의학물리. 제5권 1호 1994

Determination of Electron Beam Output Factors of Individual Applicator for ML－15MDX Linear Accelerator

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Abstract

Purpose : The determination of electron beam output factor was investigated from individual applicator for various energy of ML－15MDX linear accelerator.

The output factor of electron beam was extended from square to rectangular field in individual applicator size through with a least-square fit to a polynomial expression.

Materials : In this experiments. the measurement of output was obtained from 2×cm^2 to 20×20cm^2 of field size in different applicator size for 4 to 15 MaV electron beam energy. The output factor was defined as the ratio of maximum dose output on the central axis of the field of individual applicator size to that of a given field size. Applicator factors were derived from comparing with the output dose of reference field size 10×10cm^2.

The thickness of block was specially designed as 10mm in thickness of Lipowitz metal for field shaping in all electron energy. Two types of output curves are included as output factors versus side of square fields and that of variable side length for X and Y in one-dimensional to compare the expected values to that of experiments.

Results : Expected output factors of rectangular which was derived from that of square fields in individual applicator size from 2×2cm^2 to 20×20cm^2 in different electron energy was very closed to that of experimental measurements within 2% uncertainty. However 1D method showed a 3% discrepancy in small rectangular field for low energy electron beam.

Conclusion : Emperical non-linear polynomial regressions of square root and 1D method were performed to determin the output factor in various field size and electron energy. The expected output of electron beam of square root method for square field and 1D method for rectangular field were very closed to that of measurement in all selected electron beam energy.

KEY WORDS : Electron Ouput Factor, 1D Method

This study was supported by 1993 Research grant from Keimynung University Dongsan Medical Center.

INTRODUCTION

The variation of output factor versus electron field in different applicator size of electron beam is greater than produced by high energy photon beams caused by the relative contribution of scattered radiation at the depth of maximum dose, refer to dmax.1~3)

For a photon beam, the dose in phantom or tissue can be diyided into a primary and secondary component, mainly the collimator and phantom scatter.

We can expect the contribution of scatter is much smaller than that of the primary component in photon beam.

However, In electron beam, the dose maximum depth(Dmax) is strongly dependence of electron field and collimator system as multiply scattered electrons.

The output factor is defined as the ratio of the maximum absorbed dose on central axis to that of a reference field in electron beam.

The variation of output factor for electron field is primary due to electron scattering between the electron source -an inner wall of collimator and applicator- and the patient tissue.

It means the determination or expectation of output is clearly difficult in exact.

Mills et al.[3] has been proposed a method to predict square and rectangular field output factors with a two parameter fit of the square field output factor data based on the functional dependence as predicted by a pencil beam calculational model. And the rectangular field output factors have predicted from the product of the X and Y one-dimensional output factors.

Traditionally the output factor of equivalent square field as photon beam is not applied to clinical electron beam therapy.

Mills et al.[4] have been also showed the output factors of electron beam with one-dimensional and square root method for prediction.

However, the output factor is applied to different collimator system and applicator shape. In the present work, the non-linear regression method has been applied to expect the outpuct factor in square and rectangular field of ML-15MDX(Mitsubishi, Japan) linear accelerator from 4 to 15 MeVelectron beam energy.

Method and Materials

Output factors of electron beam energy 4, 6, 9, 12 and 15 MeV from ML－15MDX linear accelerator(Mitsubishi) were derived with least-square fit to polynomials from experimental data.[5]

The collimator system of ML－15MDX consits of primary, secondary havy metal for shielding the photon beam and acrylic applicators which size is 10×10, 15×15 and 20×20㎠ at vertual source skin distance 100㎝ and distanced 5㎝ from tip of apllicator as shown on Fig. 1.

The primary collimator is automatically opened with full collimation(35×35㎠) in electron mode and field shaping block is mounted on tip of the individual applicator.

The authors designed the square and rectangular electron block with 10㎜ thickness of Lipowitz metal(refer to cerrobend alloy, density is 9.4g/㎤ and melting point 75 degrees) for reproduceble and replaceble the electron field. The blocks were also designed for alignment of beam divergence as shown on Fig. 2.

Central axis data were obtained in a water phantom sized 45×45×60㎤ with Wp－600 dosimetric system as definition of the output factor.

