The Influence of Oblique Incidence Electron Beams to Beam Specification Parameters

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Abstract - **The changes of beam specification parameters along the normal central axis of electron beams with increasing gantry angle had been measured. The electron beams were produced by Varian Clinac2100C with energies of 6, 9, 12, 16, and 20 MeV. This work was performed using Wellhőffer water phantom provided with two small cylindrical IC-15 chambers. It was found that the oblique incidence beams cause the d_{max} depth, R_p, R_{85} at normal central axis shifted to skin surface. For all energies, the changes of gantry angle from 0 to 20 shift the d_{max} depth in the range of 2.0 % up to 17.73 %, R_p in the range of 2.02 up to 10.78 %, and R_{85} in the range of 8.93 up to 9.37 %. The percentage ionization along the diagonal fanline was also measured. The results indicated that for lower energy electron beams (6 MeV, 9 MeV, and 12 MeV) the diagonal fanline was still located at the penumbra region (80 % -20% isodose line), whereas for higher energies (16 MeV and 20 MeV) these diagonal fanline were in radiation field area particularly for the gantry angle of 15^o and 20^o.**

Keywords - **Oblique incidence, electron beams, diagonal fanline, penumbra**

I. INTRODUCTION

High energy electrons were first used in radiation theraphy shortly after the successful extraction of the beam from a betatron in 1947. By the early 1950s a few institutions using commercial betatron or unique linear accelerator were treating patients on routine basis.[1,2] The electron beam coming from linear accelerator represents important modality in modern radiotherapy. Because of its limited range (less than 5 cm) in soft tissue, electron beam is often used in combination with other techniques. For example, in breast cancer treatment one can use electron beam after the photon beam irradiation or mastectomy. For superficial cancer such as lymphoma, mycosis fungoides, and some of head-neck cancer, electron beam is commonly used[1].

Since its common use in superficial tumor, electron beam treatment often meets bend surfaces, while flat phantom is more common in verification and dose calibration. Such oblique surfaces and air gap are commonly found in breast and "head and neck" cancer, so dose determination in those cases is not easy[1,2]. Such obliquity and air gap will also change effective depth dose. Therefore, characterization of oblique incidence beam and beam specification parameters should be investigated for clinical application.

Faiz Khan *et. al.*, have studied extreme oblique incidences (30^o up to 60^o) on dose calculation. Obliquity factors for various energies were obtained to correct lower and over dose on the target volume[1,3]. This study is very important, because a radiotherapy technique uses a high dose rate to kill cancer cell with maximum errors at about ± 5 % (base on recommendation of International Commission on Radiation Measurements and Units)[4]. In this work we measured relative dose at depths for small oblique incidence beams (10^o up to 20^o) particularly at normal central axis and at penumbra area. The results of this study will give more information and correction for treatment at these oblique gantry angles. It is hoped that the use of such correction will protect patient from low or overdose and radiation hazards.

II. MATERIALS AND METHODS

The experiments were performed at Radiotheraphy Department, Persahabatan Hospital, Jakarta using Varian Clinac 2100C linear accelerator which provided electron beams with various energies of 6, 9, 12, 16 , and 20 MeV. All measurements used electron beams with 10 x 10 cm^2 applicator, SSD 100 cm, Wellhőffer water phantom with the size of 48 x 48 x 48 cm^3 which comes with two IC-15 small cylindrical chambers (0.13 cm^3), electrometer CU 500E, and data acquisition software program WP 700. Mechanically, Wellhőffer water phantom could provide detector movements along X, Y, Z axis (3 Dimension) and diagonal fan-line. The effect of reversing the polarity and cavity pertubation was found to be negligible as measured at selected depths.

First, the percentage ionization data at the normal central axis beams were collected and the results will be used as a reference. The percentage ionization data were collected particularly at points at the central axis beams with the gantry angles of 0^o, 10^o, 15^o, 20^o for all electron beam energies. From these data, d_{max} and practical range (R_p) at normal central axis incidence were obtained.

The second step, the percentage ionization at normal central axis of gantry of 0^o (I_o) and the percentage ionization at diagonal fan-line axis I_θ were measured along the diagonal fan-line **z** that started from end cone position at 5.02 cm for all measurements (see Fig.1).

