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Dose Distribution of Stereotactic Irradiation for Thorax

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Abstract

Stereotactic irradiation has been adopted in many hospitals recently. For this treatment, accurate dosimetry is important for determining the absorbed dose to target volume. But there are some difficulties caused by small field.

Especially in the case of lung cancer, it is difficult to determine the absorbed dose for narrow beam field. Because it is composed variety materials, it makes determining absorbed dose to be difficult. In the lung, which has a low density, the number of recoil electron per unit volume is smaller than the soft tissue and travels longer distance. Consequently, the recoil electron arrives the outside of the field and electron equilibrium does not exist.

In this study, the absorbed dose distribution of thorax was calculated using the EGS4 Monte Carlo simulation. The thorax model was composed of 3 layers; the thickness of front chest wall is 3cm, the thickness of back chest wall is 5cm, and between them, there is lung in which including small target volume. The variation of absorbed dose distribution as a function of field size, energy of incident X-ray and depth of target volume was investigated.

1 Background

In Japan, the death rate caused by lung cancer has been increasing. In the past, the way to treat lung cancer was through an operation. But today, thanks to the screening using a spiral CT scanner, the lesions can be found in an early stage, so radiotherapy has come to be considered an effective means of treatment.

In radiotherapy, the most important thing is to irradiate optimal dose to target volume and to minimize the damage to normal tissues. In conventional methods, there was probability of terrible side effects like pneumonia caused by the irradiation to the periphery of a tumor. The technique to irradiate intensively for target volume has been improving, by irradiating from every angle, the influence on normal tissues is minimized and the side effects are eliminated[1,2].

Stereotactic irradiation was first proposed for a patient in the 1950's with a brain tumor that could not be operated on. The use of high X-ray beams was proposed in 1974. Before, it was regarded as treatment of brain tumor, but in the future, it will be considered as a treatment method for lung cancer.

2 Introduction

Stereotactic irradiation using a linear accelerator has been widely adopted in many hospitals recently. For this treatment, accurate dosimetry is important for determination the absorbed dose to target volume. But there are some problems caused by small field in this treatment[3]. Especially, in the case of lung cancer, a thorax is composed several tissues and it is difficult to determinate the absorbed dose distribution. In the lung, the recoil electron travels longer distance and arrives the outside of the field. Furthermore the numbers of recoil election per unit volume is smaller than the soft tissue. Consequently, the second electrons equilibrium dose not exists and it makes determination of the absorbed dose to be difficult. In this study, the absorbed dose distribution of thorax was calculated using the EGS4 Monte Carlo simulation. The variation of the absorbed dose distribution as a function of field size, incident x-ray energy and optimal incident energy were investigated.

3 Methods and Materials

3.1 The geometrical arrangement

Figure 1 shows the geometrical arrangement of simulations for the absorbed dose calculation. The diameter of the thorax model was 40 cm and the thickness was 23 cm. This thorax model was composed of 3 layers. These are the front chest wall, the lung layer and the back chest wall. The density of the front chest wall and the back chest wall were 1.0 g/cm^3. The thickness of the front chest wall was 3.0 cm and the back chest wall was 5.0 cm. The thickness of lung layer was 15 cm, and the density was 0.3 g/cm^3. There was a tumor volume embedded in lung at a 10 cm depth. Its diameter and thickness were 2.0 cm. In this model, imaginary planes were arranged perpendicular to the beam axis at an interval of 0.5 cm. Furthermore, the model was divided into concentric cylinders at an interval of 0.1 cm. The absorbed dose of each volume was calculated. In the case of homogeneous model, the lung layer was replaced with water equivalent material. And the results of film method were compared. This experiment was performed for 6 MV and 10 MV X-ray with MEVATRON KD2/65 linear accelerator at the Cancer Institute Hospital. The thorax phantom was similar with the geometrical arrangement of simulation. And the absorbed dose distribution of thorax model and homogeneous model were compared.

