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Calculation of excess dose to the eye phantom due to a distanced shielding for electron therapy in head and neck cancers

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ABSTRACT

For superficial lesions, the electrons may be used for radiation therapy. The high energy photons and electrons are produced by a Linear accelerator (Linac). Many of electron fields need the shielding of normal or critical organs. The electron shields are usually lead slabs with few millimeter thicknesses which should be placed near the skin, less than 1 centimeter away from skin. In the inspection of patients setting in a clinic by a physicist, it was noted that, in some cases the technician places the shields far away from skin in the way that the shadow of the field still matches the shielded area. This is due to a conceptual mistake in which one assumes that electrons travel in a straight line and matching the shadow of lead slab is enough for the shielding. This project is about Monte Carlo simulation of this case and dosimetry in which the excess dose to the tissue under the shield is calculated.

In this study BEAMnrc and DOSXYZnrc are used for simulation of the Linac and the electron shields. The water phantom as well as the Linac head (NEPTON Linac) is simulated in the electron mode. The simulation is performed in 3 various cases in which the lead shield is placed in distances of 1, 20, 40 centimeters from the surface of the phantom. In all cases, the edge of the shield is matched with the light field, so the shields get smaller as they move from the surface because of the divergence of the light field. The simulations were done in two energies, 6 and 13 MeV. The experiments also were done with EDR2 film dosimetry and the simulation results were validated using the experimental results.

In all cases the dose under the shield were normalized to the dose in the center. The dose of the normal organ under the shield was 2 %, 38%, 43 % with respect to the center for shield distances of 1, 20, 40 cm respectively. So there is a considerable increasing of the dose due to the distanced shielding. In this work exact amount of the dose from this mistake (distanced shielding) is calculated and simulated.

Keywords:

Electron therapy, Shielding, Monte Carlo

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INTRODUCTION

Radiation therapy techniques are typically planned to conform to the volume of tissue needing irradiation. Therefore, shielding of the portion of the body outside the treatment field is essentially carried out by the machine collimators that define the field edges. After the surgery, radiation therapy prescription with incomplete margin results to improved local control and survival (1-4).

Shielding of the normal tissue is one of the important aspects of radiation therapy. Therapeutic procedures use higher energies in the megavoltage (MV) range. At these energies, the radiation is more penetrating. For high energy photons, to provide a 3 percent transmission, a thickness of approximately 6.5 cm of lead would be required for a photon beam with a typical half-value layer of 1.3 cm (4).

Nonmelanoma skin cancer is the most common type of the cancer despite of the low morbidity. Radiation therapy is one of the main options for treatment of this kind of cancer which has an equivalent outcome to surgery. For superficial lesions, the electrons may be used in for radiation therapy (5-6). Many of electron fields need the shielding of normal or critical organs. The electron shields are usually lead slabs with few millimeters thickness which should be place near the skin, less than 1 centimeter away from skin. The margin of the electron field should be between 1-2.5 cm for various sizes of tumors. For example the usage of the small field sizes around the eye cause the inhomogeneity of the dose. In electron fields, three points are important: immobilization of the patient, perpendicular direction of the beam to the surface, and the shielding(7-13). Therefore protection of the normal tissue around the tumor is essential and the shield should not transmit more that 5% of the radiation. The shielding of critical organs such as eyes is more important. The internal shielding is inconvenient for the patient, and usually the external shield is used. On the other hand the external shielding has few advantages such as the coverage of the lachrymal gland (14) and the ciliary protection.

In the inspection of patients setting in a clinic by authors (physicist and doctors), it was noticed that, in some cases the technician places the shields far away from skin in the way that shadow of field still matches the shielded area (Fig.1). This is due to a conceptual mistake in which one assumes that electrons travel in a straight line and matching the shadow of lead slab is enough for the shielding. This project is about Monte Carlo simulation of this case in which the excess dose to the tissue under the shield is calculated. The film dosimetry of this situation is also performed.

