Measurement of Scattered Radiation Dose to The Eyes, Breasts and Gonads of Patients During External Beam Radiation Therapy.

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Abstract: In Nigeria data on radiation doses to critical organs outside primary radiation beams during radiotherapy is sparse therefore the extent to which other parts of patient's body are protected during treatment could not be quantified. In clinical studies on measurement of radiation dose to critical structures, even though the doses are relatively low, have been associated with cardiac toxicity and increased risk of secondary cancer. This study is aimed at measuring scattered radiation to the eyes, breasts and gonads, of patients during Cobalt-60 external beam radiotherapy. Thirty patients with malignancy in the abdomen, breast, cervix and head and neck who consented to participate were studied. Scattered radiation was measured with thermoluminescence dosimetry (TLD) using calibrated Lithium Fluoride (LiF) phosphor and TLD Reader, Harshaw 4500. Scattered radiation dose to the eyes, breast and gonads from the treatment fields considered are: Abdomen (0.46 ± 0.10 Gy, 0.52 ± 0.10 Gy and 0.76 ± 0.50 Gy); Breast (0.58 ± 0.10 Gy, 1.10 ± 0.40 Gy and 0.50 ± 0.10 Gy); Head and neck (1.42 ± 1.10 Gy, 0.45 ± 0.10 Gy and 0.49 ± 0.10 Gy); Pelvis (0.50 ± 0.10 Gy, 0.48 ± 0.10 Gy and Nil). Gonads were not measured during irradiation of pelvic region. In this preliminary study, the scattered doses to the critical organs were found to be higher than the radiation level (0.1 Gy) at which cancer risk is considered unlikely. Further study is aimed at exploring treatment approach that would reduce scattered dose to the bearest minimum.
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Introduction

Radiation therapy has been in use as cancer treatment for more than 100 years, with its earliest roots traced from the discovery of x-rays in 1895 by Wilhelm Roentgen[1]. Radiation therapy could be administered by teletherapy or brachytherapy. The main goal of radiation therapy is to deliver maximum percentage of prescribed dose to the tumour volume while the surrounding healthy structures (or critical organs) receive as low as reasonable achievable doses. This makes it crucial in radiation therapy to know the exact doses received by critical organs, which are outside the primary radiation beams[2] and make sure that their tolerance is not exceeded. While doses delivered outside the field are small relative to the primary field doses, they are still of clinical interest because they are given to a large parts of the body where there is potential for residual long term adverse effects[3]. It has been reported in literature[4] that patients who received external beam radiotherapy had significantly higher risk of developing cancer in organs adjacent and distant to the treatment volume than those treated with brachytherapy. Moon et al[5] reported male patients, who developed second cancer in the bladder, rectum, cecum, lung and brain; five years (latency period) after radiotherapy to the prostate. Despite critical organs' high risk attributed to external beam radiotherapy, its cost benefit to patients can not be overemphasized. External beam radiotherapy improves 5- year disease free survival and local tumour control of patient, who presented at the clinic early and for those patients who presented late, external beam radiotherapy is giving to relief pain, stress and for general improvement of quality of life. This is by far cheaper than when radiotherapy is not administered.

The critical organs selected for this study have high sensitivity to radiation damage and this was shown in the latest report (ICRP, 103) of the International Commission on Radiological Protection, ICRP[6], where the tissue weighting factors of the eyes, breast and gonads were slightly modified on grounds of high susceptibility to radiation damage.

It is generally accepted that low doses of ionizing radiation to healthy critical organs could induce cancer. In Nigeria, the burden of cancer is gradually increasing. The World Health Organization reported an estimation of 100,000 new cancer cases (in the year 1990) diagnosed in the country and gave a projection of 300,000 and 500,000 by the year 2010

and 2015 respectively[7]. Till date, there is no substantial data in Nigeria to support the development of secondary malignancies following radiation therapy.

There are many variables that could influence the occurrence of secondary cancers in patients who have received radiation therapy. A clinically diagnosed cancer patient has a higher probability to develop second cancer at any site than a non cancer patient. Also, there are cancers, such as Retinoblastoma, which are known to be markers for genetic susceptibility to other cancers[8]. Administering radiation therapy at a younger age could increase the probability of developing a second cancer[9, 10]; other factors include gender, diet (smoked food), cigarette smoking and chemotherapy agents. The manifestation of secondary cancer is time dependent. For solid cancer, the latency is of the order of decades[11] while leukemia may be less than 5 years.