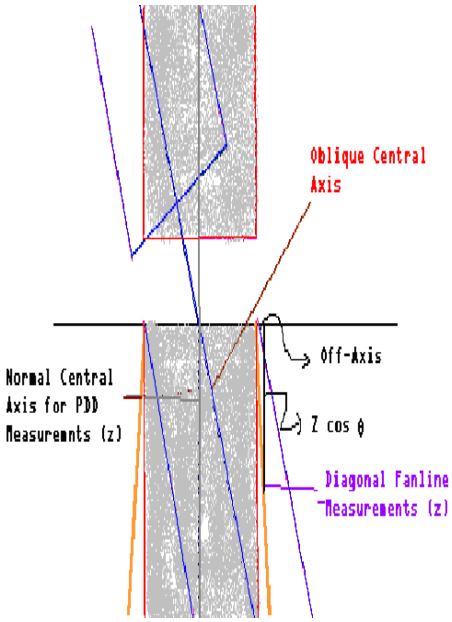


Fig. 1 Illustration of diagonal fan-line measurements which started at 5.02 cm at field size corner

III. RESULTS AND DISCUSSION

The maximum doses at normal central axis have been measured at various gantry angles. Since at oblique incidence beam direction the normal central axis will not be the primary axis, depth dose maximum (d_{max}) of central axis at oblique incidence beams will be lower than value when the gantry is 0°. The measurements result in the form of percentage ionization as a function of various gantry angles and at a certain energy. It can be concluded generally that for all electron energies the d_{max} shifted to skin surface with increasing gantry angle. The ionization curves were observed to slightly contract towards the surface.

WP 700 program also automatically provides printout of several beam specification parameters such as d_{max}, practical range (R_p), E_0 (electron energy at surface), E_{p0} (most probable electron energy at surface), and isodose line 85%, 80%, 50%, and 30 % using Task Group 25 AAPM conversion. For detailed explanation, the change of practical range (R_p), maximum depth (d_{max}), and therapeutic range (R_{85}) as a function of gantry angles can be seen in Table 4.1. The influence of gantry angles to d_{max} , R_{85}, practical range (R_p) were then plotted in Figures 2, 3, and 4. It seems the d_{max} decreases with increasing gantry angles, but there was no specific trend or correlation for a given energy. This evidence also occurred for practical range with increasing angle of beam. On the contrary, for therapeutic range (R_{85} isodose line) the curve (see Fig. 3) decreased slowly up to 10° gantry angle and then sharply decreased.

Generally, electron beam therapy at Radiotherapy Department, Persahabatan Hospital uses single field and 0° gantry angle. It is not very common to use the oblique incidence beams at higher degree angle, therefore, in this work the gantry angles was varied from 0° up to 20°. From the measurement results it was shown that the d_{max} depth, practical range (R_p), and R_{85} were shifted to skin surface. That means the oblique incidence beams caused lower penetration power and increase the dose at shallow depth. These found supports from the previous reports[5,6]. However, there was no specific trend of decreasing the rate of those parameters. That means changes of these parameters for other gantry angles can be obtained by measurements only.

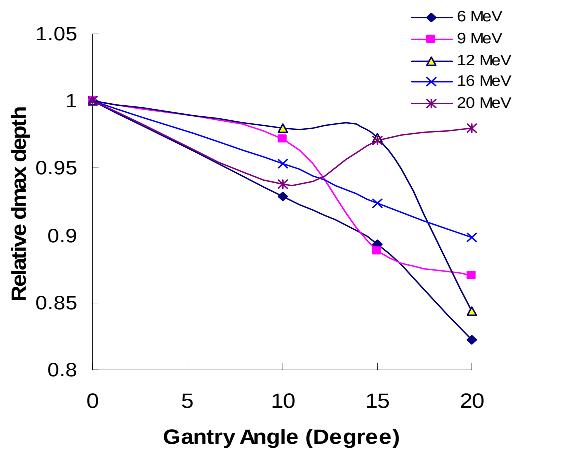


Fig. 2 Relative d_{max} depth of oblique incidence to normal incidence beams at normal central axis