The ion chamber was positioned in the water so that its effective point of measurement to proximal source is at the reference point.[6,7]

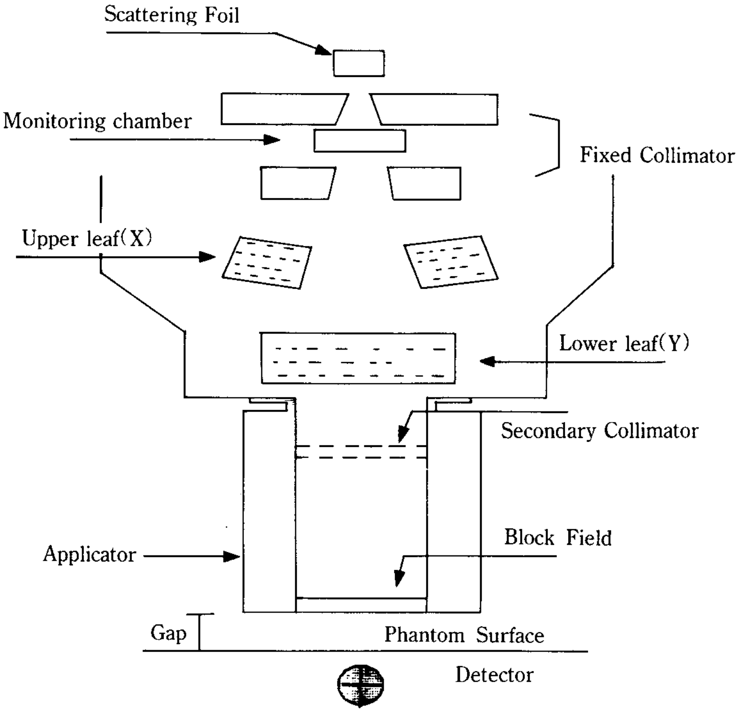

Fig. 1 Schematic drawing the electron source alignment with air-gap 5cm for virtual source-skin distance 100cm in ML-15MDX linear accelerator.

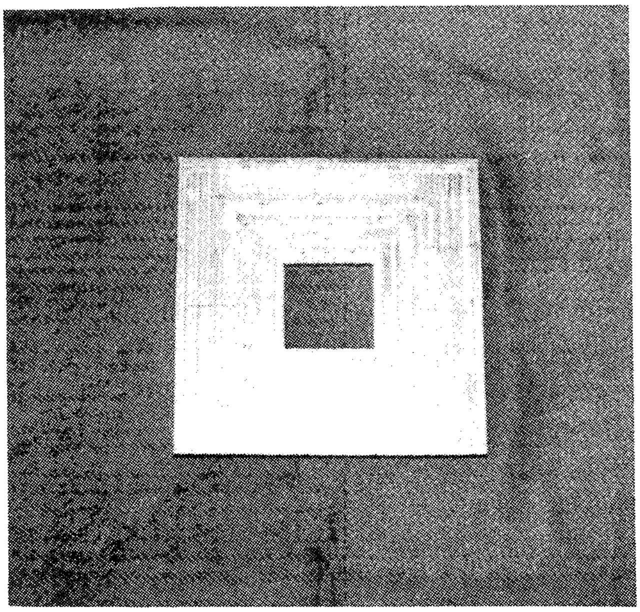

Fig. 2 The electron block was specially designed for easy replacement and reproduceble field size with 10mm thickness of Lipowitz metal in experiments.

The absorbed dose(D_W) at the reference point in water is then obtained from

$$D_W = N_d M_W S^W_a P_r \qquad (1)$$

where S^W_a is the water to air mass stopping power ratio at the radiation quality for depth of maximum dose. N_d is an air-kerma calibrated factor and M_W is the meter reading for the thimble chamber. P_r is the replacement factor for air ionization chamber.

The experimental data were from air ionization chamber(Ic−10 volume 0.14 ml) which has shown a 0.02㎜ position error as on indication. A correction was applied to the ionization data to account for the change in stopping power ratio as increasing depth.[6,7]

Output Factor

The applicator factor of electron beam is generally derived as the ratio of maximum absorbed dose on given applicator size to that of a reference field which is normally 10×10㎠.

In experiments, the various electron field is applied in clinical electron therapy with different appartured applicator size.

