Computed organ doses to an Indian reference adult during brachytherapy treatment of esophagus, breast, and neck cancers

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ABSTRACT

This study aims to generate the normalized mean organ dose factors (mGy min^{-1} GBq^{-1}) to healthy organs during brachytherapy treatment of esophagus, breast, and neck cancers specific to the patient population in India. This study is in continuation to the earlier published studies on the estimation of organ doses during uterus brachytherapy treatments. The results are obtained by Monte Carlo simulation of radiation transport through MIRD type anthropomorphic mathematical phantom representing reference Indian adult with ^{192}Ir and ^{60}Co high dose rate sources in the esophagus, breast, and neck of the phantom. The result of this study is compared with a published computational study using voxel-based phantom model. The variation in the organ dose of this study to the published values is within 50%.

Key words: Brachytherapy treatment, Indian phantom, Monte Carlo method, organ dose

Introduction

High dose rate brachytherapy treatment is accepted as a highly effective and safe mode of treatment of various cancers.[1,2] The irradiation of the healthy organs is unavoidable during brachytherapy treatments although the maximum dose is delivered to tumor volume. The doses to the healthy organs being considerably high, quantification of the dose is important to assess the risk to the patients for radiation induced cancer.[3] The treatment planning software often predicts the doses only to a few organs near the target (organs at risk) and not to the radio-sensitive organs that are far away from the treatment volume. Monte Carlo simulations in the mathematical anthropomorphic phantoms can predict the dose to organs that are beyond the treatment site taking care of in-homogeneity and complex geometry of the human anatomy. Many studies on estimation of organ doses during different brachytherapy treatments using Monte Carlo simulations with heterogeneous mathematical phantom are already reported in the literature.[4-7]

The organ dose data specific to an Indian patient population is required whose average physique is significantly smaller than that of the ICRP reference adult. Hence, the MIRD[8] phantom specifications are further scaled down to average Indian standards using appropriate factors.[9,10] The organ doses to an average Indian adult female patient treated for uterus cancer with microselectron ^{192}Ir source and BEBIG ^{60}Co sources was evaluated by simulating a modified Indian reference adult phantom and reported earlier.[10] The computed dose values were validated by comparing with the Rando phantom-based measured data[11] available in the literature. The MIRD-type phantom models are approximations to the human anatomy and these models are sufficiently accurate and valid for estimating the average dose to the organs for the radiation protection purposes. Presently, the same phantom model[10] is extended to evaluate the organ doses specific to the Indian patient population undergoing the brachytherapy of the esophagus, breast, and neck cancers with ^{192}Ir and ^{60}Co sources and the results are presented. Brachytherapy treatments of the above locations expose

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large number radiosensitive organs considerably as most of them are located at the upper part of the trunk. Also, the mean organ dose values of the present simulations during breast treatment using ^{192}Ir sources is compared with the mean organ doses evaluated using a voxel phantom reported by Mille and Xu.[4]

Materials and Methods

The three-dimensional heterogeneous anthropomorphic phantom representing a standard Indian reference adult phantom and the brachytherapy sources are simulated using Monte Carlo code MCNP Version 3.1[12] in the photon mode. The phantom model is based on the MIRD specifications scaled down to the average Indian reference man of 164 cm height and 53 kg. The brachytherapy sources (microselectron ^{192}Ir source and BEBIG ^{60}Co) were modeled for each brachytherapy treatment conditions of esophagus, neck, and breast cancers. Exact geometry of the high dose rate microselctron ^{192}Ir source and BEBIG ^{60}Co sources is modeled in all the cases.[13,14] The three cases of esophagus treatments, i.e. upper esophagus, middle esophagus, and lower esophagus, are considered. For this, the whole volume of the esophagus is divided into three equal regions along the length as the upper, middle, and lower esophagus. The location of the brachytherapy source is assumed at the geometrical center of each region of the esophagus of the phantom. For the treatment of breast, the sources are modeled at the center of the breast volume. The source is modeled at the middle of the larynx region for the neck treatment. Although the source may take different dwell positions during the treatment, the assumption of source at the center is expected to provide the mean dose value for all the dwell positions. The source spectrum of the ^{192}Ir source is taken from Ballester *et al.*[15] and that of ^{60}Co is 1.17 and 1.33 MeV with a yield of about 100% for each photon per disintegration. In the Monte Carlo calculations, the source particles are sampled from the active volume of the cylindrical source. Ten million histories are simulated. The photon energy cut off used in the simulation is 1 keV. The mean photon energy fluence spectrum is scored in the selected organs using track length estimate and subsequently converted into tissue-kerma using mass energy absorption coefficient of tissue[16] by using DE and DF tally cards of MCNP. DE and DF cards are used to convert fluence to tissue kerma. Tissue-kerma is approximated to absorbed dose assuming charged particle equilibrium exists. The existence of charged particle equilibrium can be assumed as the estimations are the average dose to the organs. The maximum range of the secondary electrons produced are of 4–5 mm in tissue, and can be considered as absorbed completely within the organ volumes that are in the order of few centimeters. The code utilizes old photon cross-section dataset.[17] The suitability of using this code is verified by comparing MCNP3.1 calculations with EDKnrc code of the year 2000.[18] The beta emission by the sources is ignored in the simulations as they are expected to be stopped by the encapsulation and do not contribute to the doses to the nearby healthy organs.