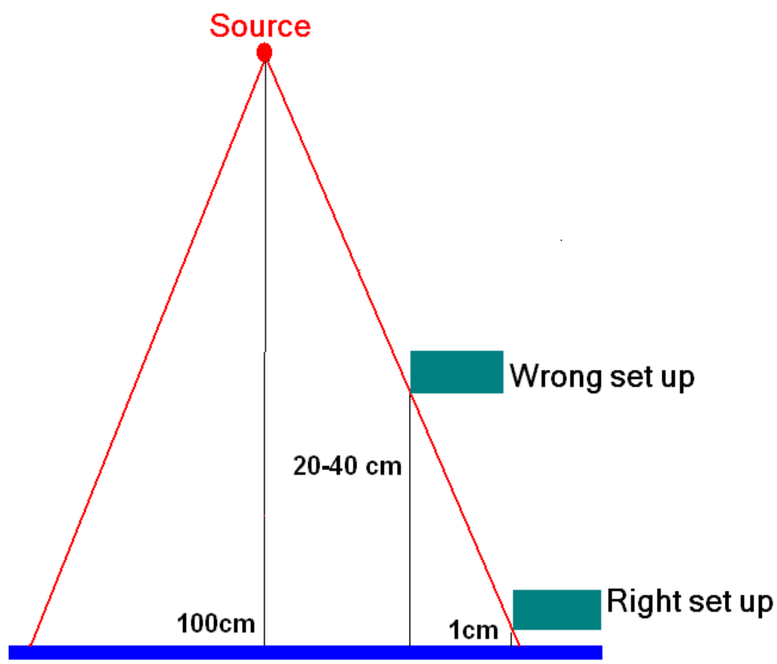

Figure 1: The lead shield used in electron mode, which is placed in various distances from the surface

MATERIALS AND METHODS

Unlike photons, electrons travel through a curve even in short distances. Therefore, the adjustment of the lead shields using the light field could cause an error. The light field is designed in a way that represents the straight line from the source to the surface. This design is appropriate for photon shielding since photons move through a straight line between each interaction. When an electron shield is placed far away from the surface, the electrons can reach the shielded organ due to a lateral scattering. It should be noted that in all cases the shield is adjusted to the light field so it looks like a right set up from the light field point of the view.

The Monte Carlo method is used to calculate the exact amount of the excess dose versus the distance of the shield from the surfaces. Monte Carlo technique is a statistical method based on random numbers. In this method many particles with random manner are simulated to calculate the parameter of interest. After simulation of very large number of particles (photons or electrons depending on Linac mode) very accurate results can be produced (15-17).

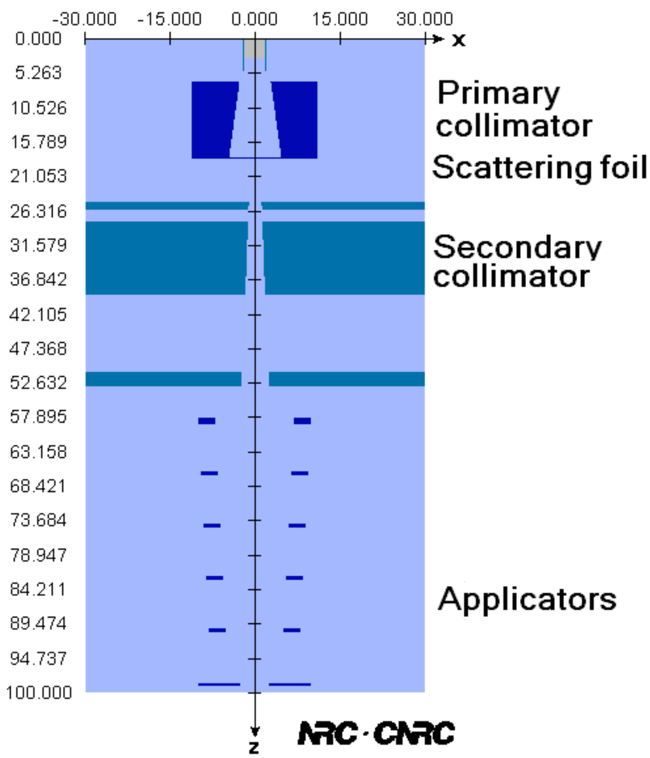

Figure 2: Simulation of the Linac's head using BEAMnrc. In electron mode, external applicators are attached to the head. The handmade shield should be placed after applicators, close to the surface.

For simulation, the head of the Linac is simulated and the main components of the Linac head should be considered (Fig.2). The primary electron beam first enters the head and passes the exit window. The primary electron beam is a narrow high energy electron pencil beam. This narrow beam cannot be used for treatment and it has to be spread over a wide area. For this reason there is a scattering foil after the collimator. The scattering foil is a lead slab with 0.5mm thickness.

In the path of the electron beam we also have the ionization chambers which monitor the amount of the linac output. The ionization chamber has 3 layers of Aluminum, air and Kapton. At the end we have secondary collimators , however in electron mode the applicators is attached to the head. The applicators extend to vicinity of the surface and generate sharp rectangular field sizes. There are many other components in the head such as mirror and light system which are not placed in the path of the electrons during the treatment and has no effect on the radiation dose.

