The dosimetric Properties of Electron Beam Using Lyon Intraoperative Device for Intraoperative Radiation Therapy

Kye Jun Kim, B.S., Kyung Ran Park, M.D., Jong Young Lee, M.D.
Hie Yeon Kim, M.D., Ki Joon Sung, M.D.*, and Sung Sil Chu, Ph.D.**

Department of Radiation Oncology, Radiology, Yonsei University Wonju College of Medicine, Wonju, Korea*
*Department of Radiation Oncology**, Yonsei University, College of Medicine, Seoul, Korea*

We have studied the dosimetric properties of electron beam using Lyon intraoperative device for intraoperative radiation therapy. The dosimetry data had compiled in such a way that a quick and correct decision regarding the cone shape, energy, and accurate calculations could be made.

Using 3 dimensional water phantom, we have got the following data: cone output ratios, surface dose, d_{max}, d_{90}, flatness, symmetry, beam profiles, isodose curve, and SSD correction factors.

The cone output ratios were measured with straight and bevelled cone, respectively. As the cone size and the energy were reduced, the cone output ratios decreased rapidly. With the flattening filter, the surface dose increased by electron beam to 85.3%, 89.2%, and 93.4%, for 6 MeV, 9 MeV, and 12 MeV, respectively. It is important to increase the surface dose to 90% or more. Inspite of diminishing dose rate and beam penetration, this flattening filter increases the treatment volume significantly. With the combination of the three levels collimation and the flattening filter, we achieved good homogeneity of the beam and better flatness and the diameter of the 90% isodose curve was increased. It is important to increase the area that is included in the 90% isodose level. The value of measured and calculated SSD correction factors did not agree over the clinically important range from 100 cm to 110 cm.

Key Words: Intraoperative Radiotherapy, Electron Beams, Dosimetry, Lyon Intraoperative Device

INTRODUCTION

In Intraoperative Radiotherapy (IORT), a large single fraction of radiation is delivered to a well defined volume of tissue, and dose characteristics of the beam become very important.

We have a Lyon Intraoperative Device (ARPLAY Corporation, Izeure, France) system for intraoperative irradiation which has been designed at the Radiation Oncology Department of Lyon Sud hospital system. This consists of two main component systems. Localizer applicators and their accessories (beam limiting rings, beam blocks, etc.) which are sterilized and positioned in the sterile conditions of the operating room. Pantographic non sterile adaptor is used only in the radiation treatment room. Lyon Intraoperative Device (LID) system provides patient safety. LID system provides good electron beam quality. It is a flattening filter to increase the irradiated volume, to ensure a dose at least equal to the prescription at the entrance portal, to minimize the hot spots when using bevelled applicator.

It is the purpose of this paper to describe the dosimetric properties of the LID for intraoperative radiation therapy.

MATERIALS AND METHOD

Clinac 1800 linear accelerator has been used for dosimetry of IORT at our institution. The dosimetry for IORT was practiced by an electron beam with electron energies from 6 to 18 MeV. This energy range corresponds to a depth range from 1.7 to 5.1 cm at the 90% dose level. For dosimetry of IORT a commercial water scanning system and a film densitometer scanning system (MULTIDATA Corporation, St louis, Mo) was used. Depth dose and beam profiles were measured with PTW cylindrical ion chamber of sensitive volume 0.1 cm^3 biased to -300 V and used in ratio mode. Surface dose and build up region were measured with the Memorial parallel plate chamber and the Markus (PTW) electron beam chamber. The cone output ratios and SSD corrections were performed using 3 dimensional water phantom scanning system. The accelerator output were measured using a Farmer type chamber, a Memorial parallel plate chamber, and a Victron 500 electrometer with the ion chamber in a polystyrene phantom. The film densitometer was used for a measurement of isodose curves in plane perpendicular to central axis. We practiced by using a gantry angle 0° and 30° for straight cones and bevelled cones (30° angle).