Here the parameter of output factor($OF_{applicator}$) was separated to applicator factor and output factor for different field size and shape in a given applicator aparture.

$$\text{Ouput Eactor}(OF)_{app} = \frac{OD_{max} \text{ of given field size}}{OD_{max} \text{ of given applicator}} \times \text{Applicator Factor} \qquad (2)$$

where OD_{max} is represented a maximum output dose of a given field size in a given applicator size. This output factor could be also nomalized to reference field.

The predicted output in rectangular and square field was performed through the polynomial regression with less experimental data.

The square-root method predicts the output factors of the rectangular fields from that of the square field according to the expression[4]

$$\text{Output Factor}(X, Y) = [OF(X, X)\ OF(Y, Y)]^{1/2} \qquad (3)$$

And the authors delivered non-linear regression for the output factor of rectangular field size as based on one-dimensional method as follows

$$\text{Output Factor}(X, Y) = OF(X, 10)\ OF(Y, 10) \qquad (4)$$

where 10 in brackets represents the side of length in cm of a given applicator size.

Results

Measurements of ionization on central axis were made in water with or without secondary block for reference dose to field shape. And the depth dose curves were made from conversion the reading scale to absorbed dose by using equation (1) as shown on Fig 3.

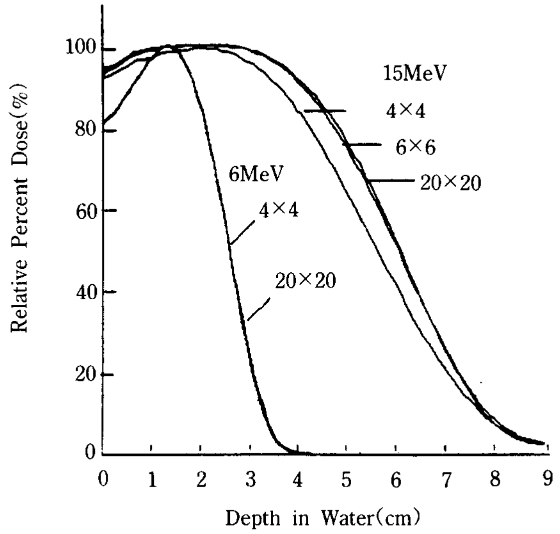

Fig. 3 Electron depth dose curves for various electron energy and field size with same applicator 20×20cm^2 in ML−15MDX linear accelerator.

In this experimental results, the dose maximum depth was very small shifted to proximal source at small field size in low electron beam energy, however it showed different dose maximum depth in 12 and 15 MeV, respectivelly, as shown on Table 1.

We found the dose maximum depth was not severely changed as field size decreased in 15×15cm^2 and other applicator size of electron beam also. However Dmax depths in small blocked fields have been showed a 1 or 5mm shift to proximal of source as increasing the electron energy. The output was also obtained from Dmax in a given applicator apparture in this work to compare the field dependency with same electrom beam.

Table 1. Dose Maximum Depth in mm of different field size in 15×15mm of applicator apparture for various electrone energy.

Electron Energy(MeV) Blocked Field	4	6 Dose Maximum	9 Depth(mm)	12	15
15×15	8.0	11.5	16.7	23.5	22.5
12×12	8.2	12.0	16.7	23.5	23.5
10×10	8.2	12.5	16.7	24.5	23.5
8× 8	7.5	11.5	16.5	23.5	23.5
4× 4	8.0	12.0	15.5	20.0	17.5

Dose Maximum Depth error = ± 0.5mm

The authors have obtained the output factors from electron energy 4MeV to 15 MeV in different field size.

This output was normalized to 10×10㎠ reference field for dose correction.

The output of large field size has shown a 5.1% higher than that of reference 10×10㎠ in low energy while a smaller change in high electron energy as shown on Fig. 4.