Results and Discussion

Organ doses

The mean organ dose factors in mGy/min/GBq with ^{192}Ir sources in upper, middle, and lower esophagus, and with ^{60}Co (BEBIG) source are presented in Tables 1 and 2, respectively. The organ doses for the left and right breast treatments are tabulated in Table 3 and the results for the neck treatment are in Table 4. The dose to adrenal, lung, ovary, kidney, and testicle is the average of the left and right organ. The relative standard deviation of the doses is less than 4% for all the organs for all esophagus, breast, and neck treatments except for the organ, testicle. The relative standard deviation of the dose to the testicles is about 6% for the left and right breast treatment using ^{192}Ir. The same during upper, middle, and lower esophagus treatment case using ^{192}Ir are about 8%, 6%, and 3%, respectively, and it is about 11% when the ^{192}Ir source is in the neck. The relative standard deviation of the dose to all the organs treated with ^{60}Co sources is lesser than that of treated with ^{192}Ir.

Comparison of results with published data

The computed mean organ dose values of this study for brachytherapy of left breast with the ^{192}Ir source is

Table 1: The computed organ dose factors in mGy/min/GBq when the ^{192}Ir microselectron source is in the esophagus

Organ	*Upper esophagus*	*Middle esophagus*	*Lower esophagus*
Adrenal	0.0238	0.0825	0.4271
Brain	0.0292	0.0083	0.0027
Breast	0.0487	0.0891	0.0876
Spine	0.5989	0.6114	0.6137
Stomach	0.0117	0.0331	0.1069
Small intestine	0.0024	0.0064	0.0206
Ascending colon	0.0015	0.0039	0.0119
Descending colon	0.0005	0.0012	0.0034
Thyroid	0.1779	0.0547	0.0158
Trachea	0.3181	0.1227	0.0326
Ovary	0.0012	0.0028	0.0095
Uterus	0.0011	0.0028	0.0087
Sigmoid colon	0.0003	0.0007	0.0019
Heart	0.1170	0.5756	0.5212
Kidney	0.0073	0.0210	0.0793
Liver	0.0183	0.0534	0.2007
Lung	0.1299	0.2485	0.2510
Spleen	0.0173	0.0445	0.1195
Thymus	0.1780	0.1890	0.0568
Bladder	0.0003	0.0008	0.0023
Bladder content	0.0003	0.0008	0.0024
Pancreas	0.0175	0.0538	0.2437
Testicle	0.0001	0.0003	0.0008

Table 2: The computed organ dose factors in mGy/min/GBq when the ^{60}co source (BEBIG) is in the esophagus

Organ	Upper esophagus	Middle esophagus	Lower esophagus
Adrenal	0.0543	0.1593	0.7141
Brain	0.0830	0.0292	0.0118
Spine	1.1629	1.1853	1.1886
Stomach	0.0336	0.0823	0.2402
Small intestine	0.0100	0.0222	0.0578
Ascending colon	0.0072	0.0152	0.0370
Descending colon	0.0023	0.0046	0.0108
Thyroid	0.4199	0.1378	0.0473
Trachea	1.0233	0.3742	0.1122
Ovary	0.0054	0.0028	0.0282
Uterus	0.0051	0.0110	0.0263
Sigmoid colon	0.0020	0.0041	0.0091
Heart	0.2483	1.1991	1.0739
Kidney	0.0233	0.0568	0.1836
Liver	0.0481	0.1217	0.4165
Lung	0.2904	0.5437	0.5473
Spleen	0.0466	0.1049	0.2671
Thymus	0.5449	0.5849	0.1780
Bladder	0.0026	0.0055	0.0123
Bladder content	0.0026	0.0054	0.0123
Pancreas	0.0468	0.1239	0.5028
Breast	0.1056	0.1837	0.1800
Testicle	0.0011	0.0023	0.0047

Table 3: The computed organ dose factors in mGy/min/GBq when the ^{192}Ir and ^{60}co source are in the breast

