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Comparison of Electron Beam Dosimetries by Means of Several Kinds of Dosimeters

Wee-Saing Kang, Ph.D.

Department of Therapeutic Radiology, College of Medicine,
Seoul National University, Seoul, Korea

Several combinations of measuring devices and phantoms were studied to measure electron beams. Silicon PN junction diode was used to find the dependence of depth dose profile on field size on axis of electron beam Depths of 50, 80 and 90% doses increased with the field size for small fields. For some larger fields, they were nearly constant. The smallest of field sizes over which the parameters were constant was enlarged with increase of the energy of electron beams.

Depth dose distributions on axis of electron beam of 10×10 cm^2 field were studied with several combinations of measuring devices and phantoms. Cylindrical ion chamber could not be used for measurement of surface dose, and was not convenient for measurement of near surface region of 6 MeV electron. With some exceptions, parameters agreed well with those studied by different devices and phantoms. Surface dose in some energies showed 4% difference between maximum and minimum.

For 18 MeV, depths of 80 and 90% doses were considerably shallower by film than by others. Parallel-plate ion chamber with polystyrene phamtom and silicon PN junction would be recommended for measurement of central axis depth dose of electron beams with considerably large field size. It is desirable not to use cylindrical ion chamber for the purpose of measurement of surface dose or near surface region for lower energy electron beam. It is questionable that film would be recommended for measurement of dose distribution of electron with high energy like as 18 MeV.

Key Words: Electron feams, Dosimeters, Polystyrene phantom, Water phantom

INTRODUCTION

Measurement of absorbed dose in electron beams has continued to be subject to uncertainties associated with 1) the measuring device, materials, and shape (geometry); 2) determination of the appropriate collision mass stopping power; and 3) phantom material. Verious concepts have been widely accepted, and adopted by some protocols[1~5].

However, the correct values for perturbation corrections, displacement factors, dose conversion factors (C_E) and the like remain uncertain. Task Group 21 of AAPM (American Association of Physicists in Medicine)[4] accepted the opinions that when calculating values of C_E for measurement using an ionization chamber, the ionization chamber, buildup cap and phantom material must be considered. These errors stem from the energy dependence of collision mass stopping power ratio of water to various materials used for dose measurement, such as air, graphite and polystyrene.

Paul, et al[6] and Kubo et al[7] reported that a slightly larger dose deviation was found with some combinations of chambers and phantoms. Hunt, et al[8] reported a deviation larger than 5% in comparison of AAPM TG-21 protocol with old protocols.

Because of these reasons, medical radiation physicists taking the responsibility of dose measurement of electron beams could not be themselves free from suspicion whether dose to water of electron is correct or not. They should be worried about not only the dose measurement of electron but also the selection of measuring device and phantom.

In present paper, authors will compare the measurements of electron beams on central axis by several combinations of measuring devices and phantoms. Measuring devices were a cylindrical ion chamber, a parallel-plate ion chamber, ready packed film and silicon diode. Phantom material was water and polystyrene.

Table 1. Physical Characteristics of Ion Chambers Used in This Study

	PR-06C, Capintec	PS-0 33, Capintec
Shape :	Cylindrical chamber	Parallel plate chamber
Wall material :	Air equivalent plastic	Aluminized polyethylene
Volume :	0.65 ml	0.50 ml
External diameter :	7.0 mm	......
Internal diameter :	6.4 mm	16 mm
Plate spacing :	......	2.4 mm
Wall thickness :	0.28 mm, 50 mg/cm^2	25 mm, 3 mg/cm^2
Length :	22 mm	......
Width of guard ring :	......	2.5 mm
A (ICRU 21)	0.985	0.985

Table 2. Physical Characteristics of Solid Detector and Film Used in This Study

Silicon PN-junction diode, Therados
  Dimension : 2 x 2 mm^2 x 0.05 mm
  Screened with a thin aluminum layer
  Encapsulated in epoxy
  Located 1 mm below the front face
X-Omat V, Kodak
  Ready packed, verification film

MATERIAL AND METHOD

The devices for measurement of electron doses on beam axis were an air-equivalent wall cylindrical ion chamber (Capintec, PR-06C), an aluminized window parallel-plate ion chamber (Capintec, PS-033), ready-packed film (Kodak, X-Omat V) and a silicon PN junction diode (Therados Co). The physical details of the ion chambers are tabulated in Table 1, and the silicon detector and film in Table 2. The phantom materials used for measurrement of electron doses were water and polystyrene. Electron beams from electron linear accelerator (Varian, Clinac-18) were used. The nominal energies of the electron beams were 6, 9, 12, 15 and 18 MeV.