The apparatus (LID) which we utilize for intraoperative irradiation is consisted of pantographic adaptor, set of cylndrical tube (in persplex, 90 mm, 110 mm diameter), tube of cone with plate base, tube of cone with bevelled base (30° angle), lead 2nd beam limiter, chrome plated brass rings (3rd beam limiter: 40, 50, 60, 70, 80, 90 mm), LEXAN flattening filter plates. The main parts are the pantographic adaptor and the localizing tubes (cone). The pantographic adaptor is an intermediate device which is placed between the head of the accelerator and the selected localizing cone. It ensures that the cone is mounted securely to the head. The adaptor is formed of two parts: superior, and inferior part. The superior part is adapted well to be fitted easily and rapidly into the head of the accelerator. The inferior part is supplied by a circular bed in which the top of the selected localizing cone is rested during the irradiation. This part has a drawer in which both the secondary collimator and the flattening filter can be slided. In our department, we have a group of two pairs of localizing cones of different cross-section. They are made of altuglass, taking a tubular from with circular cross section (Fig. 1). The tube of cone is 18 cm in length with wall thickness of 5 mm. The superior end of the cone is supplied by a male, cylindric, standard part which ensures solid fitting into the adaptor. The inferior end may be either straight or bevelled. 3 cm aobve the edge, a brass ring is fixed to the internal surface of the tube. This ring functions as a carrier for other removable rings of complex forms. These supplementary rings are considered as third collimator.

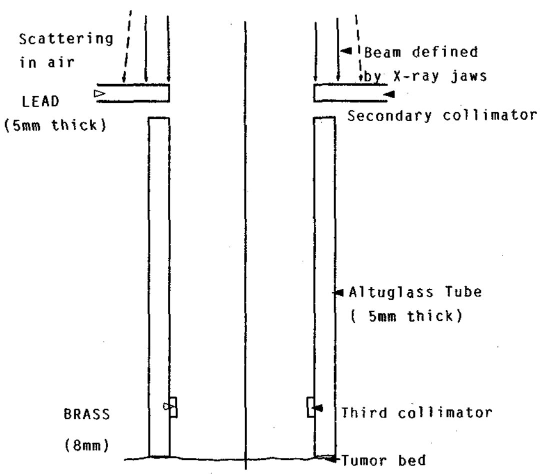


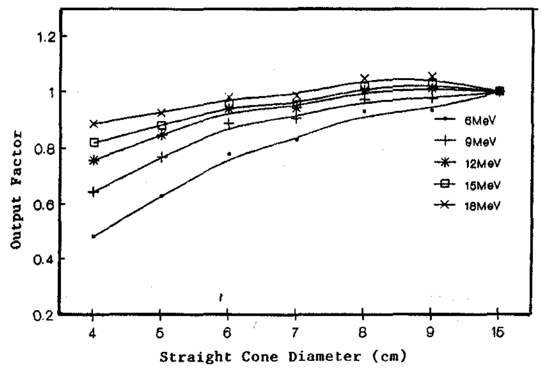
Fig. 1. Secondary and third collimators.

RESULTS

1. Cone Output Ratios

Cone output ratios (i.e., given dose per monitor unit-MU) must be determined for each applicator and for all possible energies.

This calibration is performed prior to each intraoperative procedure using the standard 15×15 cm² electron applicator for the same number of monitor units of beam delivered[1,2,3]. LID electron applicator which we utilize for intraoperative irradiation is formed of three main collimator. The primary collimator (X-ray jaws) was setting 28×31 cm² field size at SSD 100 cm. Six secondary collimator (a plate of lead in the drawer at the bottom of the panto-graphic adaptor) were supplied by LID limiting the possible treatment fields from ϕ3.8 cm to ϕ8.8 cm. Six third collimator (the ring of brass which is just above the inferior edge of the localizing cone near the target) were the following size: ϕ 4 cm, ϕ5 cm, ϕ6 cm, ϕ7cm, ϕ8cm, ϕ9cm. When LID electron applicator are used, the manufacturer recommends that the secondary collimator setting is to be larger than the third collimator.



(except 15 x 15 cm square cone)

Fig. 2. Cone size dependence of 6, 9, 12, 15, and 18 MeV electron beams from the Clinac 1800, Circular (straight) cone. Relative Output Factors are normalized to 15×15 cm field size.

The cone output ratios were measured with straight and bevelled cone, respectively. The cone output ratios measured in water for a range of circular diameter sizes from 4 cm to 9 cm and 15×15 cm^2 square field sizes. These measurements were carried out in water at d_{max} at 100 cm SSD. All readings were normalized to a 15×15 cm^2 square field size cone. The straight and bevelled cone output ratio factor as a function of field size for each electrons are shown in Fig. 2, Fig. 3, respectively. Output ratios for straight and bevelled cone are shown in Table 1 and 2, respectively.