In this study, BEAMnrc, DOSXYZnrc is used for simulation of the geometry. BEAMnrc is designed to simulated various linear accelerators (18). The code is easy to learn the accuracy of this code has been evaluated in many different situations (19-30). The water phantom as well as the Linac head (NEPTON Linac) is simulated in the electron mode. The lead shields are designed in various distances from the surface. At the long distances from the surface, the shields are placed between the applicator slabs. This is exactly what happened in real clinical cases in which, for ease of work, the technicians placed the shields on the applicators instead of the surface of the patient. The shape of the shields in the simulation was similar to a real clinical case, which is a simple rectangular 5x5 cm^2 field with a 2x2 cm^2 shield at one corner of the field. The simulation is performed in 3 various cases in which the lead shield is placed in distances of 1, 20, 40 centimeters from the surface of the phantom. In all cases, the edge of the shield is matched with the light field, so the shields get smaller as they move from the surface because of the divergence of the light field. The simulations were done in two energies, 6 and 13 MeV.

The output file of the BEAMnrc includes the entire characteristics of the exited electrons which is available after the run. This file is called Phase-space file and it can be used as an input file for DOSXYZnrc for dose calculation in the phantom(31-32). All these Monte Carlo codes are available for free in NRC web site (National Research Council of Canada). The DOSEXYZ code using exit Phase-space file, transports all of the exited particles from the Linac head in the phantom. The output file of the code includes the absorbed dose in each voxel of the phantom. This output file is imported to an in-house MATLAB software and the absorbed dose and isodose line can be derived for final evaluation.

The experiments were done with EDR2 film dosimetry and the simulation results were validated using the experimental results. EDR2 films are one of best means for 2 dimensional high energy dosimetry (33,34). The calibration curve of this film is linear in a wide dose range, between 5-600 cGy (35). For experiment the films were placed in the surface of a PMMA phantom under the Linac. The size of the phantom was 30cm in each dimension. The applicators were also attached to the gantry since the Linac is used in the electron mode. The electron shields were made from lead sheets with 3 mm thickness. For the shield placed 1 cm from the surface the shape of the field was rectangle with size of 5×5 cm^2 which had a 2×2 cm^2 shield at one corner. For larger distances of the shield from the surface which is related to the wrong set-up, the general shape of the shield is the same but the sizes are reduced because of the divergence of the light field. The dose delivery is calculated in the way that 100 cGy is delivered to the center of the field. Before the experiments the calibration of the film was performed Zeu et al and Childress et al and the calibration curve was derived for various dose values(36-38).

RESULTS AND DISCUSSION

For simulation of the BEAMnrc the run were done with minimum 40 million histories. The number of the history determines the number of the primary electrons that starts from the beginning of the Linac head. As mentioned before, the output of the BEAMnrc software is called phase-space file which is in a special format and includes all information of the particles in the related plane. In one step for evaluation of the results, the phase-space files are converted to the intensity map of the particles using an in-house MATLAB software. MATLAB with its powerful image processing toolbox is an appropriate software for evaluation of the dosimetry results (39-43). The MATLAB software using BEAMdp extracts the spatial distribution of the particles in the phase-space file which is placed at the end of the Linac head and applicators (Fig.3). It should be noted that small rectangular shield in the right corner of the field resemble the eye shield in the real clinical case.

The results of film dosimetry are illustrated in Fig. 4 in which d represents the distance of the shield from the surface. The Linac is in electron mode and the energy of the electrons are 6MeV. As illustrated, for d=1cm, there is clear sharp penumbra and the area under the shield is protected. For the case of d=20cm the dose spreads out into the shielded region. This effect gets worse with increasing the distance of the shield from the surface.

