Calculation of Organs Doses and Secondary Cancer Risk during Mantle Field Radiotherapy for Hodgkin’s Lymphoma

Mansour Zabihzadeh1, 2, Zahra Shakarami1*, Mohammad Javad Tahmasebi Birgani1, 2, Hojattollah Shahbazian2 and Mohammad Ali Behrooz1

1Department of Medical Physics, School of Medicine, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.
2Department of Radiotherapy and Radiation Oncology, Golestan Hospital, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran.

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Occurrence of radiation-induced secondary cancer risk following mantle field radiotherapy for Hodgkin’s lymphoma (HL) patients with long survival demands well-established radiotherapy strategy. Organs doses and resulted secondary cancer risk due to out-of-field photons were calculated during mantle field radiotherapy for HL patient. The male and female mathematical phantom of the Oak Ridge National Laboratory (ORNL) and validated 6MV photon beam of a Varian 2300 C/D were modeled by MCNPX 2.4.0 MC code. Using suitable lungs and thyroid shields for AP and PA fields, the organ specific absorbed doses, effective dose, and secondary cancer risk were calculated following to mantle field radiotherapy for HL. Among the out-of-field organs, the nose, eyes, head and neck’s skins and sinuses have the higher received doses. The total effective doses and secondary cancer risk for a male and female were estimated to be 199, 234 mSv and 1.72%, 1.87% respectively. During mantle field radiotherapy for Hodgkin’s lymphoma, accurately estimations of organs dose near to the field’s edge and suitable shielding of critical in-field organs are crucial factor to establish an optimal treatment plan.

Keywords: Hodgkin lymphoma (HL), Mantle Field Radiotherapy, Secondary Cancer Risk, Monte Carlo Simulation.

Second cancer resulting from radiation treatment of the first cancer has been showed by several publication1. Patient survival following to application of new modalities and techniques in the treatment of cancer has been increased the possibility of developing a radiation induced second cancer2-5. Determination of the cancer risk factor could be useful factor to establish an optimal treatment planning (TP).

Hodgkin lymphoma (HL) is one of the curable malignant. A patient is treated with anterior and posterior mantle fields, using 4, 6, or 10 MV photons. A dose of 36-44 Gy is delivered to PTV while lung and thyroid are shielded with Cerrobend block during radiation therapy6-7. Usually mantle fields are extensive and include many critical organs from mandible to diaphragm. HL is most common in young people (15-35 age), and many of them live several decades after successful treatment; thus the possibility of developing a radiation induced second cancer is increased8-10.

Most previous investigations estimated organ doses and second cancer risk from radiation treatment of prostate, breast, lung and nasopharynx. According our knowledge from
In literatures, there is not any Monte Carlo (MC) calculation or measurement study about organ doses and second cancer risk for whole body following to HL radiation therapy. Only some studies have been calculated cancer risk for some of organ such as lung, breast and thyroid using TLD dosimetry or follow up patients for years after treatment. Using of Monte Carlo calculations has become a valuable method in radiation therapy dosimetry and implemented in pioneer MC based treatment planning system (TPS). In our study, the average dose delivered to each organ, the effective dose and the secondary cancer risk following to radiation therapy HL with mantle field were calculated by the Monte Carlo method.

MATERIALS AND METHODS

The Monte Carlo code MCNPX version 2.4.0 was used to model photon beams from the Varian 2300C/D Linac for 6 MV. MCNPX is a well-known general-purpose Monte Carlo code developed at Los Alamos National Laboratories. Using the tabulated interaction cross sections for most neutral and charged particles (<150 MeV) radiation transport of these particles can be simulated in radiation therapy applications. Figure 2 shows the schematic diagram of the simulated geometry for the Varian 2300C/D Linac. The model included the bremsstrahlung target, the primary collimator, vacuum window, the flattening filter, the monitor ion chamber, the mirror, and the upper and lower jaws. The incident electrons had a Gaussian energy distribution with a full width of half maximum (FWHM) of 1 MeV that was centered at 6 MeV. The electron beam radial intensity distribution was also set to a Gaussian with the FWHM of 1.1 mm for 6 MV. During calculating of the depth doses and dose profiles, the cut-off energy was determined as 0.01 and 0.521 MeV for the photons and electrons, respectively. For depth dose calculations within the water phantom, a cylinder with a radius of one-tenth the size of the open field size was defined and divided into scoring cells with 2 mm height along the beam central axis. For beam profile calculations, the primary cylinder was positioned at the predefined depth vertically to the beam central axis with the radius of 2 mm.

The mathematical phantom of the Oak Ridge National Laboratory (ORNL) was used to estimate of organs dose, Figure 2. The male and female ORNL phantom was investigated in MC simulations, separately.

The phantom located at SSD=100 cm. As regarding to shape of the Mantle field and in order to properly shielding of lungs and thyroid, treatment field was 30×30 cm². The lungs and thyroid were shielded by 8 cm thickness shaped cerrobend alloy located on block tray (inserted in 46 cm distance from the phantom surface). Irradiation of Hl was simulated by two fields of antero-posterior (AP, 0°) and postero-anterior (PA, 180°). The *F8 tally was used to calculate of absorbed dose by organs. Energy cutoffs of 10 and 521 KeV were used for photon and electrons, respectively. The number of source photon histories needed to achieve a relative error < 5% for all cells was 10⁹. The prescription dose was 40 Gy to the planning target volume that is delivered by AP and PA projections. In a separate simulation by inserting a detector in water phantom at reference depth (i.e. 1.5 cm for 6MV) the converting coefficient was calculated to convert the MCNP output to the prescribed MU (monitor unit). Furthermore, in order to estimation of cerrobend alloy shields on the secondary cancer risk Mantle fields were applied without presence of lungs and thyroid shields. The effective dose was calculated according to the ICRP-103 report (International Commission on Radiation Units & Measurements) recommendations that is defined as the tissue-weighted sum of the equivalent doses in all organs, give by the equation

\[ E = \sum W T \cdot \sum R \cdot W R \cdot D T R \] or \[ E = \sum W T \cdot H T \]