In a radiation therapy centre with Cobalt-60 machine, the radioactive source is expected to be replaced after five years of installation but in most centres with limited funding such as our centre, the radioactive source is usually over spent. This implies that patient spent longer treatment time and the possibility of exposure to scattered radiation becomes higher.

At our centre, where this study was conducted, the radioactive source is in its second half life and the extent to which patient are exposed to scattered radiation is not known. Hence, this present study is carried out to measure scattered radiation doses to critical organs that are outside the treatment field during radiation therapy.

Materials and Method

This study was carried out in the Department of Radiotherapy, University College Hospital (UCH), Ibadan between March 2008 and September 2009. The durability of Cobalt-60 machine at this centre makes it the most functional Radiotherapy centre in the whole of Nigeria. Also, this centre is always participating in the IAEA/WHO postal dose quality audit for Co-60 and megavoltage x-ray beams organized by the International Atomic Energy Agency (IAEA), Vienna. The TLDs results for our centre are usually within the acceptable limit of 5 %.

Following the UCH/UI ethical review committee's approval to conduct this study, the consent form to participate was explained and distributed to patients at the Radiotherapy clinic. Thirty cancer patients, who consented to participate, were included in the study. Their weights and heights were measured with Weylux scale, model 424. It has dual weighing scales for measuring both height and weight. In order to facilitate post treatment follow-up of patients, their contact addresses and mobile phone numbers were documented.

The treatment machine used for all the patients was Cobalt-60 machine, model Theratron 780 C. It was manufactured by the Atomic Energy of Canada and installed in the year 1987. This machine is a rotational unit with beam stopper and the treatment head is shielded with depleted Uranium. The piston within the treatment head moves the source to "on" and "off" positions, electronically. It has a collimator, which shapes the radiation beam to the desired treatment field. The minimum treatment square field size obtainable from the machine is 4 cm x 4 cm and the highest is 35 cm x 35 cm at source to skin distance (SSD) of 80 cm.

The radioactive Cobalt-60 source at the time of this study was installed in the year 2002 and its activity at the time of installation (March, 2002) was 303.7 TBq. The source, which is encapsulated in a stainless steel, is 2 cm x 2 cm in size. The monthly calibration of the source for determination of its dose-rate (cGy/min) is based on the IAEA protocol[12]. The treatment techniques adopted at the centre for patient treatment is fixed SSD of 80 cm and the daily workload on the machine is about 100 patients.

The scattered radiation dose to critical organs was measured with TLD system comprising of LiF (LiF-100) cards and Harshaw (Thermo Electron, USA) dual channel TLD reader (model 4500). Each TLD card consists of two 0.4 cm diameter LiF chips. The TLD reader has an in-built computer system to facilitate accurate dose assessment after appropriate calibration and it is programmed to anneal TLD chips automatically for fresh use after each measurement.

The calibration of the TLD system was carried out by irradiating a set of ten TLD cards; each consisting of two freshly annealed LiF chips A and B, to known doses (1 – 4 Gy) in the Cobalt-60 machine, acting as a standard source. The standard deviation, which represents the spread in the TLD response of each chip during the calibration process, was 1.3 % and 1.1 % respectively, showing a very good precision. The mean TLD reader response, R, for each TLD card was plotted against the standard absorbed dose, D (Gy). The calibration lines for chips A and B with correlation coefficients 0.9983 and 0.9834, respectively are shown in fig. 1. The lines were fitted with equations below:

$$R_A = 0.953\ D - 0.511 \quad (1)$$

$$R_B = 0.738\ D - 0.263 \quad (2)$$

Where, D, is the actual radiation dose that gives response R_A in chip A and R_B in chip B.