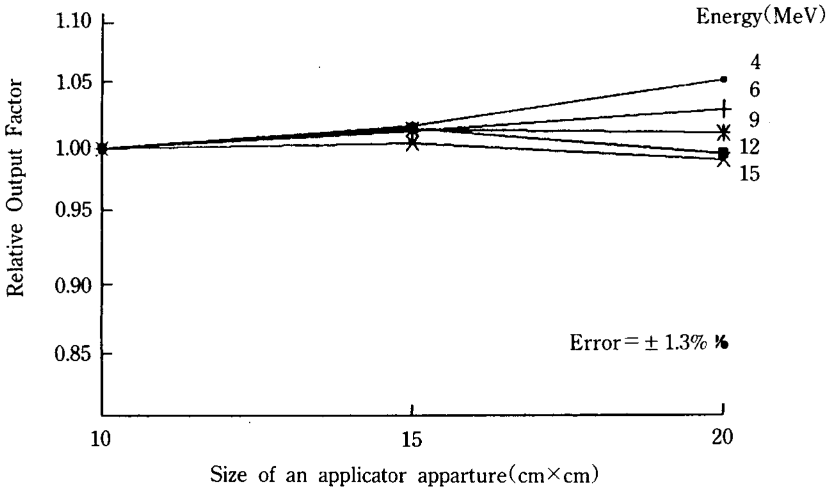

Fig. 4 Electron output factor as a function of applicator apparture

The maximum output factor were found at the medium sized block field and that of small field showed a low factors than that of a given applicator in these electron energy. However, as electron energy increased the output factor of small field was close to that of a given applicator.

The authors have obtained the output factors from 2×2㎠ of small field to applicator apparture as 10×10, 15×15㎠ with replaceble designed shaping block in different electron energy as shown on Table. 2s.

Table 2a. Output Factors in various field size in 4 MeV electron beam energy

Given Field	Applicator Size(㎠) and Applicator Factor		
Size(cmxcm)	10×10	15×15	20×20
X x Y	1.000	1.017	1.051
2 × 2	0.776	0.768	0.711
3 × 3	0.912	0.921	0.906
4 × 4	0.966	0.989	0.987
6 × 6	0.979	1.019	1.017
8 × 8	0.995	1.015	1.014
10×10	1.000	1.009	1.017
12×12	−	1.002	1.016
14×14	−	1.000	1.011
15×15	−	1.000	1.009
16×16	−	−	1.006
20×20	−	−	1.000

Table 2b. Output Factors in various field size in 6 MeV electron beam energy

Given Field	Applicator Size(㎠) and Applicator Factor		
Size(cmxcm)	10×10	15×15	20×20
X x Y	1.000	1.013	1.023
2 × 2	0.769	0.734	0.752
3 × 3	0.918	0.883	0.889
4 × 4	0.983	0.954	0.956
6 × 6	1.002	0.994	0.996
8 × 8	1.002	0.998	1.002
10×10	1.000	0.999	1.004
12×12	–	0.999	1.003
14×14	–	0.999	1.002
15×15	–	1.000	1.001
16×16	–	–	1.001
20×20	–	–	1.000

Table 2c. Output Factors in various field size in 9 MeV electron beam energy

Given Field	Applicator Size(㎠) and Applicator Factor		
Size(cmxcm)	10×10	15×15	20×20
X x Y	1.000	1.003	1.007
2 × 2	0.768	0.779	0.751
3 × 3	0.904	0.910	0.896
4 × 4	0.971	0.976	0.964
6 × 6	1.004	1.015	1.004
8 × 8	1.005	1.015	1.011
10×10	1.000	1.010	1.013
12×12	–	1.005	1.009
14×14	–	1.002	1.005
15×15	–	1.000	1.004
16×16	–	–	1.003
20×20	–	–	1.000

Table 2d. Output Factors in various field size in 12 MeV electron beam energy

Given Field	Applicator Size(㎠) and Applicator Factor		
Size(cmxcm)	10×10	15×15	20×20
X x Y	1.000	1.018	0.996
2 × 2	0.803	0.801	0.793
3 × 3	0.914	0.920	0.915
4 × 4	0.974	0.973	0.966
6 × 6	1.010	1.010	0.995
8 × 8	1.008	1.018	1.006
9 × 9	1.008	1.016	1.010
10×10	1.005	1.013	1.011
12×12	1.000	1.007	1.008
14×14	–	1.003	1.005
15×15	–	1.000	1.005
16×16	–	–	1.006
20×20	–	–	1.000

Table 2e. Output Factors in various field size in 15 MeV electron beam energy

Given Field	Applicator Size(㎠) and Applicator Factor		
Size(cmxcm)	10×10	15×15	20×20
X x Y	1.000	1.004	0.996
2 × 2	0.827	0.834	0.834
3 × 3	0.928	0.928	0.939
4 × 4	0.976	0.976	0.980
6 × 6	1.002	1.010	1.000
8 × 8	1.010	1.016	1.012
9 × 9	1.011	1.015	1.017
10×10	1.000	1.013	1.019
12×12	–	1.006	1.017
14×14	–	1.003	1.013
15×15	–	1.000	1.012
16×16	–	–	1.011
20×20	–	–	1.000