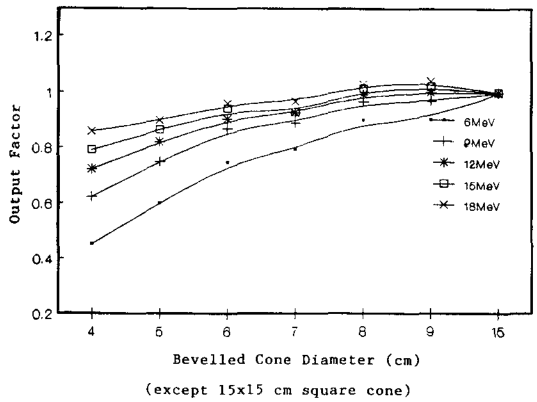


Fig. 3. Cone size dependence of 6, 9, 12, 15, and 18 MeV electron beams from the Clinac 1800, Circular (bevelled) cone. Relative Output Factors are normalized to 15×15 cm field size.

2. Depth Dose

The percentage depth dose in this study was defined at a depth in central axis and measured with 0.1 cm^3 ionization chamber in water phantom and with plane parallel plate chamber in polystyrene phantom. Fig. 4 show percentage depth dose at various energies and cone types (straight and bevelled.) The dosimetric characteristics of all energy derived from the depth dose data are presented in Table 3, 4. Table 5 shows the surface dose and depth of 90% isodose curve at the cone diameter of 7 cm. Surface dose values should be as high as possible, preferably in excess of 90%, since the prescribed tumor dose is usually defined at the depth corresponding to 90% of the dose at d_{max}. As

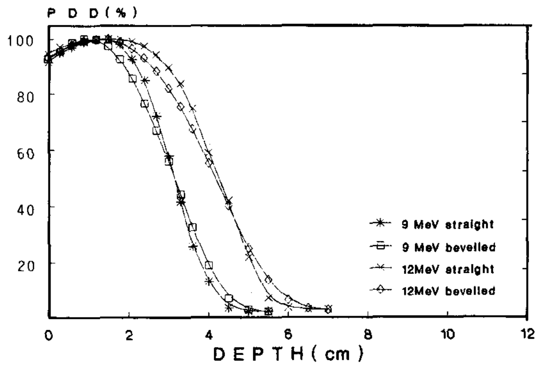


Fig. 4. Comparison of percent depth dose of straight cone to bevelled cone.

Table 1. Relative Output Factors for the Various Straight Cone Size on Clinac 1800 at D_{max} of 15×15 cm^2 Applicator (SSD =100 cm, D_{max} normalized).

Cone Size Energy	Φ4 cm	Φ5 cm	Φ6 cm	Φ7 cm	Φ8 cm	Φ9 cm	15×15
6 MeV	0.481	0.628	0.778	0.827	0.928	0.933	1.00
9 MeV	0.645	0.769	0.888	0.904	0.973	0.976	1.00
12 MeV	0.758	0.847	0.940	0.941	1.047	1.012	1.00
15 MeV	0.819	0.878	0.955	0.952	1.018	1.029	1.00
18 MeV	0.855	0.924	0.980	0.985	1.046	1.053	1.00

Table 2. Rselative Output Factors for the Various Bevelled Cone Size on Clinac 1800 at D_{max} of 15×15 cm^2 Applicator (SSD=100 cm, D_{max} normalized).

Cone Size Energy	Φ4 cm	Φ5 cm	Φ6 cm	Φ7 cm	Φ8 cm	Φ9 cm	15×15
6 MeV	0.453	0.600	0.747	0.792	0.899	0.9021.00	
9 MeV	0.623	0.750	0.869	0.890	0.967	0.970	1.00
12 MeV	0.723	0.820	0.905	0.925	0.993	0.996	1.00
15 MeV	0.792	0.863	0.941	0.926	1.013	1.020	1.00
18 MeV	0.857	0.898	0.959	0.967	1.028	1.0403	1.00

Table 3. Straight Cone (without and with flattening filter) Depth dose for the Electron Beams on the Clinac 1800