A set of three annealed TLD detector chips, labeled for each organ was used for each patient. Care was taken to ensure that the chips were placed within the centre of each organ of interest as soon as treatment set-up was accomplished. The TLD chips were fixed at this position with the help of paper tape. In order to obtain accumulated dose received by critical organs throughout the period of treatment, the same TLD chips, duly marked for that particular organ was used. The treatment period for all patients was between 3 to 6 weeks. The exposed detectors were thereafter placed in a folder customized for each patient and kept in a box provided in a radiation free room. Some unexposed annealed TLD detectors chips were also kept in this room as control detectors.

At the completion of all treatment fractions, the exposed TLD chips were read with the calibrated TLD system. The scattered dose D received by each of the critical organ was calculated as the mean of the slightly varying dose values obtained from chips A and B using equations 1 and 2. In all dose calculations, the overall environmental effects of storage and handling of TLD chips were taken into consideration by subtracting the dose value obtained from the control detector from the mean absorbed dose in the exposed TLD detector.

The results of the scattered radiation to each of the critical organ with respect to the treatment fields were analysed and presented in tables and figure.

Results

A total of thirty patients who consented to participate were considered in this study. Out of these, 20 (67%) were females and 10 (33%) were males; their mean age, weight and height was 48 ± 20 years, 57 ± 17 kg; and 156 ± 23 cm respectively (Table 1). All of them completed their treatment within 6 weeks of enrollment.

The parts of the patients' body where treatment was administered were abdomen, breast, pelvis and head and neck. The head and neck region constitutes treatment to the brain, neck, parotid and tongue. Out of all these treatment sites, the most frequent was breast 11 (37%), followed by the head and neck 10 (33%), pelvis 7 (23%) and abdomen 2 (6 %) (Table 2). The mean field sizes selected for treatment was obtained from the approved treatment planning of the target volume. The largest field sizes obtained in this study was 23 ± 2 cm^2 and it was selected for abdomen, this was followed by 16 ± 1 cm^2 for pelvis, 14 ± 1 cm^2 for breast and 12 ± 3 cm^2 for head and neck (Table 2).

The mean distance between the critical organs (eye, breast, gonads) considered in this study and the centre of the treatment field varies with respect to the treatment site. The mean distance of the (eye, breast and gonads) from the centre of the respective fields are: Abdominal treatment field (49 ± 3 cm; 24 ± 2 cm and 20 ± 2 cm); Breast treatment field (24 ± 1 cm; 15 ± 3 cm and 48 ± 2 cm); Pelvis treatment field (61 ± 8, 43 ± 3 and Nil); Head and neck treatment field (10 ± 2 cm; 31 ± 3 cm and 73 ± 6 cm). Gonad was considered to be within the pelvic treatment field hence, it was not measured during pelvic treatment (Table 3).

The mean scattered radiation doses to the studied critical organs during radiation therapy vary with respect to the treatment site. The scattered radiation dose to the eye, breast and gonads from different treatment sites are: Abdomen (0.46 ± 0.10 Gy, 0.52 ± 0.10 Gy and 0.76 ± 0.50 Gy); Breast (0.58 ± 0.10 Gy, 1.10 ± 0.40 Gy and 0.50 ± 0.10); Pelvis (0.47 ± 0.10 Gy, 0.48 ± 0.10 Gy and Nil); head and neck (1.42 ± 1.10 Gy, 0.45 ± 0.10 Gy and 0.49 ± 0.10 Gy) (Table 4).

Table1: Patients' Demographic data

Parameter	No. of patient (%)
Sex: Female Male	20 (67 %) 10 (33 %)
Age, years Mean ± Std. dev	48 ± 20
Weight, kg Mean ± Std. dev	57 ± 17
Height, cm Mean ± Std. dev	156 ± 23