Because of electron scattering and field size, depth dose profiles of electron beams would be dependent on field size, particularly for small fields. For that reason, it is required to find the range of field size for which the dose profile is constant because it is desirable to compare the dependences of electron dose profile on dosimeters under the condition that the profile is constant against for field size. For such purpose, depth dose profiles on beam axis was measured in water phantom using a silicon diode detector.

The results are described in Table 2 and Fig 1. Table 2 includes surface dose, depths of 50%, 80% and 90% dose, and practical range for each field size. For each energy, depth dose profiles for depths deeper than 90% depth were nearly constant for field size greater than 10×10 cm, and practical range was independent of field size.

Ion chambers were used to measure the central axis depth dose in polystyrene phantom. Both the axis of the cylindrical chamber and the window of the parallel plate chamber were set perpendicular to the beam axis. The field size was 10 × 10 cm^2 at 100 cm SSD. Both positive and negative polarity measurements of charge collected by the ion chambers were taken and averaged. The depth of measurement was upward to three quaters of inner radius of the cylindrical chamber from the chamber axis, and at the surface of the parallel plate chamber. The depth was converted to depth in water with scaling factor, 1.05. The absorbed dose D_W to water was calculated on the basis of I CRU 21.[1]

$$D_W = M \cdot N_C \cdot C_E$$

Where M is the instrument reading corrected for temperature and pressure; N_C is the exposure calibration factor for ^{60}Co gamma ray; C_E is the overall conversion factor to absorbed dose in water. The conversion factor includes displacement factor, A=0.985, and electron fluence perturbation correction factor, P_E[9].

Ready packed verification film was also placed between sheets of polystyrene phantom with density 1.05 g/cm^3 for measurement of central axis depth dose of electron beam. The film was set so as

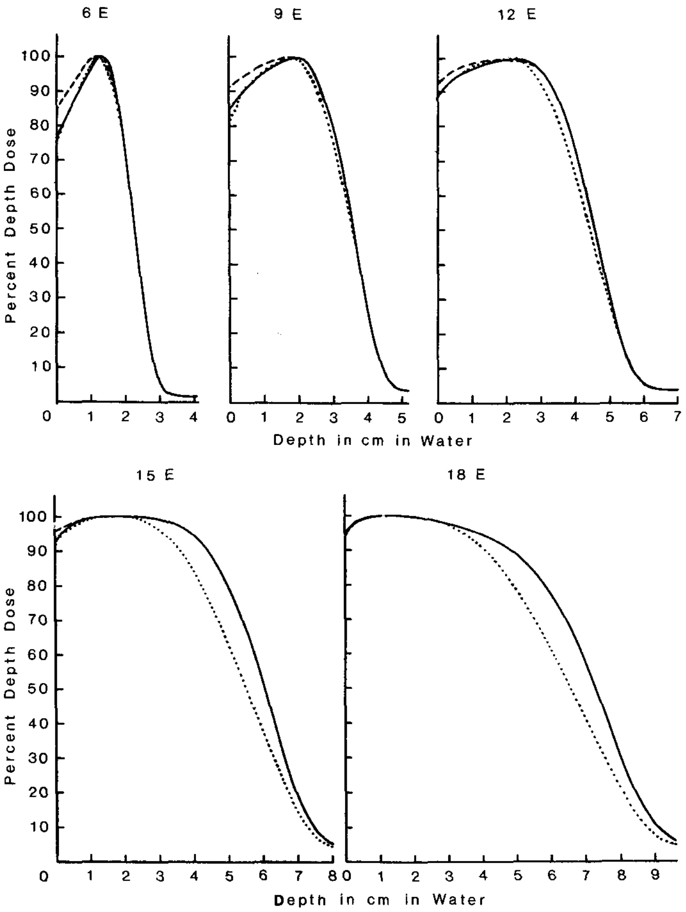

Fig. 1. Comparison of depth dose profites of electron beams These data were taken by silicon PN junction diode in water phantom at 100 cm SSD. ······ : 4x4 cm^2. ——— : 10 x 10 cm2 ——— : 25 x 25 cm^2

to be parallel to the axis of electon beam and on the principal plane.

