A study of detector size effect using Monte Carlo simulation

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The detector size effect due to the spatial response of detectors is one critical source of inaccuracy in clinical dosimetry and has been a subject of numerous studies. Conventionally, the detector response kernel contains all of the influence that the detector size has on the measured beam profile. Various analytic models for this kernel have been proposed and studied in theoretical and experimental works. Here, we use a method to determine detector response kernel simply by using Monte Carlo simulation and convolution theory. Based on this numerical method and DOSIMETER, an EGS4 Monte Carlo code, the detector response for a Farmer type ion chamber embedded in water phantom is obtained. There exists characteristic difference in the simulated chamber readings between one with carbon graphite wall and the other with Acrylic wall. Using the obtained response and the convolution theory, we are planning to derive the detector response kernel numerically and remove detector size effect from measurements for 6MV, 10x10cm2 and 0.5x10 cm2 photon beam.

Key words: detector size effect, deconvolution, Monte Carlo Simulation

INTRODUCTION

In radiotherapy, the accuracy of the absorbed dose in areas where the gradient of the radiation field is large depends strongly on the spatial response of the dosimeter used. Thus in clinical dosimetry, the detector size effect dealing with the spatial response of detectors has been extensively studied by many investigators[1-4]. According to these studies, correction is necessary to the measurements and especially important on measurements[6] of penumbra where dose gradient is large. In addition to the detector size effect, further correction to the measured dose is required if the detector and phantom materials are different. Since the charged particle fluence is perturbed due to the phantom material, the measured dose may contain inherent degradation to be corrected. This is known as in-scattering effect[6] and becomes important when measurements are made with detectors embedded in a phantom and transient charged particle equilibrium is not attained.

One of the standard techniques to remove the detector size effect is by deconvolving the detector response artifacts from the measurements[4,5,8,9]. This technique is based on the consideration that the measured beam profile is the convolution of the inherent beam profile with artifacts specific to the physical characteristics of the used detector. Commonly a representative detector spatial response function, which is also known as detector kernel, represents the physical response artifacts of a detector. Various mathematical models for detector kernel such as step functions, parabolic functions and Gaussian functions have been proposed and studied[3,4,7,8].

Previously, we proposed a method to calculate the detector kernel of an ion chamber instead of taking analytic models for granted[9]. According to this method, the detector kernel can be determined using Monte Carlo simulation and the convolution theory. Together with deconvolution technique, this kernel enables us to determine the inherent beam profile from the experimental data. In our earlier work, the simulation, for a cylindrical Farmer type chamber embedded in a water phantom at 5cm depth and being irradiated by 6MV photon pencil beam, was performed using DOSEXYZ, an EGS4 code. In this work, we adapt DOSIMETER, an EGS4 code by C Ma, and use it for the simulation. The simulated result of the ion chamber response will be presented.

Materials and methods

According to the conventional theory[3,4,7,8], measured dose profile D_m can be written as the convolution of the inherent dose profile D with a representative detector spatial response function or kernel K as

$$D_m(x) = \int_{-\infty}^{\infty} D(u) \cdot K(u-x) \cdot du \tag{1}$$

In order to obtain $D(x)$, earlier works[3,7,8] used various form of analytic model functions for detector kernel such as step functions, parabolic functions and Gaussian functions. Some other works[4,10] tried to determine the best detector kernel by checking which model gave the best fit to their experimental data. In our previous work[9], the detector kernel is determined by using Monte Carlo simulation instead of artificially selected analytic function or experimental data fitting. For this purpose, we consider a Farmer type ion chamber embedded in a water phantom at 5cm depth from and being irradiated by 6MV photon pencil beam. Both the dose profile by ion chamber, $D_{m.cham}(x)$, and the inherent dose profile at 5cm depth, $D_{wat}(x)$, in a water phantom are not measured but calculated using Monte Carlo simulation. Then the kernel of the ion chamber, $K(x)$, can be derived from the convolution equation below

$$D_{m,cham}(x) = \int_{-\infty}^{\infty} D_{wat}(u) \cdot K(u-x) \cdot du.$$

The Farmer-type ion chamber (0.6cm^3) has a cylindrical wall made of Acrylic or Carbon graphite with inner radius 3.12 mm, outer radius 3.5mm and length 2.4cm. The radius of aluminum central electrode is 0.5 mm. A slim rectangular shaped pencil beam of size 0.02 x 2.4cm^2 irradiates the surface of water phantom (SSD=100cm) with the ion chamber embedded at 5cm depth. The stem effect is ignored in this simplified cylindrical model. In most of Monte Carlo simulations related to the ion chamber study, the frequently used code is CAVITY or CAVRZ in EGS4/EGSnrc code system due to the existence of cylindrical symmetry. Previously, we used the code DOSXYZ because cylindrical symmetry of the system studied is broken. Thus the chamber had to be divided into small voxels of size 0.1x0.1x2.4 cm^3 to calculate approximately the total absorbed dose to the cavity gas. This approximation using DOSXYZ had weak points especially in the simulation of the chamber wall. In this work, we adapt DOSIMETER, an EGS4 code by C Ma, and apply it for the simulation. Using DOSIMETER, we can simulate the cylindrical ion chamber embedded in a rectangular water phantom irradiated by a mono-energetic pencil beam. Also by generalizing it, we can simulate the ion chamber embedded in a rectangular water phantom irradiated by 10x10cm^2 real beam with full phase-space file input generated by BEAM code. We also simulate the pinpoint ion chamber (0.2cm^3) with inner radius 2 mm, outer radius 2.5mm and length 1.2cm.

Results and discussion

The simulated results of $D_{m.cham}(x)$, where x is the relative distance between the chamber center and the photon pencil beam center, are shown in Fig. 1. Two results for different wall materials, one for graphite wall and the other for Acrylic wall, are put together in the Fig. 1 with respect to $D_{wat}(x)$, the simulated dose profile in water phantom at 5cm depth. The ion chamber readings are finite even when the photon beam is off the chamber edge, i.e. the relative distance x is larger than the chamber radius. It is due to the secondary components of the radiation. Furthermore, Figure 1 shows that ion chamber readings

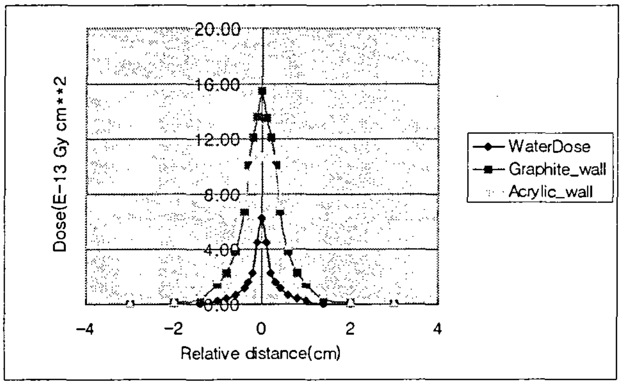

Fig. 1. Simulated results of chamber readings. Lines with square and triangle represent the chamber with Graphite and Acrylic wall respectively.

depend on the wall materials. There exists characteristic difference in the simulated chamber readings between one with carbon graphite wall and the other with Acrylic wall. Using these results and simulated annealing method, we will determine the detector kernel, *K(x)*, for the ion chamber and compare them with other results. We expect the kernel depends not only on its size but also on wall materials.

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