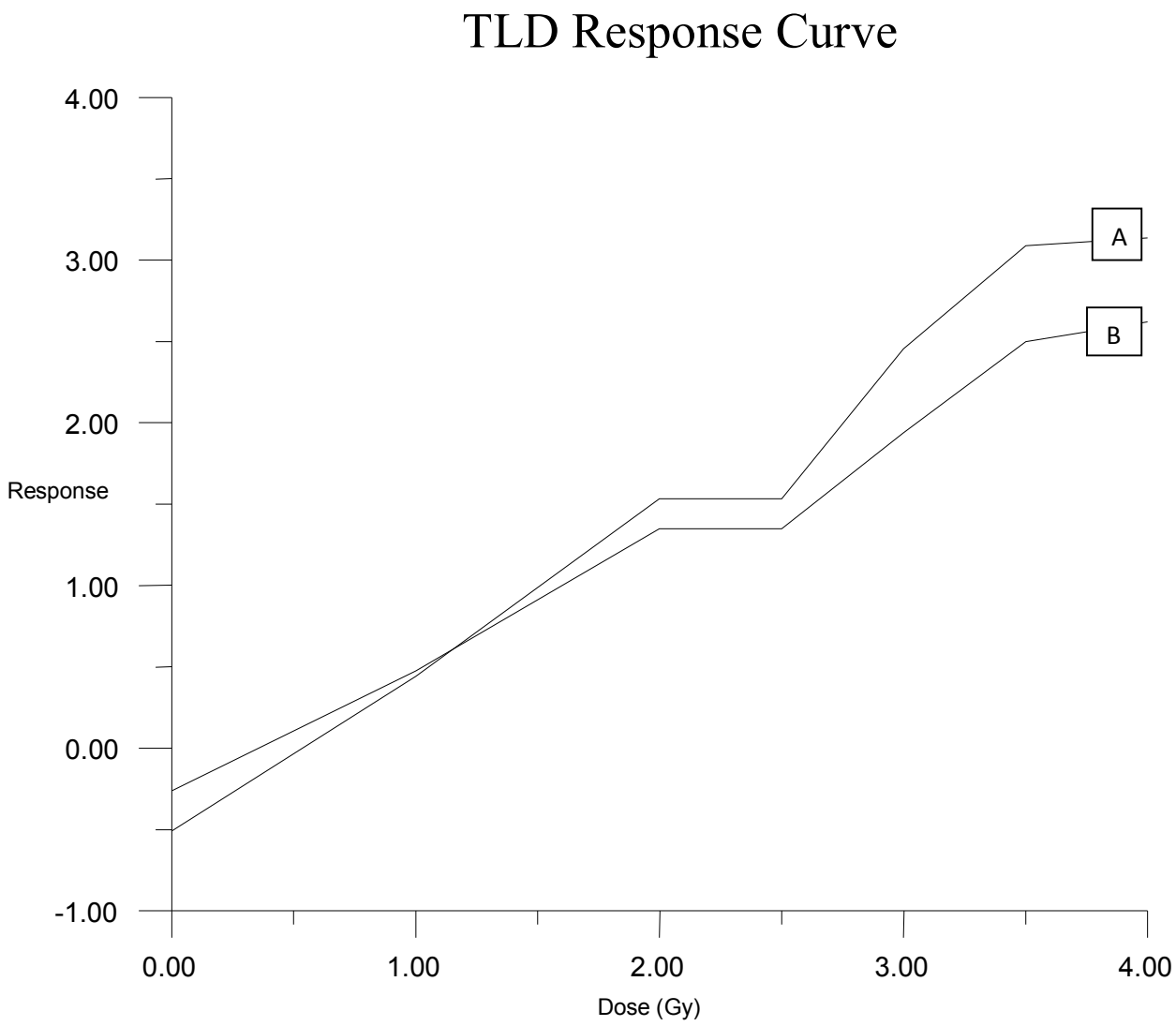

Fig. 1: Calibration Curve for chips A and B

Table 2: Number of Patients with respect to Treatment Site

Treatment Site	Mean field size, cm^2	Number of patient (%)
Head & Neck	12 ± 3	10 (33%)
Breast	14 ± 1	11 (37%)
Abdomen	23 ± 2	2 (6%)
Pelvis	16 ± 1	7 (23%)

Table 3: Mean distance of critical organ from the centre of treatment field

	Abdomen	Breast	Pelvis	Head & Neck
Eye	49 ± 3 cm	24 ± 1 cm	61 ± 8cm	10 ± 2 cm
Breast	24 ± 2 cm	15 ± 3 cm	43 ± 3 cm	31 ± 3 cm
Gonads	20 ± 2 cm	48 ± 2 cm	-	73 ± 6 cm

Table 4: Mean Scattered Dose to critical organ with respect to the treatment site