Energy Depth	6 MeV	9 MeV	12 MeV	15 MeV	18 MeV
D_{max}	1.1 (0.9)	1.7 (1.5)	2.2 (1.8)	1.5 (1.5)	0.8 (0.7)
surface (1 mm)	83% (85.3)	87.6%(89.2)	92.7%p(93.4)	96.5%(96.7)	97.6%(97.8)
90%	1.56(1.41)	2.49(2.31)	3.34(3.16)	3.96(3.78)	4.01(3.70)
80%	1.73(1.59)	2.78(2.61)	3.73 (3.56)	4.57(4.38)	5.09(4.85)
70%	1.88(1.74)	3.00(2.84)	4.01(3.84)	4.93(4.78)	5.74(5.35)
60%	2.01(1.87)	3.19(3.04)	4.27(4.09)	5.25(5.10)	6.23(6.03)
50%	2.13(1.99)	3.37(3.23)	4.49(4.34)	5.54(5.04)	6.65(6.44)
40%	2.26(2.11)	3.54(3.39)	4.73(4.54)	5.83(5.68)	7.04(6.84)
30%	2.38(2.24)	3.73(3.58)	4.93(4.79)	6.11(5.97)	7.41(7.21)
20%	2.54(2.37)	3.93(3.78)	5.17(5.04)	6.44(6.27)	7.84(7.65)
10%	2.73(2.55)	4.19(4.06)	5.53(5.39)	6.88(6.73)	8.40(8.24)
Rp	2.75(2.60)	2.23(4.09)	5.55(5.40)	6.88(6.72)	8.46(8.29)
X-ray contami -nation	0.4%(0.5)	1.1%(1.2)	1.5%(1.6)	2.0%(1.9)	2.2%(2.2)

( ): with flattening filter

Table 4. Bevelled Cone (without and with flattening filter) Depth dose for the Electron Beams on the Clinac 1800.

Energy Depth	6 MeV	9 MeV	12 MeV	15 MeV	18 MeV
D_{max}	0.8 (0.8)	1.3 (1.1)	1.6 (1.5)	2.0 (1.7)	1.3 (0.8)
surface (1 mm)	85.8% (90.2)	87.3%(91.1)	90.3%(92.1)	93.5%(95.3)	96.7%(98.3)
90%	1.37(1.61)	2.14(1.94)	2.83(2.64)	3.51(3.31)	3.83(3.72)
80%	1.60(1.39)	2.49(2.29)	3.31 (3.11)	4.09(3.93)	4.69(4.60)
70%	1.79(1.60)	2.78(2.61)	3.68(3.53)	4.58(4.38)	5.33(5.23)
60%	1.99(1.78)	3.04(2.84)	4.04(3.86)	5.00(4.81)	5.86(5.78)
50%	2.16(1.95)	3.23(3.11)	4.36(4.18)	5.38(5.19)	6.39(6.29)
40%	2.34(2.13)	3.56(3.38)	4.69(4.51)	5.78(5.61)	6.87(6.76)
30%	2.51(2.30)	3.84(3.63)	5.00(4.84)	6.20(6.01)	7.40(7.26)
20%	2.71(2.50	4.13(3.94)	5.36(5.18)	6.62(6.44)	7.97(7.83)
10%	2.94(2.76)	4.50(4.31)	5.88(5.70)	7.23(7.07)	8.75(8.59)
Rp	3.00(2.82)	4.58(4.36)	5.89(5.73)	7.23(7.07)	8.73(8.54)
X-ray contami -nation	0.6%(0.4)	1.2%(1.1)	1.6%(1.5)	1.9%(1.9)	2.2%(2.3)

( ): with flattening filter

Table 5. Surface dose & Depth of the 90% Isodose Level vs. Electron Energy for 7 cm Circular Cone.

Energy		6 MeV	9 MeV	12 MeV	15 MeV	18 MeV
Depth dose at 1 mm	ST	83.0	87.6	92.7	96.5	97.6
	ST (F)	85.3	89.2	93.4	96.7	97.8
	BV	85.8	87.3	91.1	95.3	96.7
	BV (F)	90.2	91.1	92.1	95.3	98.3
Depth of the 90%	ST	1.56	2.49	3.34	3.96	4.01
	ST (F)	1.41	2.31	3.16	3.78	3.70
	BV	1.37	2.14	2.83	3.51	3.83
	BV (F)	1.16	1.94	2.64	3.31	3.72

ST: straight cone BV: bevelled cone
(F): with flattening filter

the electron energy was raised, the surface dose increased[4~6]. For energies greater than 12 MeV, the surface dose was increased to 92.7% and it decreased to 83% and 87%, which for 6 MeV and 9 MeV. Using the flattening filter, the surface dose increased to 85.3% and 89.2%, for 6 MeV and 9

MeV, respectively.(Fig. 5).

A representative set of depth dose profiles which compare with flattening filter to without flattening filter are shown in Fig. 6. We compared a straight cone to a bevelled cone at each energy. (see Fig. 4). There are 2~5 mm difference between depth dose of straight cone and depth dose of bevelled cone type at all energy. We measured central axis percentage depth dose curves, in water for different field sizes at each energy (Fig. 7). The depth of maximum dose shifts by more than 1~3 mm as the field size is decreased from ϕ 9 cm to ϕ 4 cm.