The prediction of output factors was investigated from polynomial regression as a functrion of field size in which square and rectangular field with 4th order to 10×10㎠ and 7th order to 20×20㎠ applicator size, respectively. Table 3 shows the parameters of high order for ploynomial regression in which follows ;

$$OF = a_0 + a_1X + a_2X_2 + a_3X^3 \cdots\cdots\cdots a_7X^7 \qquad (5)$$

where a's and X represent the emperical constants ad length of one side of field size, respectively.

Table 3. Emperical coefficients of least-square fit to polynomials for determining the output factor of various electron beam and applicators in ML-15MDX linear accelerator

Electron Energy	parameters and Applicator size							
					Applicator 10×10㎠			
MeV	a0	a1	a2	a3	a4			
4	.350	.59483333	-.13785417	-013854167	-.00050520833			
6	.200	.58529167	-.12805208	.012177083	-.00042447917			
9	.1450	.47216667	-.09658333	.008708333	-.00029166667			
12	.3350	.34337500	-.06482291	.005406250	-.00016927083			
15	.3450	.37237500	-.07990625	.007656250	-.00027343750			
					Applicator 15×15㎠			
MeV	a0	a1	a2	a3	a4	a5	a6	a7
4	-.063512821	.68753150	-.17611668	.023113350	-1.597967E-3	4.9504764E-5	-8.8217093E-8	-2.0906466E-8
6	-.074188811	.67527097	-.17976813	.026137774	-2.237228E-3	1.1270336E-4	-3.0979871E-6	3.5944958E-8
9	.137272730	.51106548	-.12152443	.015143276	-1.035038E-3	3.5392992E-5	-3.6695075E-7	-5.0730521E-9
12	.018207459	.72108819	-.23477181	.043379407	-4.787058E-3	3.1056670E-4	-1.0897790E-5	1.5933864E-9
15	.383836830	.35615916	-.08306879	.009838852	-5.482368E-4	3.9716080E-6	8.9729422E-7	-2.7648855E-8
					Applicator 20×20㎠			
MeV	a0	a1	a2	a3	a4	a5	a6	a7
4	-.456192310	1.0055232	-.28223745	.042243068	-3.649919E-3	1.8266774E-4	-4.9223996E-6	5.5296808E-8
6	.022327866	.60517448	-.15869385	.022723010	-1.907726E-3	9.3651819E-5	-2.4879230E-6	2.7613359E-8
9	-.062180717	.69013125	-.18988955	.028623745	-2.528142E-3	1.3014142E-4	-3.6106194E-6	4.1683737E-8
12	.021925809	.68587065	-.20607613	.033670232	-3.184335E-3	1.7355174E-4	-5.0507465E-6	6.0707102E-8
15	.110569230	.65855802	-.20533491	.034369749	-3.297291E-3	1.8123440E-4	-5.3038910E-6	6.4031021E-8

In our fittings the predicted output factors were very close to that of experimental measurements within ± 0.2% uncertainties in maximum field.

As output showed that the X and Y field length do not affect to varience similarly in experimental measurements, predicted output does not account for the difference of X and Y length, ie. the output of 20×10cm field size is almost same to that of 10×20cm. This predicted output factor was compared to that of X and Y one-dimensional calculation for sevral applicators in 6 and 12 MeV electron beam as shown on Table 4s.

The output factor as a function of field size was varied with blocked field size caused on electron scattering. As the varience of output factor is dominant to blocked field and shape after secondary block. we obtained the that from changing the length of one side of field to get that of rectangular field and the output was normalized to a given applicator apparture in 6 MeV electron beam as shown on Fig. 5.

Table 4a. Applicator correction factor and field size factor of rectangular field in 6 MeV electron beam energy.