	Abdomen	Breast	Pelvis	Head & Neck
Eye	0.46 ± 0.10 Gy	0.58 ± 0.10 Gy	0.47 ± 0.10 Gy	1.42 ± 1.10 Gy
Breast	0.52 ± 0.10 Gy	1.10 ± 0.40 Gy	0.48 ± 0.10 Gy	0.45 ± 0.10 Gy
Gonads	0.76 ± 0.50 Gy	0.50 ± 0.10 Gy	-	0.49 ± 0.10 Gy

Discussion

The gender bias observed in this study reflected the distribution of patients at our radiotherapy clinics where, female specific malignancy namely, breast and cervical cancer predominates. In Dhaka, Bangladesh[12], where similar study was performed, the incidence of female malignancy, that is, breast cancer and cervical cancers, was 29 % and 37 % respectively, whereas in our centre and among the studied patients, the percentage of breast cancer and cervical cancer was 37 % and 23 % respectively. The mean age (years) of patients was 48 ± 20. All of them completed their treatment within 5 weeks of enrollment. This period is similar to what is practiced in Bangladesh, a developing country like Nigeria, where treatment of cancer of any organ took a period of 4 – 5 weeks duration. The part of the patients, where treatment was administered, was abdomen, breast, pelvis and head and neck. The head and neck region constitutes treatment to the brain, neck, parotid and tongue.

The amount of scattered radiation that is present during a particular treatment set-up is a function of treatment field sizes and this is derived from the approved planning target volume. There are various field sizes selected for patients during this study. The minimum equivalent square field size at the surface of the patient was 144 cm^2 and the maximum was 529 cm^2. It was reported by Miah et al[12] that different parts of cancer patients received scattered radiation dose in increasing order of field sizes during radiotherapy.

In this study, it was found that the maximum field size (529 cm^2) selected for abdominal treatment region did not result in higher dose to the studied critical organs. This implies that, apart from field sizes, there are other factors that could determine the amount of scattered radiation to different parts of patient during radiotherapy and one of these factors is distance. According to the inverse square law, the intensity of radiation at a particular point varies inversely as the square of its distance from the radiation source.

Among the studied critical organs, the eye is the closest (10 ± 2 cm) organ to the centre of the head and neck treatment field. This explains why the eye

received the highest dose (1.42 ± 1.10 Gy) during head and neck treatment. The breast is the closest (15 ± 3 cm) organ to the centre of the contra-lateral breast treatment field and the highest radiation dose to the breast (1.10 ± 0.40 Gy) was obtained from this treatment field. The gonad is the closest (20 ± 2 cm) organ to the centre of the abdominal treatment field and the highest radiation dose (0.76 ± 0.50 Gy) to gonads was obtained from this treatment field. Miah et al also reported that scattered radiation dose to different organs varies with the height of the patient.

The induction of cancer and other stochastic health effects of ionizing radiation have not been observed consistently at low doses (≤ 0.1 Gy). This is because the existence of a risk at such level is so low that it could not be detected by current epidemiological data and method. However, the health Physics Society[13] recommended assessments of radiogenic health risks of radiation dose estimated above 0.1 Gy. In a study conducted by Wolfgang et al[14], it was found that significant number of secondary cancer was induced at the site, outside the treatment field, that received radiation dose of less than 6 Gy. This implies that the amount of scattered radiation dose measured in the critical organs considered in this study has potential to induce secondary cancer between 5 – 10 years after radiation therapy. The latency period for the manifestation of most secondary cancer is about 5 – 10 years.

In general, to minimize scatter radiation to critical organs, radiation therapy centre should choose the field sizes without compromising the tumour volume and should carefully make use of multi-leaf collimator if available.

Conclusion

The highest scattered dose (1.42 ±1.10 Gy) measured among the studied critical organs (eye) was found to be higher than the threshold (0.1 Gy) for cancer induction but far less than the maximum dose (9.096 ± 25 Sv) obtained in the similar study conducted in Dhaka Bangladesh. While following up the patients for possible occurrence of secondary cancer in the studied organs, patients would be counseled to avoid as much as possible such factors that could dispose them to secondary cancer.

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