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Calculation of dose enhancement effect of various naoparticles in breast cancer brachytherapy using the AccuBoost system: A Monte Carlo study

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Abstract

Radiosensitization using high atomic number nanoparticles (NPs) have been recently investigated in various radiation therapy modalities. In this work we investigated the dose nehancement effect of Au, Pb, Ti, Fe, Ag, Bi, Gd and Ta NPs in brachytherapy of breast cancer by the AccuBoost system by using Monte Carlo simulations. The results showed Bi, Pb and Au to be the most effective while suggested the smallest NP size and highest concentration of NPs in tumour to give the highest dose enhancement resulting in the shortest treatment time.

Keywords: AccuBoost, Nanoparticles, MIRD phantom, MCNPX, Brachytherapy, ^{192}Ir source

Introduction

Brachytherapy is a type of radiation therapy in which the radiation source is placed in the patient's body to deliver a prescribed dose that is sufficiently high to the intended target while keeping the dose to organs at risk within the acceptable range. AccuBoost is a type of high dose rate (HDR) brachytherapy systems specially deveoped for partial breast irradiation. This sytem uses mammography paddles for immobilization and compression purpose along with two peripheral applicators above and bottom of the compressed breast that allow for the collimation of the photons generated by a ^{192}Ir HDR source on the target tissue [1].

High atomic number (Z) nanoparticles (NPs) are known for their radioenhancement effect in various modalities of radiotherapy [2]. Monte carlo simulations are the standard procedure for characterization of brachytherapy situations [3] as well as radiosensitization effects of NPs in brachytherapy [4]. Although, the primary literature on characterization of AccuBoost system have reported the use of MC simulations [5], so far less attention has been made to the evaluation of physical dose enhancement in this radiotherapy modality. The aim in this work is to address this issue and to investigate the potentiality of high Z NPs to be used as radioenhancer in AccoBoost brachytherapy.

Methods

Monte Carlo simulations

Monte Carlo N Particle code (version MCNPX2.6) was used in this study to simulate the AccuBoost brachytherapy system, ^{192}Ir HDR source and MIRD(ORNL) female phantom to calculate the absorbed dose in tumour with and without presence of NPs. Dose enhancement factor (DEF) defined as the ratio of absorbed dose in tumour in presence of NPs to the absorbed dose in their absence was calculated for various NPs including Au, Pb, Ti, Fe, Ag, Bi, Gd and Ta. Concentrations of 10, 40, 70 and 100 mg of NPs per g of tumour tissue (mg/g) were considered while a range of spherical NP diameters 5, 10, 30, 50, 80 and 100 nm were simulated. Figure 1 shows the simulated phantom with material compositions taken from ICRU44 report [6] that was purposely modified with a cubic left breast to simulate the compressed breast between AccuBosst paddles. A spherical 1 cm diameter tumour was modeled inside the compressed breast.

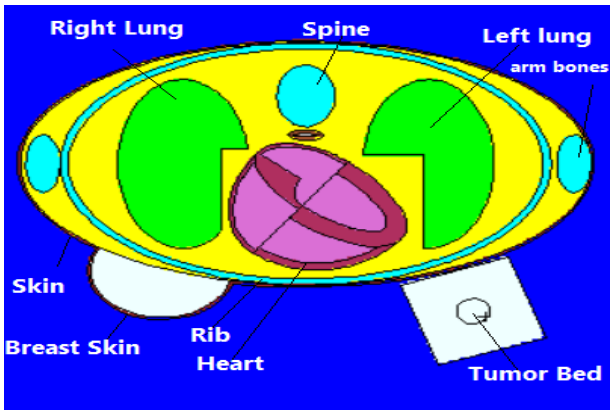

Figure 1. cross-sectional view of the MCNPX simulated MIRD female phantom with compressed left breast

Figure 2 shows the simulated paddles and applicators of the AccuBoost system on the top and bottom of the breast. Tumour surface was assumed to be 5 mm away from the skin lower surface. Each applicator contains 18 number of ^{192}Ir HDR source positioned in a plastic ring emitting photons in the energy range from 11.1 to 885

keV. NPs were defined inside the tumour with a uniform distribution by using the Lattis card of the code and absorbed dose in tumour was calculated using the *F8 tally.