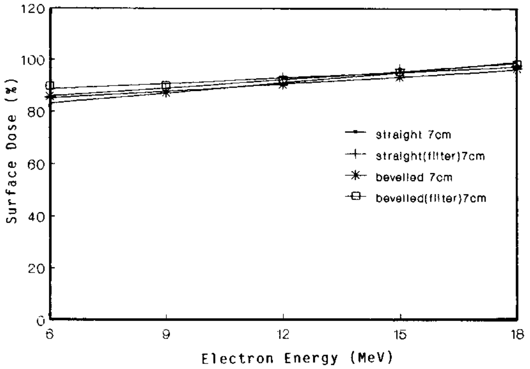


Fig. 5. Surface dose Vs. Electron energy for 7 cm Circular cone.

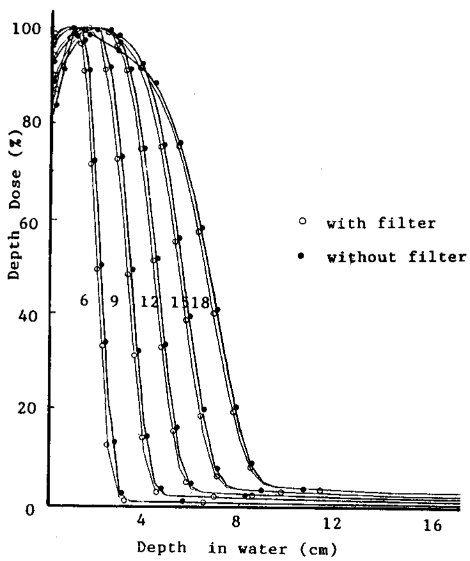


Fig. 6. Comparison of percent depth dose variation with equalizing filter to without equalizing filter.

The depth of maximum dose, d_{max} as measured along the central axis, must be known for the determination of cone ratio. Examination of the our institution data for the Clinac 1800 revealed that d_{max} varied only a few millimeters from the d_{max} value for the intraoperative applicator varied.

3. Beam Profiles and Isodose Curves

The shapes of the isodose charts and cross beam profiles from the LID electron applicator are influenced by the design of the applicator system and the setting of the X-ray jaws (primary collimator) which are used with each applicator[1,7~10]. These effects are complicated by the bevelled applicators and straight applicator shapes which are used for IORT. Eight beam profiles and a central axis depth dose curve were measured in order to generate isodose curves. Isodose curves were measured at each energy for these field size: straight applicator ϕ 4 cm, ϕ 5 cm, ϕ 6 cm, ϕ 7 cm, ϕ 8 cm, and ϕ 9 cm, bevelled applicator ϕ 4 cm, ϕ 5 cm, ϕ 6 cm, ϕ 7 cm, ϕ 8 cm, and ϕ 9 cm.

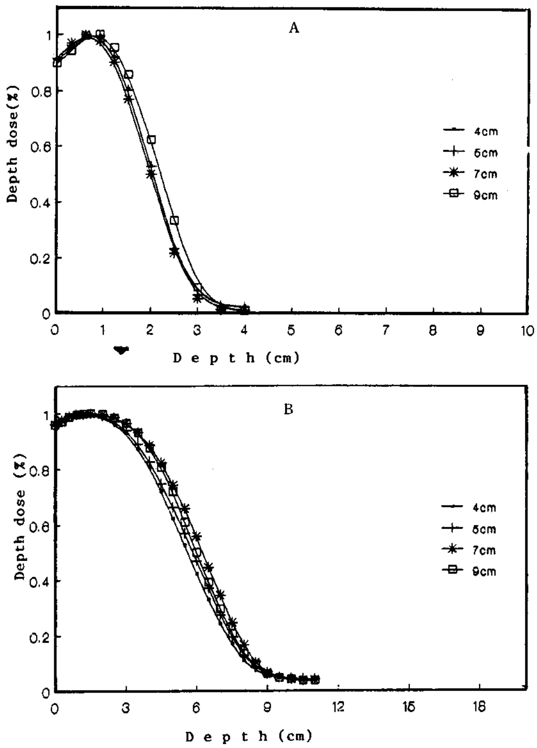


Fig. 7. Central axis percent depth dose curves in water for four different bevelled cone sizes
(a) 6 MeV, (b) 18 MeV