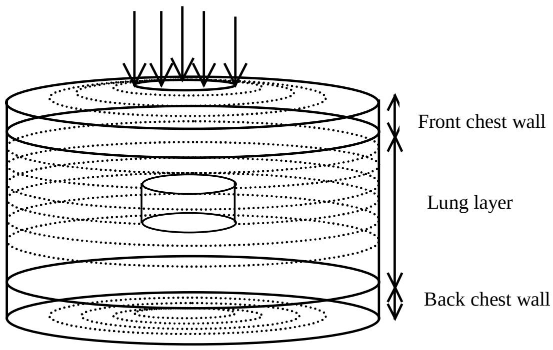

Figure 1. Geometrical arrangement of Monte Carlo simulation

3.2 Condition of simulation

The absorbed dose distribution was calculated using the EGS4 Monte Carlo simulation. An EGS4 user code, which recorded the absorbed dose at arbitrary depth for an arbitrary field size, was coded for this study. The incident beams were parallel beam of photons. Field shape was circular field. Those Spectra data was quoted from Mohan's data[4]. A set of 5,000,000 photons was generated per batch and ten batches were performed for field diameters of 2.8, 3.0 and 3.2 cm respectively. The simulation was performed for a 4, 6, 10 and 15 MV X-ray.

4 Results and Discussion

4.1 Variation in OCR

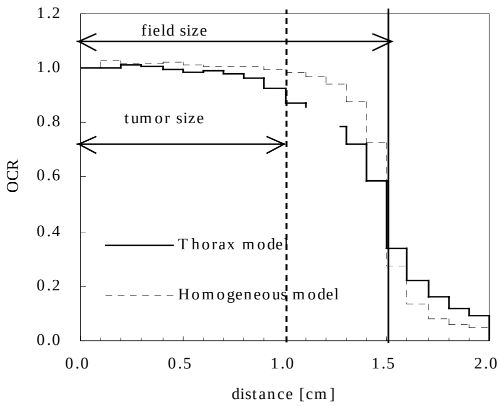

Figure 2. Comparison of OCR for thorax model and homogeneous model of 4 MV at 9 cm depth.

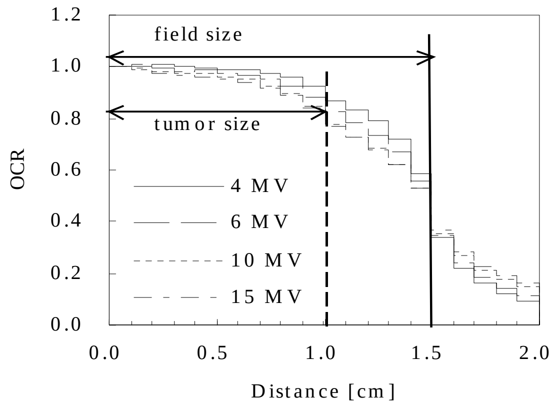

Figure 3. Variation of OCR as a function of X-ray energy.

The off-center ratio (OCR), which is the ratio of the dose at a point off the central ray to the dose at the same depth on the central ray, represents one-dimensional dose distribution for perpendicular direction to beam axis. Figure 2 shows the OCR in the thorax and homogeneous model at a 9 cm depth for a 3.0 cmϕ field of 4 MV X-ray. The standard deviation was about 3.5 % near the beam axis and less than 1.0% at 1.0 cm from the axis. In a region between the center and 1.5 cm from the center, the OCR curve of the thorax model declined more steeply than the one of the homogeneous model. But outside of the field, the OCR in thorax model was greater than the OCR of the homogeneous model. Figure 3 shows the variation of OCR as a function of X-ray energy. The OCR curve became to be more steeply as the X-ray energy increased. In the case of 4 MV, the difference of OCR at the center and at 1.0 cm was 7.3 %. In the case of 15 MV, the difference of OCR at the center and at 1.0 cm was 15.0 %. The flat range of OCR in the tumor decreased as the X-ray energy increased. And in the lung area, the OCR increased as the X-ray energy increased.

