Investigation of dose perturbations around brachytherapy seeds in high-energy photon beams

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JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION and PURPOSE

Radiation therapy for prostate cancer is external beam radiation therapy (EBRT), brachytherapy, and combo-RT, which combines these two treatments. Commonly used materials for seeds are classified as high atomic number (high-Z) materials. The seed implants of such these high-Z materials, cause dose perturbations due to backscatter and attenuation of the photon beam during combo-RT. At present, the difference in the magnitude of dose perturbation by type, position and number of seeds, and photon beam type has not been clarified. The purpose of this study was to investigate the dose perturbation around the seed in high-energy photon beams.

METHOD

▸Seed implants

The type of I-125 seed used in our institution is TheraAgX100 (TAX: Theragenics Corporation, Fig. 1(a)) and Bard BRACHYSOURCE STM125I (BBS: C.R. Bard, Inc., Fig. 1(b)). The external dimensions of these seeds are nearly identical, but the materials of their internal composition differ greatly.

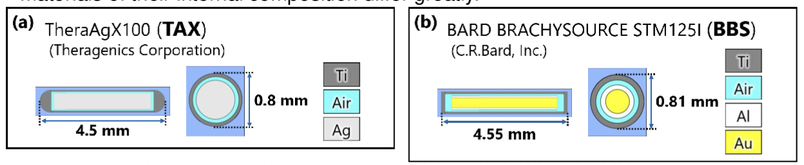

Fig. 1 Schematic diagram of I-125 seeds, TAX and BBS.

▸Monte Carlo simulation

Dose calculations were performed by the Monte Carlo (MC) code (Particle and Heavy Ion Transport code System: PHITS, version 3.11). In this study, phase-space files (PSF) of the photon beam for the Varian TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, USA) were used to simulate conventional (with-flattening filter: WFF) and the flattening-filter-free (FFF) beams. Beam energies of PSF are 6 MV and 10 MV. MC simulations with TAX and BBS were undergone in two geometric conditions (Fig. 2). The field size was set at 10 x 10 cm^2. The percentage depth dose (PDD) and off-axis ratio (OAR) were calculated under the above conditions. The dose perturbation is defined as the difference between the dose with seed and the dose without seed.

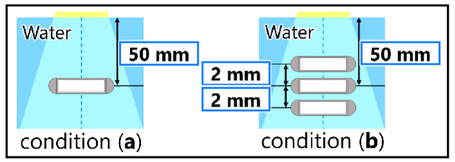

Fig. 2 Placements of seeds for MC calculation

In a clinical, the seed will be irradiated by multiple fields. The source position was moved to reproduce the situation, and an elliptical columnar water phantom was irradiated from five directions (Fig. 3).

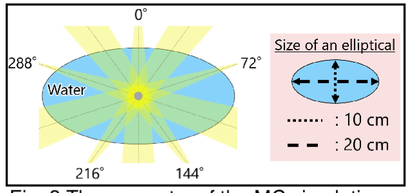

Fig. 3 The geometry of the MC simulation by using multiple fields. A seed was inserted the center of the phantom.

▸Film measurement

The measurement using GafchromicEBT3 films carried out to verify the accuracy of the MC calculation in the presence of seeds. Film measurements were performed using TAX. The EBT3 Films were scanned and analyzed using a flatbed scanner (Epson Expression 11000 XL, Epson America Inc., Long Beach, CA, USA) and ImageJ 1.52v (National Institutes of Health). The measured results with EBT3 film evaluated the dose perturbation as in the MC simulation results.

RESULTS and DISCUSSIONS

Fig. 4 shows the results of the MC simulation and the measurement on condition (a). The results of MC simulations and measurements showed good agreement within 4%. WFF beam tended to have a slightly wider backscattering range. This is because the WFF beam contains high energy components than the FFF beam. The magnitude of dose perturbations did not depend on the seed type and the beam energy. This result could be due to the small size of the seeds.

The Maximum dose enhancement of OAR was 9%. The range of dose perturbation to lateral direction was -2 mm to 2 mm from the beam axis. The dose perturbation of OAR did not depend on the seed type and beam energy. The dose reduction to lateral direction was not observed.

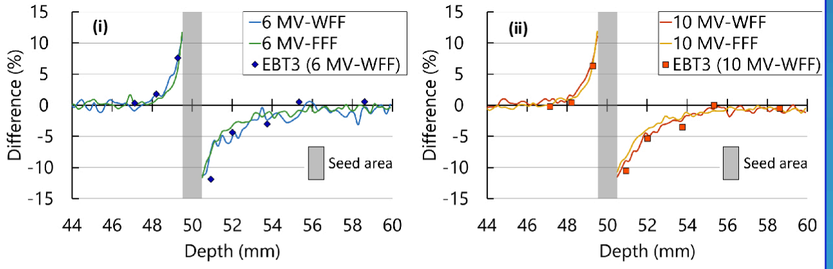

Fig.4 Dose differences with TAX for the (i) 6 MV and (ii) 10 MV photon beam under condition (a)

Fig. 5 shows the results of MC simulation on condition (b). The tendency of dose perturbation was the same as under condition (a). Maximum dose reductions under condition (b) tended to be much greater than that under condition (a). The dose after passing through three seeds was always reduced by 1%. These effects are prominent in combo-RT because multiple seeds are present in the prostate.

Fig. 6 shows the dose difference distribution around TAX in the MC simulation using multiple fields (10 MV-WFF). The higher the beam energy, the wider the range of dose perturbations. In the result of multiple fields, only dose enhancements were observed; dose reductions are not observed as in the case of using a single field. This phenomenon suggests that not only backscattering and attenuation but also lateral scattering contribute to dose perturbations. These results suggest that the dose enhancement effect may increase as the number of irradiation fields increases.

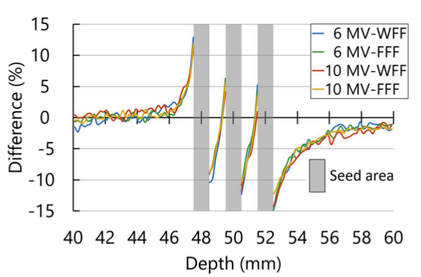

Fig. 5 Dose differences with TAX under condition (b)

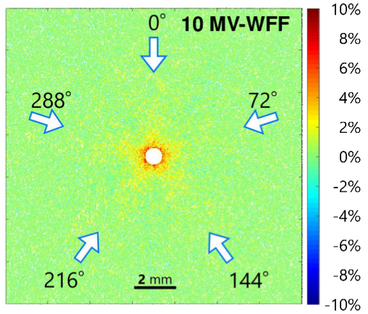

Fig. 6 Dose difference distribution around TAX

CONCLUSIONS

Dose perturbations around seeds in high-energy photon beams were investigated by the MC simulation and actual measurements. The magnitude of dose perturbations varies with seeds position and type, and photon beam type. Only dose enhancements occur in the MC simulation assuming clinical conditions. It is a clinically important phenomenon.

The limitation of this study is the actual clinical effect of combo-RT has not been considered yet. The dose distribution on patient CT images with the MC should be compared to a treatment planning system in the future.

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