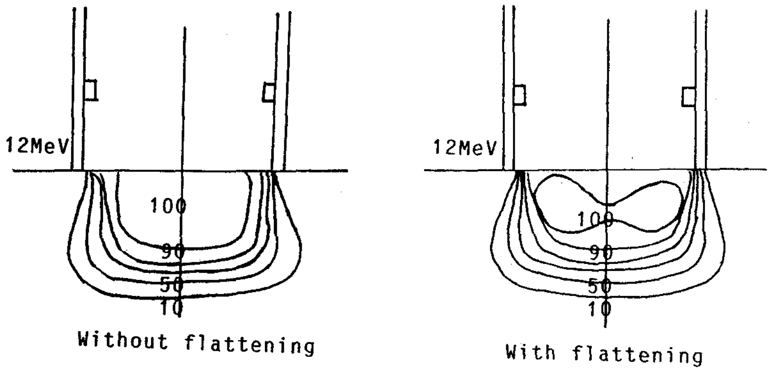


Fig. 8. Dose distribution for straight cone (Ist collimator 12×12 cm, 2nd collimator 80 mm, 3rd collimator 70 mm)

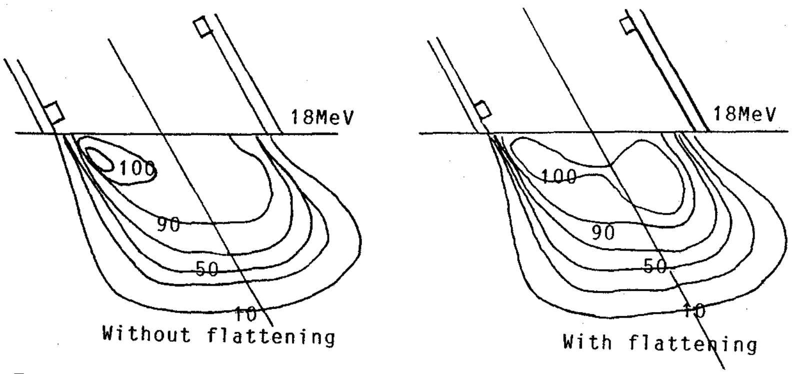


Fig. 9. Dose distribution for bevelled cone (angle 30°, Ist collimator 12×12 cm, 2nd collimator 80 mm, 3rd collimator 70 mm)

Isodose curves and beam profiles at d_{max} are needed to document the behavior of the dose distribution off the central axis. Field width, beam flatness, and symmetry can be determined from the beam profile at d_{max}. These data are very important for bevelled cones and for the small diameter circular cones, where the isodose distributions tend to be bullet shaped. But, Using three levels of collimation and the flattening filter, we achived a reduced constriction of the 90% isodose curve. The ϕ 6 cm isodose curves at selected energies are showed in Fig. 8, 9.

Flatness and symmetry can be determined from beam profiles at d_{max}. Acceptable criteria may not be straight enough for beams to be used in the "standard" clinical cones, even though most of the applicator beam energy combinations studied indicate that a flatness requirement of ±5% and a symmetry requirement of ±2% can usually be met[9~12].

4. SSD Corrections

In many treatment situations, it is impossible to treat at the standard SSD of 100 cm. A simple inverse square law factor (using the virtual SSD) may be appropriate, but the validity of this procedure should be carefully checked. This correction did not follow the inverse square law and is dependent on field size and energy. A set of tables has been generated to cover all possible cases (see Table 6, Fig. 10)[13].

DISCUSSION

The dosimetry associated with an intraoperative applicator system can be divided into three parts : 1) Optimization of photon jaw settings, 2) dosimetric properties of the beams, and 3) additional studies, such as source to skin (SSD) corrections, field within the field, and effects of field

Table 6. SSD Correctin factor for Various Cone Size at 12 MeV (SSD 100 cm normalized).

