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Development of a Multi-layer Solid Phantom for Intensity-Modulated Radiation Therapy

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1. Introduction

The Intensity-Modulated Radiation Therapy (IMRT) based on the conformal radiotherapy has been generally used to deliver non-uniform fluence to the patient. Hence, before a treatment, accurate dose verification is required to obtain the successful treatment of tumors.

The evaluation of dose distribution has been normally performed with a phantom and an ion chamber. Most of phantoms in other studies are generally designed for homogeneous condition, in spite of radiation treatment environment depended on the various patient-specific conditions.

Therefore, a heterogeneous plastic phantom transformed into the diverse configurations was designed in this study, and manufactured to increase the accuracy of Quality Assurance (QA) in practice.

2. Methods and Results

2.1 Composition of Heterogeneous Phantom

The heterogeneous phantom in this study was designed following the criteria of International Commission on Radiation Units and Measurements (ICRU) [1]. The phantom was composed of some materials equivalent with human body (i.e. muscle, fat, bone, lung, and air cavities). Especially, these materials filled in the solid phantom were considered with density, the chemical composition, and the effective atomic number similar to those of the body tissues. The effective atomic number is useful to represent the average atomic number for a compound or mixture of materials and the reaction between the photon and the materials. Therefore, the effective atomic number, Z_{eff}, was employed and can be expressed as follows [2]:

$$Z_{eff} = A_{eff} \sum w_i \frac{Z_i}{A_i} \qquad (1)$$

A comparison of the properties for the body tissues and the selected tissue-equivalent materials is shown in the Table 1. Several materials were analyzed by comparing the physical properties in this study, polystyrene, polyethylene, polytetrafluoroethylene, and polyurethane foam were finally chosen to alternate the muscle, fat, bone, and lung, respectively [3]. The maximum difference of density in the compared result is less than 4 %. The effective atomic numbers of selected materials are also composed of the low atomic numbers less than 12. It is recognized that the physical characteristics of the selected materials are similar to those of the tissues.

Table 1. Physical Properties of the Human Body Tissues and Selected Materials

	ρ [g/cm^3]	Z_{eff}		ρ [g/cm^3]	Z_{eff}
Muscle	1.04	7.71	Polystyrene	1.05	6.00
Fat	0.95	6.63	Polyethylene	0.94	5.95
Bone	1.92	11.18	Polytetra-flourethylene	2	8.31
Lung	0.26	7.80	Polyurethan Foam	0.28	6.94

IMRT technique has been performed using MV photon beams generated from the linear accelerator. In order to compare the interaction between the photon beams and the materials, the cross-section data for photon beams should be analyzed. In this study, we compared the cross-section data for the body tissues with those for the selected materials.

Total mass attenuation coefficients for muscle and polystyrene, as the function of the energy, are presented in Fig. 1. The data was obtained from the National Institute of Standards and Technology (NIST) XCOM database [4]. The cross-section data of selected polystyrene is well agreed with the muscle data within the range of 10^0 to 10^2 MeV, which is the interesting energy region in IMRT. The cross-section data of other materials is also same with the each equivalent human tissue within the same energy regions. Therefore, it is found that the characteristic of selected materials is almost equitant with the actual human body.

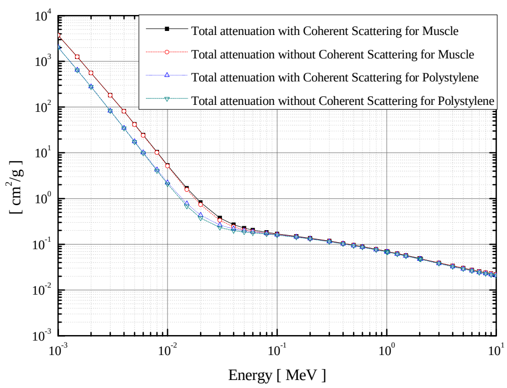
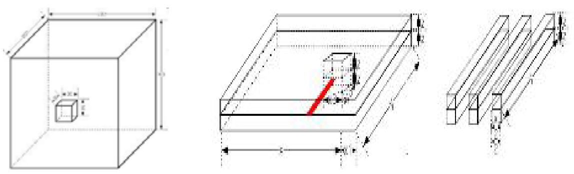


Fig. 1. Total Mass Attenuation Coefficients for Muscle and Polystyrene, as a Function of the Energy

2.2 Phantom Design

The Basic scheme of the heterogeneous phantom for IMRT is shown in figure 2. (a) and (b). The standard dimensions are 20×20×20 cm^3. This phantom can be transformed into the diverse design because it is sectioned transversely and vertically into the multi-size slices for dosimetric applications. The selected materials similar to the human tissues and some detectors can be also easily inserted into the any slab of solid phantom, as the IMRT quality assurance protocol.



(a) (b)

Fig. 2. (a) Basic Scheme of the Phantom (b) Phantom slices which can be transformed into the diverse design and have a detector hole

The dose distribution in the heterogeneous phantom was calculated to compare the dose profile of general water phantom by using MCNP code (see Fig.3). The phantom edge was set at the X-axis of 1 cm, and the X-ray beam penetrates along the X-axis. The calculated result shows that the depth of maximum dose (D_{max}) is about 13 mm, which is almost same with that of general water phantom (15 mm).

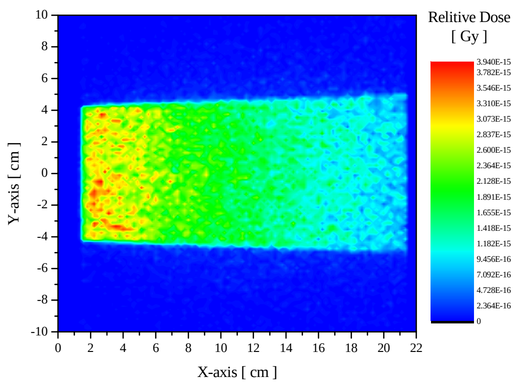
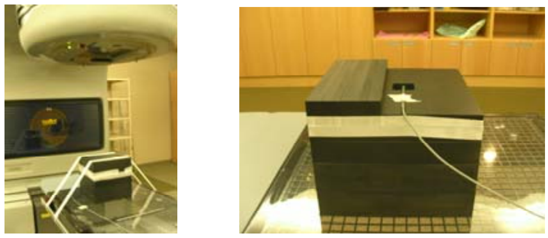


Fig. 3. The Evaluation for the Depth of Maximum Dose (D_{max}) in the Phantom, Using MCNP Code

2.3 Development

The head-and-neck multi-layer phantom for IMRT quality assurance was developed in this study (see fig.4.(a)). The phantom is composed of the diverse axial and coronal slabs (see fig.4.(b)). The unrestricted design allows the physicists to properly convert the phantom under the patient condition. Film measurements through the axial and coronal direction are also allowed by rotating the accelerator beam header.



(a) (b)

Fig. 4. (a) Quality Assurance using the Developed Phantom (b) Developed phantom which can be converted into the diverse design with the axial and coronal slabs

3. Conclusions

In this study, the head-and-neck multi-layer phantom has been developed to accurately validate IMRT treatment plans. The phantom can be user-configurable and inhomogeneous under the patient-specific condition. Hence, it is more efficient and convenient to use than other homogeneous or water phantoms. Consequently, the newly developed phantom can be applied for the IMRT quality assurance procedure in near future.

Acknowledgement

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