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Original research article

Monte Carlo calculation of photo-neutron dose produced by circular cones at 18 MV photon beams

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ABSTRACT

Aim: The aim of this study is to calculate neutron contamination at the presence of circular cones irradiating by 18 MV photons using Monte Carlo code.
Background: Small photon fields are one of the most useful methods in radiotherapy. One of the techniques for shaping small photon beams is applying circular cones made of lead. Using this method in high energy photon due to neutron contamination is a crucial issue.
Materials and methods: Initially, Varian linac producing 18 MV photons was simulated and after validating the code, various circular cones were also simulated. Then, the number of neutrons, neutron equivalent dose and absorbed dose per Gy of photon dose were calculated along the central axis.
Results: Number of neutrons per Gy of photon dose had their maximum value at depth of 2 cm and these values for 5, 10, 15, 20 and 30 mm circular cones were 9.02, 7.76, 7.61, 6.02 and 5.08 ($\mathrm{n\,cm^{-2}\,Gy^{-1}}$), respectively. Neutron equivalent doses per Gy of photon dose had their maximum at the surface of the phantom and these values for mentioned collimators were 1.48, 1.33, 1.31, 1.12 and 1.08 ($\mathrm{mSv\,Gy^{-1}}$), respectively. Neutron absorbed doses had their maximum at the surface of the phantom and these values for mentioned collimators sizes were 103.74, 99.71, 95.77, 81.46 and 78.20 (μGy/Gy), respectively.
Conclusions: As the field size gets smaller, number of neutrons, equivalent and absorbed dose per Gy of photon increase. Also, neutron equivalent dose and absorbed dose are maximum at the surface of phantom and then these values will be decreased.

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1. Background

External Beam Radiation Therapy (EBRT) is the most popular form of radiotherapy. Linear accelerators (Linacs) that produce electrons or X-rays at energies of 4–25 MV are usually used for EBRT delivering. Linacs enable administration of high doses of X-rays to deep seated tumors. Also, these accelerators produce unintended radiation source like scattered radiation from the head of the accelerator and inside the patient body, leakage radiation from different parts of machines, and when the photon energy is high enough, secondary neutrons are produced from photonuclear interactions.[1,2] These photoneutrons are produced in a range of energy associated with higher radiobiological damages and sometimes secondary malignancies are reported as the late effect of the produced photoneutron.[3]

Small photon fields are increasingly used in modern radiotherapy techniques, especially in Intensity Modulated Radiation Therapy (IMRT) and Stereotactic Radio-Surgery (SRS) treatments.[3] Stereotactic means knowing the accurate site of the target. For this aim, the patient should be in a fixed three-dimensional coordinate system which is referenced to a point in the treatment room. SRS is performed by Gamma knife and linac in small photon fields.[4–6]

One way to produce small photon fields in linac based SRS is using the circular cones that can be attached to a linac head as an accessory. Therefore, X-rays from the machine are collimated into fine beams and precisely focused on the target and small fields with sharp penumbras and steep dose gradients external to the treatment volume, are yielded.[5,7,8]

By considering the crucial role of small field radiotherapy, it is important to be aware of different aspects of this technique in high energy photon beams. One of the most critical issues is neutron contamination.

The main photoneutron source in radiotherapy technique is the Giant Dipole Resonance (γ, n) reaction with high Z materials in the linac head. Since the cross section of photoneutron production in high Z materials is more than low Z materials (W: 400 mb; C: 8 mb), the linac head provides the major contribution in neutron contamination. The resulting neutrons can travel through a treatment room and a maze, thus not only the patients but also the staff are affected by neutrons. The probability of photoneutron interaction increases steeply with photon energy and the energy threshold of the (γ, n) reactions is about 8 MeV for most of isotopes. On the other hand, the absorption cross sections of materials in the accelerator head are not enough for shielding neutrons. Therefore, such neutrons will irradiate the patient and they contribute to an additional dose which is not taken into account in routine radiotherapy treatment. Due to high Z material (lead) in circular cones and their high cross section of photoneutron interactions, it is important to be aware of the circular cones effects on neutron generation irradiating by 18 MV photon beam in small photon fields.[9–11] The dosimetry of neutrons in mixed photon-neutron fields has many difficulties that cause uncertainty of more than 10%. Therefore, Monte Carlo (MC) simulation seems to be a reliable solution because the dose contribution from each type of particle can be calculated separately.[12]

2. Aim

The aim of this study is to calculate neutron fluences, neutron equivalent dose and neutron absorbed dose per Gy of photon dose in the presence of various circular cones and 18 MV photon beams using MCNPX MC simulation.

3. Materials and methods

3.1. *MC simulation*

For calculating the neutrons contributions to the dose absorbed, MCNPX MC simulation was applied. To access this aim, initially, the detailed geometry of Varian Clinac 2100 C/D Linac head (including target (W,Cu), primary collimators (W), flattering filter (Ta,Fe), ion chambers (Kapton) and collimator jaws (W)) were simulated according to the information of the manufacturer and previous studies.[13,14] Also, a cubic water phantom with dimension of 30 cm × 30 cm × 40 cm at the distance of 100 cm from the source (SSD = 100 cm) was simulated.[15]

3.2. *MC validation*

For validating the simulation, the percentage depth dose (PDD) and beam profile of simulated geometry were compared with those of practical dosimetry. For this purpose, a point-like source emitting electrons in a single direction and a 0.2 cm radius disk, were chosen. Initial electrons had a Gaussian energy distribution with a Full Width at Half Maximum (FWHM) of 1 MeV and the peak energy of 18.37 MeV for photon beams. The jaws were fixed to produce a 10 cm × 10 cm field size for SSD of 100 cm. Energy deposition was calculated by *F8 tally in 1.75 cm × 1.75 cm × 0.1 cm cells at the central axis to calculate the PDD. Calculation of beam profile was also performed by *F8 tally in 0.1 cm × 1.75 cm × 1.75 cm cells which were located at the vertical direction of the central axis at depth of 5 cm in the water phantom. Energy cut off for electrons and photons was 0.5 and 0.1 MeV, respectively. The code was run in photon-electron mode and also 2×10^9 particles were chosen for code running, the estimated statistical relative error of this simulation was about 2.3%. Then measurements of both depth dose and beam profile were performed by a Semiflex ionization chamber (PTW, Freiburg, Germany) at SSD of 100 cm and 10 cm × 10 cm field size, similar to simulation situations.

The procedure of neutrons production and tracking of them was simulated by MCNPX version 2.6 and its library, this procedure was benchmarked for neutron fluence and energy spectra of neutrons in the study of Kry et al.[16,17]

3.3. *Neutron calculation*

In this section, various circular cones made of lead producing field sizes of 5, 10, 15, 20 and 30 mm diameters were added to the simulation. The fourth entry on the PHYS:P card was set to −1 in order to activate photoneutron generation in code.[12] The cells used for this part were of size 2 cm × 2 cm × 0.5 cm.