SSD	ST cm	ST 7 cm	ST 9 cm	BV 4 cm	BV 7 cm	BV 9 cm
100	1.000	1.000	1.000	1.000	1.000	1.000
101	0.966	0.970	0.972	0.967	0.970	0.972
102	0.938	0.941	0.947	0.940	0.942	0.950
103	0.916	0.915	0.923	0.915	0.918	0.927
104	0.893	0.892	0.901	0.894	0.894	0.906
105	0.871	0.869	0.881	0.873	0.873	0.885
106	0,850	0.851	0.860	0.855	0.853	0.868
107	0.832	0.832	0.840	0.837	0.834	0.850
108	0.816	0.815	0.824	0.819	0.817	0.833
109	0.799	0.799	0.807	0.803	0.801	0.817
110	0.787	0.785	0.795	0.788	0.788	0.805

ST: straight cone BV: bevelled cone

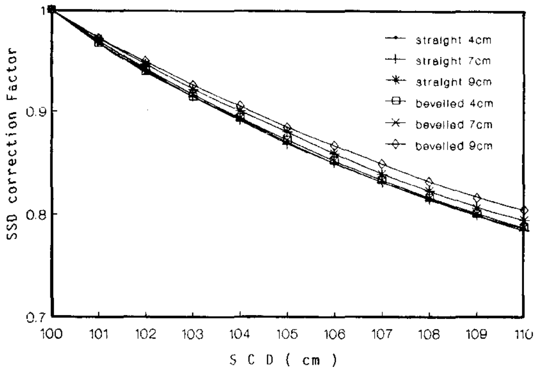


Fig. 10. SSD correction factor for various cone size at 12 MeV (SSD 100 cm normalized)

shaping[11,14,15].

The LID electron applicator which we utilize for IORT is consisted of three main collimator. The manufacturer recommends that the secondary collimator setting be larger than the third collimator[16]. By this system of collimation we succeeded to minimize greatly the penumbra.

The straight and bevelled cone output ratio factors are dependent on the electron scattering at the LID applicator of collimator. As the cone size and energy was reduced, the cone output ratio decreases rapidly[13,17].

Surface dose values should be as high as possible, preferably in excess of 90%, since the prescribed tumor dose is usually defined at the depth corresponding to 90% of the dose at d_{max}. On the clinac 1800, surface dose values were reported to 90% or greater for nominal electron beam energies of 12 MeV or greater. As the electron energy was raised, the surface dose increased. At 12 MeV it was approximately 92.7%, which for 6 MeV and 9 MeV, it decreased to 82% and 87.6%, respectively. With the flattening filter, the surface dose increased to 85.3%, 89.2% and 93.4% which for 6 MeV, 9 MeV and 12 MeV, respectively. For those energies and applicators where the surface dose is significantly below 90%, dose values between the surface dose and d_{max} dose should be documented to determine the amount of bolus material that is needed to ensure a 90% surface dose. In general, 5 mm of bolus material is sufficient, and any of the newly available optically transparent tissue equivalent elastomer materials should be satisfactory. We were used a flattening filter. This flattening filter is very important to reduce the contamination of the beam by the secondary electrons emitted from the brass ring closer to the tumor surface and compensates for the inverse square law. With the combination of the three levels collimation and the flattening filter, we achieved good the beam homogeneity and better flatness that the diameter of the 90% isodose curve was increased. But, in our LID electron applicator technique, the energy of the beam is reduced secondary to the interaction of the beam with the flattening filter.

The cone output measurement were made in the central axis at source to chamber distance from 100 cm to 110 cm[18]. The measurements normalized to the reading at SSD 100 cm. If the output varied according to the inverse square law then the measured output would simply vary as the reciprocal of the source chamber distance square. However, the measured output did not follow the inverse square law for small field sizes. Therefore, the effective source position must be determined for variation of the output from that predicted by inverse square alone.

The characteristics of the LID electron beams from the Clinac 1800 medical linear accelerator have been described. In spite of the unusual geometry and wide range of electron beam energies employed, the simple applicator system that has been described and documented herein appears to provide electron beam adequately suited for intraoperative electron beam therapy.

Further work is needed in relation with dosimetric properties when additional shielding is used to produce irregularly shaped fields.