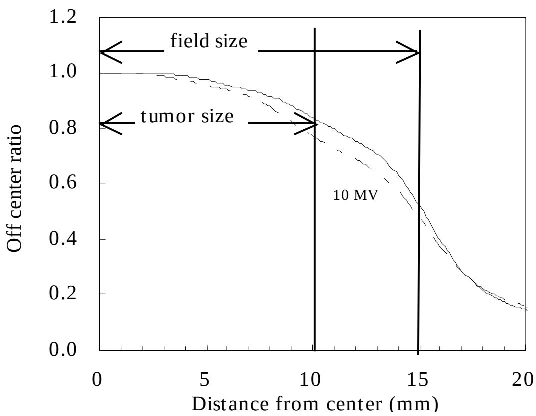

Figure 4. The difference of OCR between 6 MV and 10 MV with film method

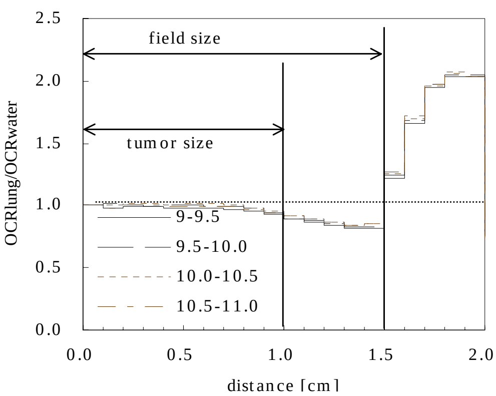

Figure 5. The change of ratio of the OCR of thorax model for the OCR of homogeneous model for a 3.0 cmϕ field of 4 MV X-ray.

The range of the 0.2-0.8 and 0.8-0.8 of OCR are summarized in Table1. The range of the 0.2-0.8 of OCR is the distance between the points at 20% and 80% of the central-axis dose value[5]. The 0.8-0.8 of OCR is the width that receives at least 80% of the dose on the central axis. The range of the 0.2-0.8 of OCR increased as the X-ray energy increased. The 0.8-0.8 of OCR decreased as the X-ray energy increased. Thus, with higher energy a greater margin must be maintained around a lung tumor. Figure 4 shows the difference of OCR between 6 MV and 10 MV with film method. The flat range of OCR in the tumor decreased as the X-ray energy increased. By comparing this result and the prior result, it was found that their results behave similarly. Figure 5 shows the change of ratio of the OCR of thorax model to the OCR of homogeneous model for a 3.0 cmϕ field of 4 MV X-ray. The y-axis shows the ratio of OCR in the thorax model to homogeneous model. In the region between 1.0 cm and 1.5 cm distance from the center, the ratio decreased. And in the region from 1.5cm to 2.0 cm from the center, the ratio increased. At a 1.5 cm, the OCR of lower energy almost corresponded with the one of higher energy. But in the tumor, the OCR ratio increased as the X-ray energy decreased. Figure 6 shows the change of OCR as a function of field size. As the result, it was found that the flat range increased as the field size increased but the OCR increased outside of the tumor.

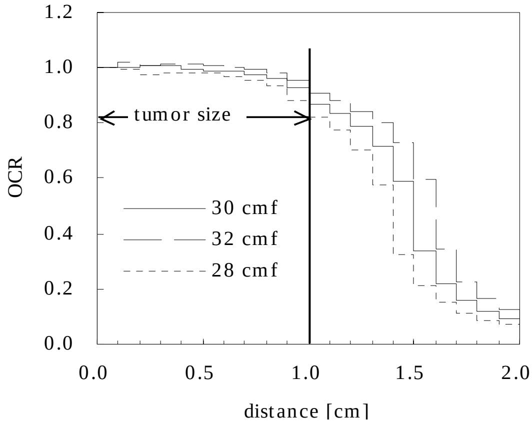

Figure 6. The change of OCR as a function of field size for 4 MV X-ray.