The field size was 10×10 cm^2 at 100 cm SSD. Dose corresponding to 150 monitor units was applied to the film. Irradiated films were rapidly processed. The absorbed dose was converted on the basis of characteristic curve of same batch films that were exposed by cobalt gamma ray and processed at the same time. The scaling factor was applied to conversion of dose to water from dose to film.

RESULT

The results quoted are the average of three independent measurements with each detector. Table 3 shows the parameters of 6, 9, 12, 15 and 18 MeV electron energies studied by silicon diode detector in water phantom using 4×4, 6×6, 8×8, 10×10, 15×15 and 25×25 cm^2 electron applicators at 100 cm SSD. Fig 1 shows depth dose profiles of the electron beams studied by silicon diode detector in water phantom using 4×4, 10×10 and 25×25 cm^2 electron applicators at 100 cm SSD. Doses were normalized to the maximum dose of each field size. Depth dose profiles at depth deeper than maximum dose depth were constant for the whole described field sizes for 6 MeV electron beams, but only for some large field sizes for higher energy beams.

Table 3. Physical Parameters of Electron Beams Measured by Silicon Diode

Electron energy		Field size					
		4x4 cm^2	6x6 cm^2	8x8 cm^2	10x10 cm^2	15x15 cm^2	25x25 cm^2
6meV	SD	76 %	76 %	78 %	78 %	81 %	85 %
	d_{90}	0.7, 1.7cm	0.8, 1.8cm	0.6, 1.7cm	0.6, 1.7cm	0.6, 1.7cm	0.3, 1.7cm
	d_{80}	0.2, 1.9cm	0.2, 1.9cm	0.2, 1.9cm	0.2, 1.9cm	1.9cm	1.9cm
	d_{50}	2.3cm	2.3cm	2.3cm	2.3cm	2.3cm	2.3cm
	Rp	2.9cm	2.9cm	2.9cm	2.9cm	2.9cm	2.9cm
9MeV	SD	82 %	82 %	83 %	85 %	87 %	87 %
	d_{90}	0.2, 2.5cm	0.6, 2.7cm	0.5, 2.7cm	0.3, 2.7cm	0.2, 2.7cm	2.7cm
	d_{80}	2.9cm	3.0cm	3.0cm	3.0cm	3.0cm	3.0cm
	d_{50}	3.5cm	3.6cm	3.6cm	3.6cm	3.6cm	3.6cm
	Rp	4.4cm	4,4cm	4.4cm	4.4cm	4.4cm	4.4cm
12MeV	SD	88 %	86 %	87 %	89 %	90 %	92 %
	d_{90}	0.2, 3.1cm	0.3, 3.3cm	0.2, 3.3cm	3.4cm	3.4cm	3.4cm
	d_{80}	3.5cm	3.7cm	3.7cm	3.8cm	3.8cm	3.8cm
	d_{50}	4.4cm	4.5cm	4.5cm	4.6cm	4.6cm	4.6cm
	Rp	5.5cm	5.5cm	5.5cm	5.6cm	5.6cm	5.6cm
15MeV	SD	92 %	91 %	91 %	92 %	93 %	95 %
	d_{90}	3.6cm	4.3cm	4.3cm	4.4cm	4.4cm	4.4cm
	d_{80}	2.2cm	4.8cm	4.9cm	5.0cm	5.0cm	5.0cm
	d_{50}	5.5cm	5.9cm	5.9cm	6.0cm	6.0cm	6.0cm
	Rp	7.3cm	7.3cm	7.3cm	7.3cm	7.3cm	7.3mc
18MeV	•SD	93 %	93 %	93 %	93 %	94 %	94 %
	d_{90}	4.0cm	4.5cm	4.7cm	4.8cm	4.8cm	4.8cm
	d_{80}	4.8cm	5.4cm	5.6cm	5.7cm	5.7cm	5.7cm
	d_{50}	6.5cm	7.0cm	7.1cm	7.2cm	7.2cm	7.2cm
	Rp	8.8cm	8.8cm	8.9cm	9.0mc	9.0cm	9.0cm

SD : Surface dose
d_n : Depth of n % dose on beam axis
Rp : Practical range of electron beam in water

The smallest of field sizes over which the parameters were constant was enlarged with increase of the energy of electron beams, even though that could not be definitely determined. Variations of the parameters were more severe for higher energy and smaller field size.