Applicator Size cmxcm	Given Field X Y	Measured	Output Factor Sq Root	1D	1D method % of uncertainty
10×10	10× 2	0.812	0.877	0.812	0
	10× 4	0.982	0.992	0.982	0
	10× 6	1.007	1.001	1.007	0
	8 × 2	0.853	0.878	0.823	−3.5
	8 × 4	0.992	0.993	0.995	0.3
	8 × 6	1.010	1.003	1.020	1.0
	6 × 2	0.845	0.878	0.818	−3.2
	6 × 4	0.992	0.993	0.989	−0.3
	4 × 2	0.821	0.869	0.797	−2.9
15×15	15× 2	0.856	0.857	0.856	0
	15× 4	1.001	0.977	1.001	0
	15× 6	1.009	0.997	1.009	0
	15× 8	1.012	0.999	1.012	0
	15×10	1.005	1.000	1.005	0
	15×12	1.002	1.000	1.002	0
	12× 2	0.840	0.856	0.857	2.0
	12× 4	1.002	0.976	1.003	0.1
	12+ 6	1.019	0.997	1.011	−0.8
	12× 8	1.022	0.999	1.014	−0.8
	12×10	1.022	0.999	1.007	−1.5
20×20	20× 2	0.777	0.867	0.777	0
	20× 4	0.972	0.978	0.971	−0.1
	20× 8	0.992	1.001	0.990	−0.2
	20×10	0.996	1.002	0.998	−0.2
	20×12	0.996	1.002	0.998	0.2
	20×15	1.000	1.001	0.999	−0.1
	16× 4	0.988	0.978	0.972	−1.6
	16× 8	1.006	1.002	0.990	−1.6
	16×12	1.011	1.002	0.998	−1.3

Table 4b. Applicator correction factor and field size factor of rectangular field in 12 MeV electron beam.

Applicator	Given Field	Output Factor			1D method
Size cmxcm	X Y	Measured	Sq Root	1D	% of uncertainty
10×10	10× 2	0.872	0.896	0.872	0
	10× 4	0.973	0.987	0.973	0
	10× 6	1.005	1.005	1.005	0
	10× 8	1.009	1.004	1.009	0
	8 × 2	0.867	0.900	0.879	1.4
	8 × 4	0.979	0.991	0.982	0.3
	8 × 6	0.999	1.009	1.014	1.5
	6 × 2	0.853	0.901	0.876	2.7
	6 × 4	0.977	0.992	0.978	0.1
	4 × 2	0.853	0.884	0.848	−0.6
15×15	15× 2	0.894	0.895	0.894	0
	15× 4	0.994	0.986	0.994	0
	15× 6	1.009	1.005	1.009	0
	15× 8	1.010	1.009	1.010	0
	15×10	1.005	1.007	1.005	0
	15×12	1.005	1.004	1.002	−0.3
	12× 4	0.981	0.990	0.995	1.4
	12× 6	1.010	1.009	1.011	0.1
	12× 8	1.013	1.013	1.012	−0.1
	12×10	1.013	1.010	1.007	−0.6
20×20	20× 2	0.830	0.890	0.830	0
	20× 4	0.991	0.983	0.990	−0.1
	20× 8	1.014	1.003	1.013	−0.1
	20×10	1.016	1.006	1.016	0
	20×12	1.011	1.004	1.013	0.2
	20×15	1.005	1.002	1.005	0
	16× 4	0.988	0.986	0.995	1.7
	16× 8	1.019	1.006	1.018	−1.1
	16×12	1.011	1.007	1.017	1.3

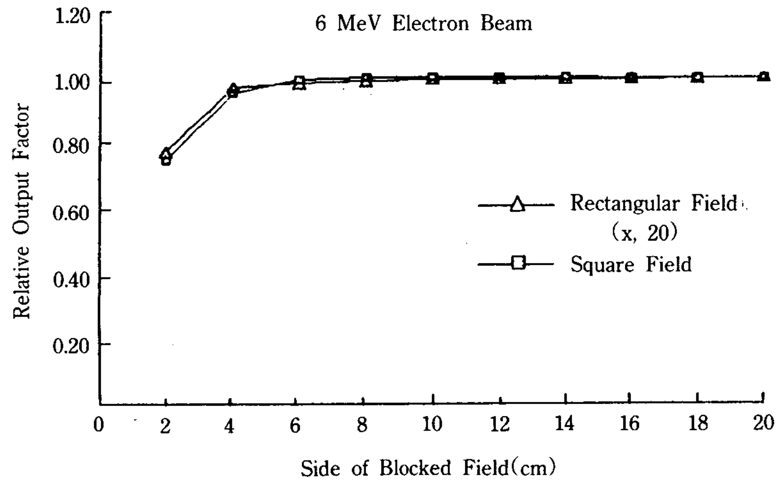

Fig. 5 Output Factor as function of field shape in a 20×20㎝ applicator for 6 MeV electron beam energy.