REFERENCES

1. **Michael D, Kenneth RH, Robert SF, et al:** Determination of electron beam output factors for a 20 MeV linear accelerator. Med Phys 12:473-476, 1985
2. **AAPM Task Group 21:** A protocol for the determination of absorbed dose from high-energy photon and electron beams. Med Phys 10:741-756, 1983
3. **Mills MD, Hogstrom KR, Almond PR:** Prediction of electron beam output factors. Med Phys 9:60-65, 1982
4. **Biggs PJ:** The effect of beam angulation on central axis percent depth dose for 4-29 MeV electrons Phys Med Bio 29:1089-1096, 1984
5. **Biggs PJ, Ling CC:** Electons as the cause of the observed d_{max} shift with field size in high energy photon beams. Med Phys 6:291-295, 1979
6. **Mohan R, Chil CS, Fontenla D, et al:** The effect of angular spread on the intensity distribution of arbitrarily shaped electron beams. Med Phys 15: 204-210, 1988
7. **Brian J, Mcparland:** A method of calculating the output factors of arbitrarily shaped electron fields. Med Phys 16:88-93, 1989
8. **Rashid H. Islam MK. Gaballa. et al:** Small-field electron dosimetry for the philips SC25 linear accelerator.Med Phys 17:710-714, 1990
9. **Brien PO, Michaels HB, Aldrich JE, et al:** Characteristics of electon beams from a new 25-Mev linear accelerator.Med Phys 12:799-805, 1985
10. **Frass BA, Frank S, Harrington, et al:** Television system for verification and documentation of treatment fields during intraoperative radiation therapy. Int J Radiat Oncol Biol Phys 9:1409-1411, 1983
11. **Jeffrey A, Meyer, Jatinder R, et al:** Demonstration of relatively new electron dosimetry measurement techniques on the Mevatron 80. Med Phys 11:670 -677, 1984
12. **Jatinder R, Palta, Inder K, et al:** Electron beam characteristics on a Philips SL25. Med Phys 17:27 -34, 1990
13. **Subhash CS, David LW, Baby Jose:** Dosimetry of small fields for Therac 20 electon beams. Med Phys 11:607-702, 1984
14. **Frass BA, Miller RW, Kinsella TJ, et al:** Intraoperative radiation therapy at the National cacer institute: Technical innovations and dosimetry. Int J Radiat Oncol Biol Phys 11:1299-1311,% 1985
15. **Biggs PJ, Epp ER, Ling CC, et al:** Dosimetry, field shaping and other consideration for intraoperative electron therapy. Int J Radiat Oncol Biol Phys 7: 875-884, 1981
16. **Goed MR, Gooden DS, Ellis RG, et al:** A versatile electron collimation system to be used with electron cones supplied with Varian's Clinac 18. int J Radiat Oncol Biol Phys 2:791-795, 1977
17. **Petter J, Biggs, Arther L, et al:** Electron dosimetry of irreguar fields on the Clinac 18. Int J Radiat Oncol Biol Phys 5:433-440, 1979
18. **McKenzi AL:** Air-gap correction in electron treatment planning. Phys Med Biol 24:628-635, 1979

국문초록 =

LID (Lyon Intraoperative Device)를 이용한 수술중 방사선치료시 전자선의 선량분포 특성

연세대학교 원주의과대학 치료방사선과학교실, 진단방사선과학교실*
연세대학교 의과대학 치료방사선과학교실

김계준 · 박경란 · 이종영 · 김회연 · 성기준* · 추성실**

수술중 방사선치료를 환자에 적용하기에 앞서 본원이 보유하고있는 LID를 이용한 전자선의 선량분포 특성을 연구하였다. 이러한 선량 특성에 대한 자료는 적절한 Cone의 모양이나 크기, 에너지를 결정하게하며 빠르고 정확한 계산을 위하여 필요하다. 따라서, 본 저자들은 3-Dimensional Water Phantom Dosimetry System를 이용하여 Cone의 크기, Cone의 모양, 보상필터 사용 유무에 따라 Cone의 출력인자, 조직표면선량, 선축상 최대치 지점, 90%의 깊이, 대칭도와 편평도, SSD 보상인자, 선량분포 등을 측정하여 다음과 같은 결과를 얻었다.

1) Cone의 출력인자는 Cone 모양에 따라 각각 측정하였으며 Cone의 크기와 에너지가 작을수록 급격하게 감소하는 결과를 보였다.

2) 보상 필터의 하나인 Flattening Filter를 사용한 결과 표면 선량이 6 MeV, 9 MeV, 12 MeV에 대하여 각각 85.3%, 89.2%, 93.4%였고, 이 보상 필터를 사용하므로 선량률과 beam의 투과율은 감소하지만 치료부위에 따라 beam의 모양을 변형시키며 특히, 표면선량을 90%나 그 이상으로 증가시킬 수 있었다.

3) 3차에 걸친 beam의 collimation과 보상 필터를 결합하여 사용한 결과 매우 좋은 beam의 균일성과 편평도 뿐만아니라 90% 등선량곡선 넓이가 커지는 결과를 보였다.

4) 치료를 위하여 중요한 간격인 SSD 100 cm에서 SSD 110 cm까지의 출력인자는 측정치와 계산치가 Cone의 크기와 모양, 에너지에 따라 1~3%의 차이를 보였다.