The practical range, however, for each energy was nearly constant for field sizes. The parameters specified depths increaed with field size, but for some small field sizes, surface dose decreased with the increase of field size.

Table 4 shows the parameters of electron beams with the above described energies for 10× 10 cm^2 field size at 100 cm SSD, studied by 4 kind of radiation detectors; 1) air-equivalent cylindrical ion chamber in polystyrene phantom, 2) aluminized window parallel-plate ion chamber in polystyrene phantom, 3) ready packed film in polystyrene phantom, 4) silicon PN junction diode in water phantom. Fig 2 shows depth dose profiles obtained by 4 kind of detectors under the same conditions. Doses were normalized to the maximum dose. The maximum dose and the corresponding depth were obatined from direct measurement for silicon diode or film, but calculated by interpolation of the measurements for ion chambers. Except for surface doses and 18 MeV, the value of the parameters, such as d_{90}, d_{80}, d_{50} and R_P, agreed well within ±1

Table 4. Physical Parameters of Electron Beams Measured by Several Radiation Detectors for 10x10 cm² Field Size

Electron energy		Radiation detector			
		Cylindrical	Parallel-plate	Diode	Film
	SD	----	74 %	78 %	----
	d_{90}	1.7cm	1.7cm	1.7cm	1.7cm
6MeV	d_{80}	1.9cm	1.9cm	1.9cm	1.9cm
	d_{50}	2.3cm	2.3cm	2.3cm	2.3cm
	Rp	2.9cm	2.9cm	2.9cm	2.9cm
	SD	----	82 %	85 %	----
	d_{90}	2.8cm	2.8cm	2.7cm	2.7cm
9Mev	d_{80}	3.1cm	3.0cm	3.0cm	2.0cm
	d_{50}	3.5cm	3.6cm	3.6cm	3.6cm
	Rp	4.4cm	4.3cm	4.4cm	4.2cm
	SD	----	88 %	89%	88 %
	d90	3.4cm	3.5cm	3.4cm	3.4 cm
12MeV	d_{80}	3.7cm	3.9cm	3.8cm	3.8cm
	d_{50}	4.4cm	4.6cm	4.6cm	4.6cm
	Rp	5.6cm	5.6cm	5.6cm	5.6cm
	SD	---	96 %	92 %	94 %
	d_{90}	4.4cm	4.5cm	4.4cm	4.4cm
15MeV	d_{80}	4.9cm	5.1cm	5.0cm	4.9cm
	d_{50}	5.9cm	6.0cm	6.0cm	5.9cm
	Rp	7.2 cm	7.0cm	7.3cm	7.2cm
	SD	----	97 %	93 %	93 %
	d_{90}	5.0cm	5.1cm	4.8cm	4.4cm
18MeV	d_{80}	5.9cm	6.0cm	5.7cm	5.3cm
	d_{50}	7.2cm	7.3cm	7.3cm	7.1mc
	Rp	9.0cm	8.9cm	9.0cm	8.8cm

Parameters are the same as Table 3.
d_n : Depth of n % odse on beam axis
Rp : Practical range of electron beam in water

mm from the average values for each energy of electron beam.

The cylindrical ion chamber could not be used for measurement of surface doses because of the limitations such as size of the chamber and structure of the polystyrene phantom. For 6 and 9 MeV, surface doses by film are not put on Table 4. It is the reason that the doses have large error of which source seems to be air gap on both sides of film near the surface of solid phantom. The surface dose did not consist with that measured with different combination of measuring device and phantom. In the case of 6, 15 or 18 MeV, the difference between minimum and maximum of surface doses was as large as 4%, the largest. It seems that the difference of suface doses by different measuring system would be related to perturbation in spectrum of electrons caused by the combination of measuring device and phantom. For 10×10 cm², higher the energy of electron beam, the surface dose was greater. The rate of the increase of the surface dose was greater for parallel-plate ion chamber than for silicon PN junction diode.

As the result, the results that the surface dose for lower energy (6~12 MeV) beam was lower for parallel-plate ion chamber than for silicon diode converted to that the surface dose for high energy beam was higher for parallel-plate chamber than for silicon diode.