Where \( W T \) is the tissue weighting factor derived from ICRP-103 report and \( H T \) or \( W R \cdot D T R \) is the equivalent dose in the organ. The unit for the effective dose is the same as for absorbed dose, J/kg⁻¹, and its special name is sievert (Sv). The conservative maximal risk of secondary cancer (SC) was calculated for out-of-field organs. Coefficient of secondary cancer risk for each organ were extracted from NCRP-116 report (National Council on Radiation Protection & Measurements). The whole-body risk of (SC) was taken as the sum of the risks for these organs.
RESULTS

The MC-calculated PDD (percentage depth dose) curves and beam profiles were firstly compared with the measurements to validate our MC model. There was a good agreement between the measurements and calculations for beam profiles and PDD curves (Fig. 3). Local differences of less than 1% were seen for PDD values in descending part up to 30 cm depth, but it increased up to 6% for the buildup region and for the largest field size; e.g. 40 × 40 cm² (Fig. 3a). For beam profiles, local differences less than 2% were seen for flat region, but it increased to 13% for region located out of field (Fig. 3b). Readers is referred to our previous paper to the details of validation of our simulated linac’s head (19).

The equivalent dose of out-of-field organs for mantle field with 6MV photon beam followed by dose prescription of 40 Gy to the planning target volume were calculated (see fig 4). Among the out-of-field organs, the nose, eyes, head and neck’s skins and sinuses have the higher received doses.

The total effective doses integrated over the out-of-field organs of a male and female were
estimated to be 199 and 234 mSv, respectively. Removing of applied shields on lungs and thyroid increase these calculated effective doses up to 343 and 384 mSv.

From figure 5, the higher effective doses and risks of second cancer were calculated for the nose, eyes and total sinuses due to their adjacency to the primary radiation field and therefore its higher absorbed doses. The skin of female has the larger cross-sectional area for scattered radiation exposures and therefore received higher dose and also higher second cancer risk.

**DISCUSSION**

The radiation-induced second cancer risk was estimated for AP and PA mantle field with 6MV photon beam. Both male and female phantoms were investigated. The organs located at further distance from the treatment field were received low absorbed dose (i.e. lower portion of leg).

Our results showed that out-of-field organs near the field received higher dose from scattered photons. The out-of-field organs such as the nose wall and contents, eyes, head and neck’s skins and total sinuses have the higher received...
doses. The larger dose to the organs adjacent to the applied field edges result higher effective dose and probability of second cancer risk. Therefore accurately estimations of organs dose near to the field's edge are crucial factor to optimise a well-established therapeutic plan. However applying of modern techniques such as intensity modulated radiation therapy (IMRT) provide better coverage of target volume but lead to higher effective dose and secondary cancer risk to patients due to delivering of increased monitor units in comparison to conventional radiotherapy.\(^2,^4,^20\). In a study by Koh et al. (2007), the mean dose and risk of second cancer were assessed on 41 patients with Hodgkin disease by 3 modality of treatment. Involved Field Radiation Therapy (IFRT) modality was reduced significantly risk of second cancer.\(^2\).

Using of ionization chamber and thermo luminance dosimeters to measuring of dose in form of equivalent dose as function of distance from the field edge\(^21\) could not be an ideal manner. Considering organ specific doses\(^22\) and also nonuniformity of dose distribution due to presence of inhomogenities is essential to prediction of out-of-field doses that could be implemented by MC modeling. In current study the effect of heterogeneities of tissues on mean absorbed dose was investigated by substitution of different materials of female phantom with water in the AP projection. The calculated effective dose of phantom with main material showed an increase of 17% compared to homogeneous water phantom.

Breasts in the case of female phantom with large volume compare to male's breast received considerable dose due to partly locating inside the irradiated field. The fatal cancer risk of breasts for female was calculated about 0.063%. Our finding is in agreement with one measured by Kowalski et al. (1998) that indicate notable radiation dose would be delivered to breast tissue during mantle field irradiation for Hodgkin’s disease.\(^9\). The greatest risk of developing secondary breast cancer is reported in <30 years old female during HL treatment and in female who treated with radiotherapy alone.\(^6\). De Bruin et al. (2009) reported Mantle field irradiation results in >2-fold increase in the risk of developing secondary breast cancer compared to administration of radiation to the mediasten with a similar dose (36-44 Gy).\(^7\).

As depicted in figure 6, the total secondary cancer risk followed by mantle field irradiation in AP and PA projections were calculated about 1.72% and 1.87% for male and female, respectively. Swerdlow et al.\(^23\) reported the relative risk of secondary cancers as 3.9 and 2.0 after combined modality treatment and chemotherapy alone, respectively. Increasing of the secondary cancer risk to 2.71% and 2.99% by removing of thyroid and breast shields confirms that accurately shielding of these critical organs adjacent to irradiation field is an important factor to decrease the late effect of radiotherapy of Hodgkin’s disease.

CONCLUSION

In the current study, the equivalent absorbed dose, effective dose from out-of-field radiation were calculated during mantle field radiotherapy for Hodgkin’s lymphoma for male and female.

Our results showed that out-of-field organs near the Mantle field (nose, eyes,…) received higher dose from scattered photons and result higher effective dose and probability of second cancer risk. Therefore accurately estimations of organs dose near to the Mantle field’s edge and suitable shielding of critical organs such as lungs and thyroid are crucial factor to optimise a well-established therapeutic plan.
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