐만 아니라 선량분포도 바꿀 것으로 생각된다. 따라서 수술중 전자선치료용 cone장치에 대한 선량분포 측정은 임상에서 선량의 불확정도를 최소화하기 위해 필수적이다.