In the case of 18 MeV, except for film the parameters studied agreed well within ±1.5 mm from the average values. Depths of 80 and 90% doses measured by film in polystyrene phantom were 0.7 cm shallower than those measured by paralllel-plate chamber in polystyrene phantom.

DISCUSSION

Silicon PN junction diode was found to give the result that depth dose profile on central axis of electron beam varied with field size, in particularly small fields, but was nearly constant for large fields. The smallest of field sizes for which the parameters were constant increased with the energy of electron beams, even though that could not be definitely determined. Variations of the parameters were more severe for higher energy and smaller field size.

These results are similar to other reported results[10~14] even though some of them were given with cylindrical ion chamber[11~13], parallel-plate ion chamber[14] or film[12,13].

As the field size increases, the surface dose obtained by silicon diode decreases for small fields but increases for large fields. This result is similar to the result of Sharma, et al[11] but contrary to the results of Niroomand-Rad, et al[12], George, et al[13], Jamshidi, et al[14]. The fact that increasing rate of surface dose depended on combination of measuring device and phantom, and one combination showing lower surface dose for lower energies in turn showed higher surface dose for higher energies and vice versa was observed. Even though it is well known that the surface dose of

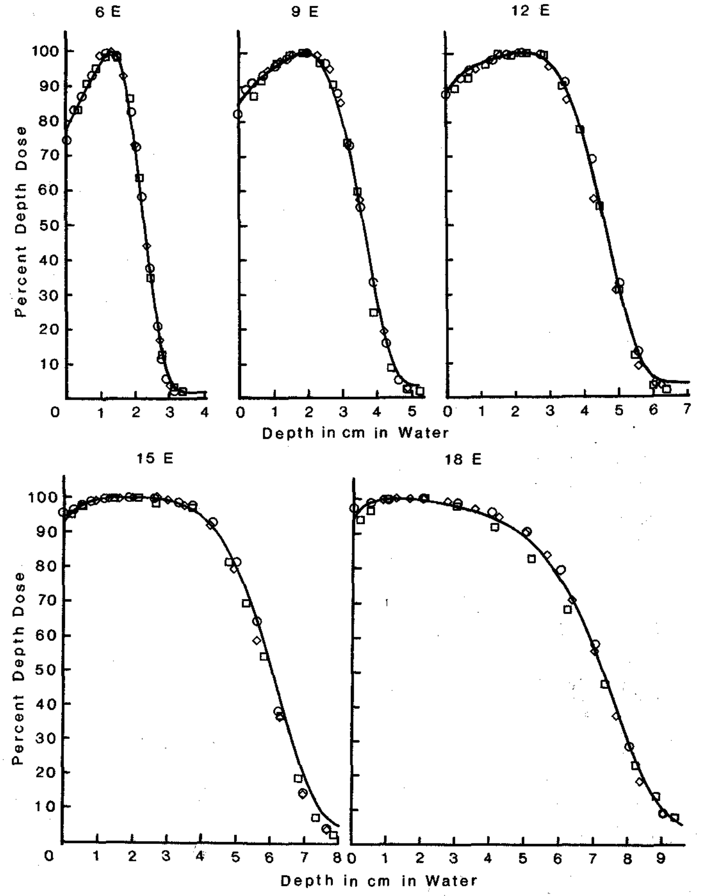

Fig. 2. Comparison of central axis depth doses of electron beams by 4 combinations of measuring devices and phantoms. Field size was 10x10cm^2 at 100 cm SSD. ○ : parallel-plate ion chamber in polystyrene phantom, ◇ : cylindrical ion chamber in polystyrene phantom, □ : film in polystyrene phantom, ——— : silicon PN junction diode in water phantom.

electron beam increases with the incident energy, the fact that relative surface dose related to combination of measuring device and phantom depends on the combination have not yet been reported.

NACP[2] recommends that cylindrical ion chamber be not used for dosimetry of electron beam with energy lower than 10MeV. HPA[5] recommends parallel-plate ion chamber for measurement of the surface dose of electron beams but not cylindrical ion chamber. Authors have same opinion as their recommendations.