Table 1 the range of the 0.2-0.8 and 0.8-0.8 of OCR

Energy	0.2-0.8 of OCR [cm]	0.8-0.8 of OCR [cm]
4 MV	0.5	2.4
6 MV	0.6	2.2
10 MV	0.8	2.0
15 MV	0.8	2.0

4.2 Summary of OCR

It was found that the flat range decreased as X-ray energy increased. From the variation of OCR as function of field size, the flat range increased as the field size was extended but a greater amount of normal tissue must be irradiated.

4.3 Variation in percentage depth dose

The Percent Depth Dose (PDD) is the ratio of the dose to the dose at standard depth. PDD represents one-dimensional dose distribution on beam axis. Figure 7 shows the comparison of PDD between thorax and homogenous model at a center for 3.0 cmϕ field of 4 MV X-ray. The graph was normalized at a peak depth. At a 3.0 cm depth, the build-down exists; re-buildup and build-down exist at the interface of lung and tumor. Figure 8 shows the change of PDD as a function of X-ray energy. The PDD curve became more steeply at the interface of lung and tumor as the X-ray energy increased. And the flat range in the tumor decreased. Figure 9 shows the difference of PDD between EGS4 and RTAR at the center for a 3.0 cmϕ of 4 MV X-ray. RTAR is the inhomogeneous correction without scatter correction. It is used generally in clinical. The PDD of EGS4 was less than the one of RTAR. The difference between EGS4 and RTAR was summarized Table 2. In the tumor, the difference between EGS4 and RTAR for 4 MV and 6 MV was about 5 %. Figure 10 shows the difference of PDD between 6 MV and 10 MV with film method. X-axis shows depth from the surface in mm. The

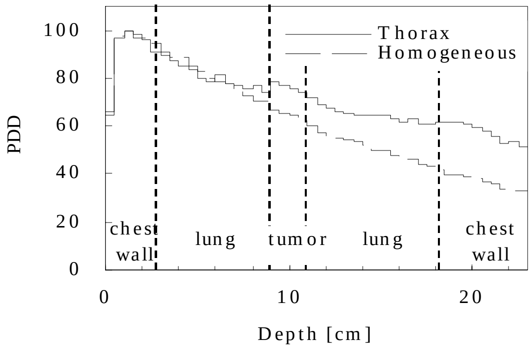

Figure 7. The comparison of PDD between thorax and homogenous model at a center for 3.0 cmϕ field of 4 MV X-ray.

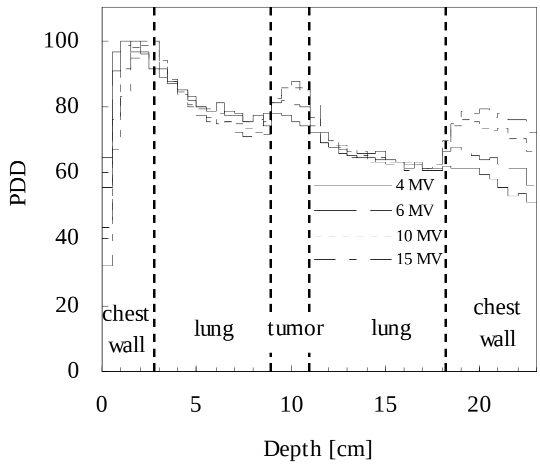

Figure 8. The change of PDD as a function of X-ray energy

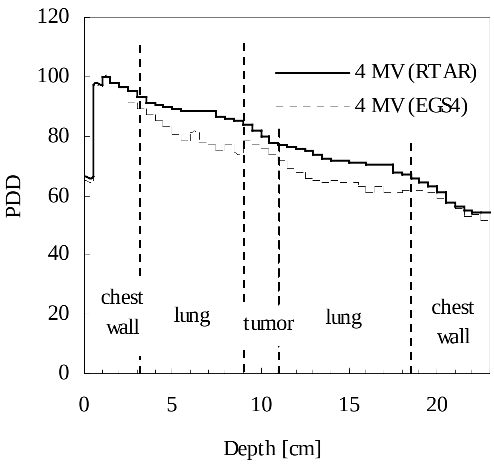

Figure 9. The difference of PDD between EGS4 and RTAR at the center for a 3.0cmϕof 4 MV X-ray.