Discussion

The variance of output in electron beam is predominant to blocked field size rather than that of primary and secondary collimator which are automatically opened to full and fixed in ML−15MDX linear accelerator.1)

A few researchers3,4,8,9) described the prediction of output dose of electron beams with square root or one-dimensional method. However the output dose is strongly dependent to collimator syste, and applicator shape include the block size. the authors investicated the output factor of 4,6,9,12 and 15 MeV electron beam in ML−15MDX linear accelerator.

The heavy metal collimator have a secondary function as they often act as a source of scattered electrons which may alter the output dose. However, in this experiments, the field size and shaping did not largely effected to the dose maximum depths and output factors in sevral different applicator size and electron energy. This samall differency of dose maximum depth and output factor are expected that collimator was full opened and 5cm of air gap from tip of field block to phantom surface. This air-gap helps to avoid most of the problems due to nonflat patient surface and it was expected to a small contribution of secondary electron scattering to reference depth.

The output dose was measured at dose maximum depth in a given applicator size for comparing to that of reference 10×10cm^2 applicator.

The outputs were fitted that of the 2×2cm^2 to 20×20cm^2 in square field and one-side lengthened rectangular field. in two types of output factors were included which is the output factors versus side of square for square fields and output factors versus length of variable side for X and Y length for that of a elongated rectangular field, respectively.

Output factor was chagned with increasing field size, it refered to applicator correction factor. However this correction factor was decreased as increasing the electron energy.

We found the output factor presented the maximum at medium sized block field in given applicator at this ML−15 MDX electron beam.

The polynomial regression fitting for 1D method was revealed close to experimental measurement data within 2% uncertainty in rectangular field but the decrepancy was relatively high in a very large ectended field shape.

Conclusion

The output factor was increased by applicator size increasing but that was small changed in high energy electron beam. It was also effected on field shaping as rectangular field.

The output factor was closely fitted with 4th order in 10×10cm^2 applicator size and 7th order in 15×15cm^2 and 20×20cm^2 applicator size. The expected output factor based 1D method was very closed to measured data in square and rectangular field within 3% discrepancy.

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선형가속기 ML-15MDX의 각 Applicator에 대한 전자선 출력선량 계수 결정

최태진, 김옥배
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초 록

목적 : 선형가속기 ML-15MDX의 전자선에너지 대한 출력선량계수가 Applicator크기에 따라 결정되도록 하며 각 Applicator에서 정방형조사면과 직사각형조사면에 대한 출력선량계수는 측정값으로 부터 다항식을 이용하여 결정되었다.

방법 : 실험에서, 출력선량의 측정은 전자선에너지 4, 6, 9, 12MEV대해 2×2㎠에서 20×20㎠까지 이루어졌다. 출력선량계수는 각 아프리케이터의 조사면중심선속의 최대선량에 대한 임의 조사면의 최대선량의 비로 얻어졌고, 각 아프리케이터의 출력선량계수는 기준 아프리케이터(10×10㎠)와 비교되었다.

전자선조사면의 차폐는 모든 실험에너지 영역에서 균등하게 10㎜ 두께의 Lipowitz(밀도 9.4g/㎤)를 사용하였으며, 조사면크기 및 모양 결정이 용이하도록 고안하여 사용되었다.

임의의 전자선조사면에 대한 출력선량계수는 조사면의 한변을 고정한 직사각형의 출력선량계수를 이용한 1-Dimension방법에 의한 다항식으로 부터 구하였다.

결과 : 직사각형의 전자선조사면에 대한 출력선량계수는 4×4㎠에서 20×20㎠의 범위에서는 2%이내의 불확실성을 보였으며, 이들 보다 작은 직사각형조사면에서는 약 3%의 오차를 보였다.

결론 : 전자선에너지의 정사각형 및 직사각형조사면에 대한 출력선량계수가 실험자료를 이용한 다항식으로 부터 실제값에 매우 근사한 예상값을 얻을 수 있었다.