Practical ranges in water of electron beams taken for 10×10 cm^2 field at 100 cm SSD were nearly constant without respect to the combination of measuring device and phantom for each energy of electron beam. The results of comparison of the practical ranges that 1) Sharma, et al[11], get using film in Temex rubber and cylindrical chamber; 2) Niroomand-Rad, et al[12], using film and ion chamber in polystyrene for 5 to 18 MeV, 10×10 cm^2 at 100 cm SSD; 3) George, et al[13], using film in polystyrene, and diode and cylindrical chamber in water for 9 MeV, 10×10 cm^2 at 100 cm SSD; 4) Dutreix, et al[15], using ion chamber, film and ferrous sulfate in lucite for 20 MeV; 5) Feldman, et al[16], film in opaque polystyrene and cylindrical chamber in polystyrene for 7.0, 11.0 and 18.0 MeV, 10×10 cm^2 showed that the practical range was independent of measuring device and phantom. The practical range was independent of measuring device and phantom. The result of this study agreed well with them.

For each electron beam with the range of 6~15 MeV, depths of 50, 80 and 90% doses on the central axis taken for 10×10 cm^2 at 100 cm SSD were nearly constant without respect to combination of measuring device and phantom. For 18 MeV electron beam, depths of 50, 80 and 90% doses showed also good agreement for 3 combinations, that is, cylindrical chamber and parallel-plate chamber in polystyrene, and diode in water, except for film in polystyrene. Niroomand-Rad, et al[12], comparing central axis depth doses by film and ion chamber in polystyrene for 5 to 18 MeV, 10×10 cm^2 at 100 cm SSD, George, et al[13], comparing central axis depth doses by film in polystyrene, and diode and cylindrical chamber in water for 9 MeV, 10×10 cm^2 at 100 cm SSD reported good agreement of central axis depth doses.

Dutreix, et al[15], compared central axis depth doses taken by ion chamber, film and ferrous sulfate in lucite and reported result that central axis depth doses of 20 MeV electron beam by film and ferrous sulfate agreed with each other but were higher than those by ion chamber. The result of Dutreix, et al, that central axis depth doses of 20 MeV electron by film were higher than by ion chamber is opposed to our result for 18 MeV electron.

For accurate and reliable dosimetry of high energy electron beams, hence, more elaborate studies for dosimeters, particularly ion chamber and film in polystyrene, are required.

CONCLUSION

Central axis depth doses of electron beams in water were studied for several field sizes given by the electron applicators supplied from the manufacturer of Clinac-18 using a silicon diode. Also, the depth doses for 10×10 cm^2 at 100 cm SSD were studied for 4 combinations of measuring devices and phantoms; cylindrical chamber, parallel-plate chamber and film in polystyrene, and diode in water.

The conclusions got from this study are as follows:

1. Central axis depth doses of electron beam vary with field size, but nearly constant for some large fields.
2. As field size increased, the surface dose decreased for small fields but increased for large fields. Field size with minumum surface dose increased with the energy of electron beam.
3. For each energy of electron beam except for 18 MeV, the depths of 50, 80 and 90% doses agreed well with depths taken by different combination of measuring device and phantom.
4. Practical range was constant for both field size and the combination of measuring device and phantom.
5. It is desirable not to use cylindrical chamber for measurement of surface dose in surface region of electron beam of lower energy than 10 MeV. For that purpose, parallel-plate chamber is recommended.
6. Silicon PN junction diode could be recommended for dosimetry of electron beam.

REFERENCES

1. **International Committee on Radiological Units and Measurements:** Radiation Dosimetry: Electrons with Initial Energies between 1 and 50 MeV. ICRU Report 21:1972
2. **Nordic Assiciation of Clinical Physics:** Procedures in external radiation therapy dosimetry with electron and photon beams with maximum energies between 1 and 50 MeV. Acta Radiol Oncol 19:55-79, 1980
3. **Nordic Assiciation of Clinical Physics:** Electron beams with mean energies at the phantom surface below 15 MeV. Acta Radiol Oncol 20:401-415, 1981
4. **American Association of Physicists in Medicine. Task Group 21:** A protocol for the determination of absorbed dose from high-energy photon and electron beams. Med Phys 10:741-771, 1983
5. **Hospital Physicists' Associations:** Code of practice for electron beam dosimetry in radiotherapy. Phys Med Biol 30:1169-1194, 1985
6. **Paul JM, Koch RF, Philip PC:** AAPM Task Group 21 protocol: Dosimetric evaluation. Med Phys 12:424-430, 1985
7. **Kubo H, Cheng P:** Absorbed dose comparison among commercial ionization chambers in polystyrene and acrylic phantoms. Med Phys 15:269-272, 1988
8. **Hunt MA, Malik S, Thomason C, et al:** A comparison of the AAPM 'Protocol for the determination of absorbed dose from high-energy photon and electron breams' with currently used protocols. Med Phys 11:806-813, 1984
9. **Khan FM:** The Physics of Radiation Therapy. Williams & Wilkins, Baltimore, 1984:122-156
10. **Meyer JA, Palta JR, Hogstrom KR:** Demonstration of relatively new electron dosimetry measurement techniques on the Mevatron 80. Med Phys 11:670