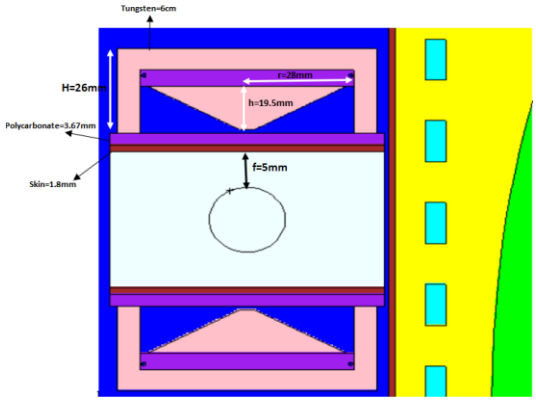

Figure 2. AccuBoost system paddles and applicators simulated in MCNPX

Results and discussion

The number of initial photons in all simulations in this work was increased to obtain statistical uncertainties of better than 1 %. Figure 3 shows the calculated DEFs in terms of the NPs diameter. As it is obseved, the highest DEF is obtained by the samllest NPs, 5 and 10 nm while DEF is almost independent from NP diameter above 30 nm. This is likely to be due to the increasing self absorption effect and decreasing surface to volume ratio with increasing the size [2]. The other observation is that highest DEFs are obtained with Bi, Pb and Au followed by Ta and Gd. Au is perhaps the best radioenhancer in this case due to the better biocampatibility and lower cytotoxicity [7].

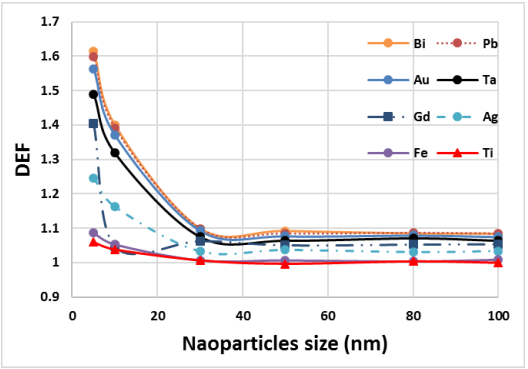

Figure 3. Effect of NP size on DEF

Fiure 4 shows the effect of NP concentration on DEF. As expected, DEF increases with NP concentration and its impact is more substantial than NP size [2]. For instance, in case of Au NPs, it increases from 1.56 at 10 mg/g to 5 at 100 mg/g, the limitations on NPs concentration in practice being the cellular uptake and cytotoxicity factors [2]. The treatment time with 5 nm Au NPs of typical concentration of 10 mg/g would be reduced by a factor of 1.5 and this is of great importance in pracice on quality of patients treatment.

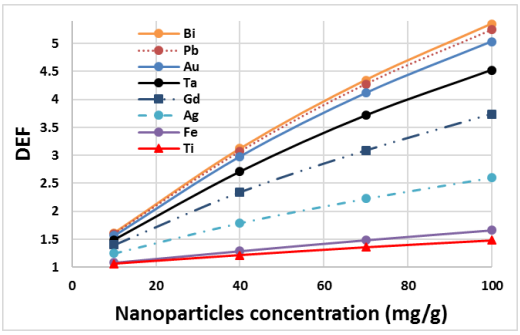

Figure 4. Effect of NP concentration on DEF

Conclusions

The physial dose enhancement effect of several type NPs with various sizes and concentrations was investigated in this study in the AccuBoost brachytherapy treatment on a MIRD(ORNL) female phantom using MC simulations. The results showed the maximum DEF obtained by the use of Bi, Pb and Au NPs respectively. Smallest NP diameter and highest NP concentration demonstrated the highest potential dose enhancement. The possible impact of NPs addition on dose to organs at risk in the phantom will be evaluated and reported in the future work.

References

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