Organ	Left breast		Right breast	
	^{192}Ir	^{60}Co	^{192}Ir	^{60}Co
Adrenal	0.0386	0.0823	0.0381	0.0817
Brain	0.0037	0.0151	0.0037	0.0151
Spine	0.0347	0.0736	0.0345	0.0733
Stomach	0.0572	0.1428	0.0188	0.0555
Small intestine	0.0071	0.0248	0.0069	0.0244
Ascending colon	0.0037	0.0151	0.0066	0.0237
Descending colon	0.0019	0.0067	0.0010	0.0043
Thyroid	0.0269	0.0778	0.0271	0.0799
Ovary	0.0036	0.0131	0.0028	0.0028
Uterus	0.0038	0.0134	0.0037	0.0135
Sigmoid colon	0.0012	0.0058	0.0009	0.0050
Heart	0.1508	0.3322	0.1513	0.3326
Kidney	0.0139	0.0417	0.0137	0.0413
Liver	0.0271	0.0729	0.0651	0.1549
Lung	0.0994	0.2533	0.0995	0.2533
Spleen	0.0421	0.1089	0.0116	0.0372
Thymus	0.0545	0.1851	0.0902	0.2967
Bladder	0.0016	0.0092	0.0016	0.0091
Bladder content	0.0016	0.0091	0.0015	0.0090
Pancreas	0.0515	0.1258	0.0258	0.0701
Testicle	0.0012	0.0065	0.0008	0.0065
Esophagus	0.0563	0.1218	0.0509	0.1111
Trachea	0.0433	0.1572	0.0433	0.1585

Table 4: The computed organ dose factors in mGy/min/GBq when the ^{192}Ir and ^{60}co source are in the neck

Organ	^{192}Ir	^{60}Co
Adrenal	0.0054	0.0161
Brain	0.1773	0.4198
Spine	0.0535	0.1118
Stomach	0.0030	0.0119
Small intestine	0.0006	0.0036
Ascending colon	0.0004	0.0027
Descending colon	0.0001	0.0008
Thyroid	1.4242	3.0836
Ovary	0.0003	0.0020
Uterus	0.0003	0.001955
Sigmoid colon	0.0001	0.0008
Heart	0.0212	0.0579
Kidney	0.0019	0.0085
Liver	0.0046	0.0163
Lung	0.0264	0.0717
Spleen	0.0040	0.0147
Thymus	0.0496	0.1657
Bladder	0.0001	0.0010
Bladder content	0.0001	0.0010
Pancreas	0.0037	0.0137
Breast	0.0173	0.0465
Testicle	3.97E-05	0.0004
Esophagus	0.0597	0.1219
Trachea	1.3435	3.9721

compared with the mean organ dose values published by Mille and Xu. The present study uses a MIRD-type heterogeneous phantom 164 cm height and 53 kg weight, whereas the study by Mille and Xu is 163 cm height and 60 kg weight voxel-based phantom simulated using the CT information. As the overall external dimensions of the phantom models being nearly the same, the comparison of results can provide an insight to the influence on the organ dose values computed using MIRD based phantom model and the sophisticated voxel based phantom model. The organ dose values are expected to vary for both the studies because the models have different parameters such as dimension of the organs, the interspatial distance, and the degree of heterogeneity between the source and target organs. The dose values of the published study are presented in Gy for a dose of 34 Gy in water at 3.2 cm from the center of the source. Hence, for the purpose of comparison, the organ dose values obtained by this study are also converted to the similar units. For this, the dose in water at 3.2 cm is obtained by simulating a ^{192}Ir point source at the center of a cylindrical water phantom of 30 cm diameter and 15 cm height. The energy fluence spectrum was scored in a ring at 3.2 cm from the source and converted into the dose using appropriate conversion factors. Table 5 presents the comparison of the normalized organ doses for six organs; the organ masses and the distance between the source and the organ used

Table 5: Comparison of mass of organ and the distance between the source and organ, and the mean organ dose of the present study and the published study of Mille and Xu

Organ	*Mass of organ (g)*		*Interspatial distance between the source to organ (cm)*		*The mean organ dose (Gy) for 34 Gy at 3.2 cm from the source in water*		*Variation of Indian values to published study (%)*
	Present study	*Published study*	*Present study*	*Published study*	*Present study*	*Published study*	
Brain	1151	1300	35.5	34.7	0.0638	0.0824	22.581
Spleen	141.7	130	18.0	20.2	0.7339	0.6290	16.677
Heart	230.9	250	10.1	11.9	2.6280	2.4400	7.705
Uterus	51.4	79.9	37.1	31.5	0.0667	0.1120	40.446
Ovary, left	3.25	5.49	35.8	30.1	0.0723	0.1380	47.609
Ovary, right	3.25	5.49	38.5	31.7	0.0542	0.1050	48.381

in the present study and published study. The interspatial distance is the distance between the center of the organ and the center of the source for the present study and the mean distance from the organ to balloon center for the published study. It is observed that for the organs, namely brain, uterus, left and right ovaries, the dose values of the present study are less compared to those of the published study and these are located at larger distance in the present model when compared to the voxel model. Similarly for spleen and heart, the dose values of this study are higher than the published values and these organs are at smaller distance in comparison with the voxel model. The variation is observed between 8% and 50%.

Conclusion

The normalized organ dose factors are generated during the brachytherapy treatment of esophagus, breast, and neck cancers using ^{192}Ir and ^{60}Co sources to an Indian reference patient. The data is useful to assess the representative dose specific to the Indian population for radiation protection purposes. The organ dose values of the breast treatment case are compared with a similar Monte Carlo simulation study and found agreeing.

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