-677, 1984
11. **Sharma SC, Wilson DL, Jose B**: Dosimetry of small fields for Therac 20 electron beams. Med Phys 11: 697-702, 1984
12. **Niroomand-Rad A, Gillin MT, Kiline RW, et al**: Film dosimtry of small electron beams for routine radiotherapy planning. Med Phys 13:416-421, 1986
13. **George RE, Frost SV, Hartson-Eaton M**: Characteristics of electron beams from a medical microtron. Med Phys 13:533-538, 1986
14. **Jamshidi A, Kuchnir FT, Reft CS**: Characteristic parameters of 6~22 MeV electron beams from a 25-MeV linear accelerator. Med Phys 14:282-288 1987
15. **Dutreix J, Dutreix A**: Film dosimetry of high-energy electrons. Ann New York Acad Sci 161:33-43, 1969
16. **Feldman A, de Almeida CE, Almond PR**: Measurements of electron-beam energy with rapid-processed film. Med Phys 1:74-76, 1974

=국문초록=

수종의 측정기에 의한 전자선의 선량 측정의 비교

서울대학교 의과대학 치료방사선과학교실

강 위 생

전자선의 선량을 측정하기 위하여 수종의 측정기와 팬톰의 조합에 대해서 실험 및 결과를 분석하였다. 전자선의 선축상 선량분포가 조사면의 크기에 좌우되는지를 알기 위하여 실리콘 PN 접합형 다이오드를 사용하였다. 50 및 80, 90% 선량점의 깊이가 작은 조사면에 대해서는 조사면의 크기에 따라 증가하지만, 큰 조사면에 대해서는 거의 일정했다. 그러나 그 깊이가 일정한 경우 최소 조사면의 크기가 뚜렷하지는 않으나 전자선의 에너지가 증가함에 따라 증가하였다. 6~18 MeV의 전자선에 대해 조사면의 크기가 10×10 cm^2 이상인 경우 그 깊이가 어느 에너지에 대해서도 조사면의 크기에 무관함이 측정치에서 관찰되었다. 그래서 수종의 측정기와 팬톰의 결합에 따른 전자선의 선축상 선량분포의 차이점을 관찰하고자 하는 실험에서 조사면의 크기로 10×10 cm^2을 선택하였다.

원주형 전리함과 평판형 전리함, 필름은 폴리스티렌 팬톰과 함께, 실리콘다이오드는 물팬톰과 함께 선량측정에 이용되었다. 원주형 전리함은 표면선량이나 6 MeV처럼 낮은 에너지의 선량증가 영역에서 선량을 측정할 수 없었다. 몇가지를 제외하고는 측정된 변수들은 서로 다른 측정기 및 팬톰의 결합에 관계없이 거의 동일하였다. 어떤 에너지에서는 서로 다른 측정기에 의한 표면선량이 4%정도 차이가 났으며, 에너지가 증가함에 따라 그 대소가 반전되기도 하였다. 18 MeV의 경우 필름에 의한 80 및 90% 선량점의 깊이가 다른 측정기에 의한 것보다 꽤 얕았다. 평판형 전리함과 실리콘 다이오드는 전자선의 선량분포측정에 사용될 수 있겠으나 평판형 전리함은 큰 조사면에서만 사용하는 것이 바람직할 것이다.

표면선량 측정이나 저 에너지 전자선의 선량증가 부분에서 선량측정에는 원주형 전리함을 사용하지 않는 것이 바람직할 것이다.

18 MeV와 같이 높은 에너지의 전자선의 선량분포 측정에 필름이 사용되어도 좋을지 의심스럽다.