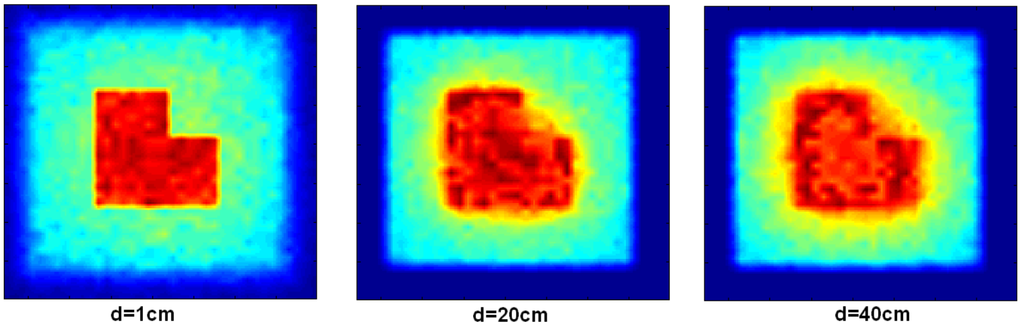

Figure 3: Intensity map generated from BEAMnrc code for the case in which the shield is placed 1,20 and 40 cm from the surface. ($5x5cm^2$, 6 MeV). For large distances, the increasing of the dose outside the field is clearly visible.

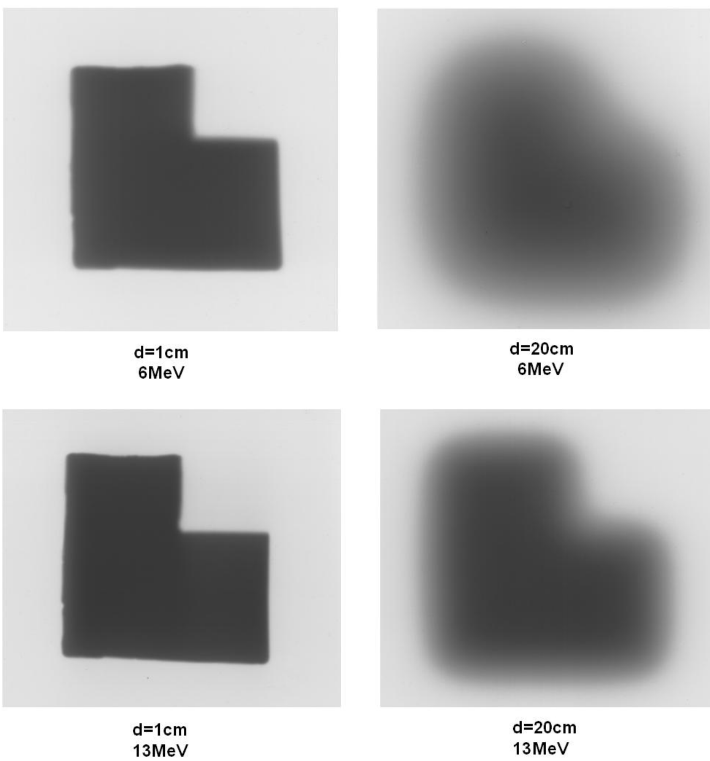

Figure 4: Film dosimetry of the electron field in which the shield is placed 1 cm and 20 from the surface (6MeV and 13 MeV electrons). For the case in which the shield is placed 20 cm from the surface, the light field still matches the shielded area.

The lateral scattering of the electron decreases for high energies since the electrons tend to move in forward direction. For this reason the amount of the excess dose decreases versus energy increasing, however we can still see the excess dose in the shielded region. This is illustrated in Figure 4 for 13 MeV electrons. In the left figure, the shield is placed 1 cm away from the surface, in which we have again a radiation field with sharp edges. In the right, the distance of the shield is 20 cm from the surface and there is still considerable dose to the area under the shield.

For film development and processing it is recommended that that irradiated films should not developed sooner that one hour from the time of irradiation. This point is required to get stable results for dosimetry. Therefore all the films were kept in the cover and they were processed and developed one day after the experiment. It is also recommended that the development situation would be similar to the situation at the time of the film calibration. Therefore, the same equipment in one radiology center is used for processing and development of the films for film calibration as well as dosimetry experiments.

In all cases the dose under the shield were normalized to the dose in the center. The dose of the normal organ under the shield was 2 %, 38%, 43 % with respect to the center for shield distances of 1, 20, 40 cm respectively. So there is a considerable increase of the dose due to distanced shielding.

CONCLUSIONS

The electron shielding has a different concept compare to photon shields. The electrons, because of the multiple scattering and continues lost of the energy, move through a curve. Even in the air, the path of the electron cannot be assumed as straight line. This is a known fact that the electron should be placed close to the surface. In this project the amount of the excess dose is calculated due to the distanced shielding. This shielding, is due to a conceptual mistake of technician who applies the electron shield similar to photon shield far away from the skin. In this work exact amount of the dose from this mistake is calculated and simulated. For photon mode, the shields are usually placed in a tray which is more that 20cm away from the surface however that electron shields should not be placed more that 1 centimeter from the skin of the patient.

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