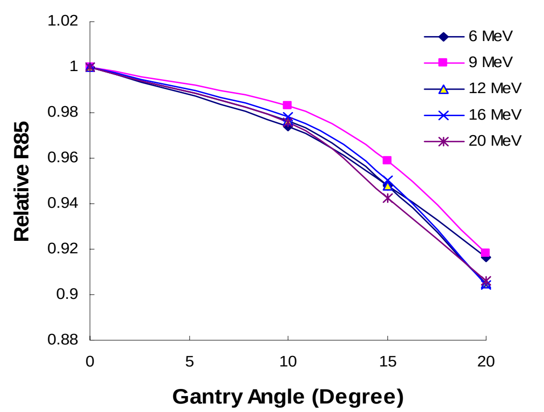


Fig.3 Relative isodose line of 85% of oblique incidence to normal incidence beams at normal central axis

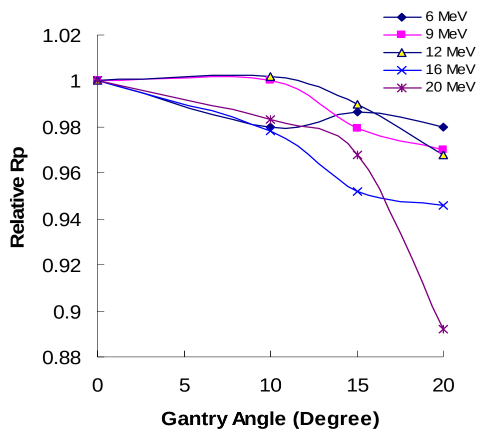


Fig. 4 Relative practical range of oblique incidence to normal incidence beams at normal central axis

Table 4.1. Influence oblique incidence beams to d_{max}, R_{85} practical range (R_p)

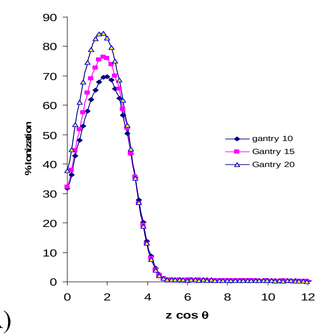
Electron Energies	Gantry Position	d_{max} (cm)	R_{85} (cm)	R_p (cm)
6 MeV	0°	1.41	1.92	2.96
	10°	1.31	1.87	2.90
	15°	1.26	1.82	2.92
	20°	1.16	1.76	2.90
9 MeV	0°	2.15	2.93	4.33
	10°	2.09	2.88	4.33
	15°	1.91	2.81	4.24
	20°	1.87	2.69	4.20
12 MeV	0°	2.94	4.20	5.95
	10°	2.88	4.10	5.96
	15°	2.86	3.98	5.89
	20°	2.48	3.80	5.76
16 MeV	0°	3.44	5.44	7.91
	10°	3.28	5.32	7.74
	15°	3.18	5.17	7.53
	20°	3.09	4.92	7.48
20 MeV	0°	2.43	6.61	10.01
	10°	2.28	6.45	9.84
	15°	2.36	6.23	9.69
	20°	2.38	5.99	8.93

From Tables 4.1, it can be calculated that the highest shift of d_{max} occurred at about 17.73% at 20° gantry angle for 6 MeV and the lowest shift appeared at about 2% for 20 MeV electron energy. The most important parameter for clinical application is therapeutic range R_{85}. It was interested that relative R_{85} has only two values for all electron energy 9.37% for 12 MeV, 16 MeV, and 20 MeV and 8.93 %. for 6 MeV, 9 MeV at 20 gantry angle. There is no particularly trend correlation between relative R_p and gantry angle from Figure 4. It can be seen at gantry 20° the relative R_p dropped up to 10.78 % for 20 MeV and at 2.02% for 6 MeV electron energy.

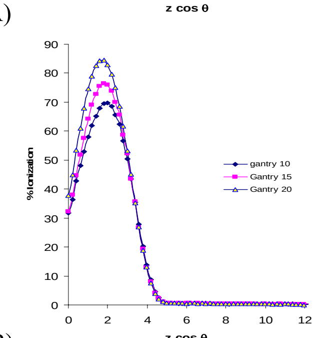
The Wellhőffer water phantom provided WP 700 program that can measure diagonal fan-line to scan the penumbra area of electron beams. The data measured represent the percentage ionization along a line which value at about 2° up to 3° with a normal surface. The measurements along the fanline depend on electron beam energy.