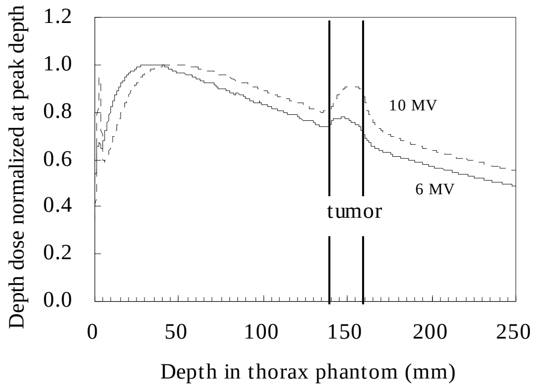

Figure 10. The difference of PDD between 6 MV and 10 MV with film method. In this case, absorbed dose distribution was measured with spherical tumor phantom.

build-up and build-down exist at the interface between lung and tumor. And in the tumor, the flat range of PDD increased as the X-ray energy decreased. By comparing the results of film method and simulation, it was found that their results behave similarly.

Table 2. The difference [%] between the result of EGS4 and RTAR

	4 MV	6 MV	10 MV	15 MV
In the tumor	5.4	5.3	7.0	9.8
In the lung	10.1	13.5	20.1	23.9

The coefficient of variance of the absorbed dose in tumor as a function of X-ray energy was examined. The change of the coefficient of variance was show in Figure 11. In the tumor, the coefficient of variance increased as the X-ray energy increased.

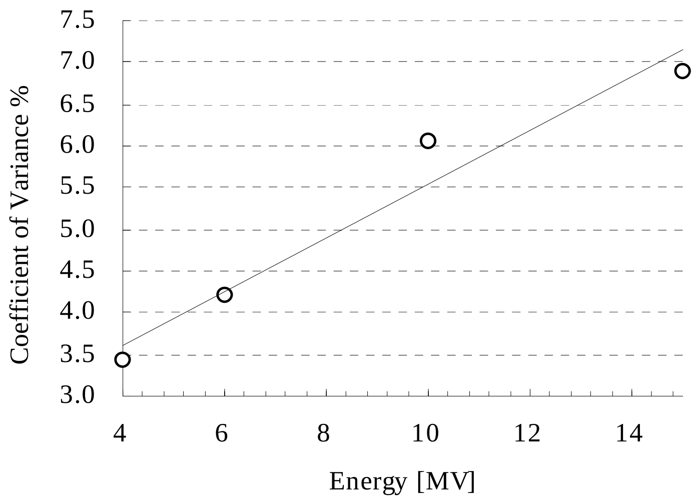

Figure 11. Coefficient of variance in the tumor

4.4 Summary of PDD

As the result, the build-up and the build-down caused by decrease of the number of secondly electrons in the lung existed at the interface of the front chest wall and lung, and the interface of lung and tumor. The PDD curve became more steeply at the interface of lung and tumor as X-ray energy increased. And the difference between the result of EGS4 and the one of RTAR is about 5 % for 4 MV X-ray. But the differences increase as the X-ray energy increase.

5 Conclusion

In this study, the absorbed dose distribution of tumor in the lung could be calculated using the EGS4 Monte Carlo simulation. As the result, it was found that a lower energy could irradiate with better the absorbed dose distribution rather than a higher energy, because the flat range of OCR and PDD in the tumor increased as the X-ray energy decreased. In stereotactic irradiation for lung cancer, it is required that high equality of absorbed dose in the tumor and decreasing radically out side of the tumor[6]. Consequently, a lower energy was recommended rather than a higher energy.

References

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