The value of vertical depth **z cos θ** (in centimeter) and off-axis determine the coordinate point of diagonal fan-line measurements, where the off-axis value is **z sin θ + 5.02** (in centimeter) where θ is the angle during fanline measurement to normal surface. These measurements data were illustrated in the form of curves in Figures 5A, 5B, 5C, 5D, and 5E for beam energies of 6, 9, 12, 16, and 20 MeV respectively. In all Figures, the percentage ionization along the normal central axis were presented as reference. It appears that the percentage ionization of diagonal fan-line has symmetrical trend particularly in high energy electron beams. It was found that the surface dose at higher energy dropped to much lower values with oblique incidence beams.

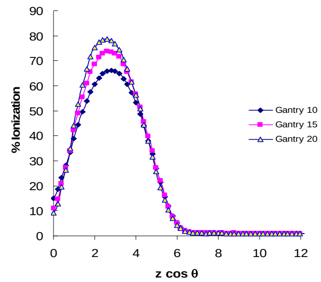
In general, the curves started at same points at the surface and started increasing until a maximum value and then decreased slowly. After certain point in the curves, percentage ionization is independent to the gantry angle, whereas on the contrary for the maximum value. For all energy, the highest (maximum value) relative percentage ionization occurred at 20° gantry angle then followed by 15° and 10° respectively.



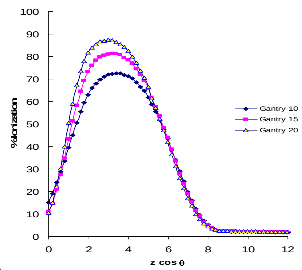
(A)



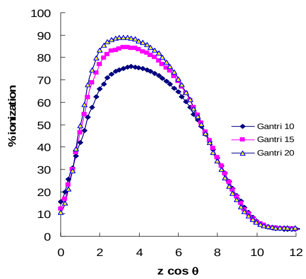
(B)



(C)



(D)



(E)

Fig. 5 Percentage ionization of penumbra area at 6 (A), 9(B), 12 (C), 16(D), and 20 (E) MeV electron energy for various gantry angles

The information of penumbra area is important for clinical application, in order to predict the dose outside and around the target area. In this work, the penumbra area was measured starting at a point 5.02 cm laterally beyond field edge. The penumbra is defined at area from 80% - 20% isodose line[2] and 90% - 10% isodose line[7]. If the first definition was applied in this works the diagonal fanline was located in penumbra for lower energy, whereas at higher energy (16 MeV and 20 MeV) the diagonal fanline was in the radiation field particularly at gantry angle at 15^o and 20^o.

The relative dose at penumbra shifted to skin surface due to the increase of air gap between surface and applicator. The result implied that the penumbra was broader with increasing electron energies and gantry angle at the large size space, whereas for other side there will be possibility of hot spots occurrences[7]. From figure 5A, 5B, 5C, 5D, and 5E the percentage ionization along the diagonal fanline tend to symmetrical form for higher electron energy (12,16, and 20 MeV). This results caused the surface dose at penumbra side for higher energy was relatively lower and surface dose at penumbra side for lower energy (6 and 9 MeV) are relatively higher.

IV. Conclusion

From this work, it can be concluded that the oblique incidence beams change beam specification parameters relative to that attributed to the normal incidence beam. The values of d_{max}, R_p, and R_{85} at normal central axis shifts to surface direction that still depends on electron energy and gantry angle. Measurement results indicated that for 6 MeV to 20 MeV electron beam energies, the changes of gantry angle up to 20^o affecting respectively d_{max} that shifted in the range of 2.0 % up to 17.73 %, R_p in the range of 2.02 up to 10.78 %, and R_{85} in the range of 8.93 up to 9.37 %. These results support Ekstrand's and Dixon's results except that their measurements were done at gantry angles greater than 30^o.

The oblique incidence beams also influenced the percentage ionization along the diagonal fanline that makes about 2^o - 3^o to normal surface. For lower electron energies beams (6 MeV, 9 MeV, and 12 MeV) the diagonal fanline was still located at the penumbra region (80 % -20% isodose line), whereas for higher energies (16 MeV and 20 MeV) these diagonal fanlines were in the radiation field area particularly for the gantry angle of 15^o and 20^o. So far the author has not found similar or comparable study or publication at this range of gantry angle values.

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