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 192Ir and 60Co 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. 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. 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.

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 phantom specifications are further scaled down to average Indian standards using appropriate factors. The organ doses to an average Indian adult female patient treated for uterus cancer with microselectron 192Ir source and BEBIG 60Co sources was evaluated by simulating a modified Indian reference adult phantom and reported earlier. The computed dose values were validated by comparing with the Rando phantom-based measured data 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 is extended to evaluate the organ doses specific to the Indian patient population undergoing the brachytherapy of the esophagus, breast, and neck cancers with 192Ir and 60Co sources and the results are presented.

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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 \(^{192}\text{Ir}\) 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 \(^{192}\text{Ir}\) source and BEBIG \(^{60}\text{Co}\)) were modeled for each brachytherapy treatment conditions of esophagus, neck, and breast cancers. Exact geometry of the high dose rate microselectron \(^{192}\text{Ir}\) source and BEBIG \(^{60}\text{Co}\) 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 \(^{192}\text{Ir}\) source is taken from Ballester \textit{et al.}\(^{[15]}\) and that of \(^{60}\text{Co}\) 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 \(^{192}\text{Ir}\) sources in upper, middle, and lower esophagus, and with \(^{60}\text{Co}\) (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 \(^{192}\text{Ir}\). The same during upper, middle, and lower esophagus treatment case using \(^{192}\text{Ir}\) are about 8\%, 6\%, and 3\%, respectively, and it is about 11\% when the \(^{192}\text{Ir}\) source is in the neck. The relative standard deviation of the dose to all the organs treated with \(^{60}\text{Co}\) sources is lesser than that of treated with \(^{192}\text{Ir}\).

#### Comparison of results with published data

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

| 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          |
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 192Ir 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 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     | $^{192}$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     | 0.0727    | 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          | 0.0773     | 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    |
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 ¹⁹²Ir and ⁶⁰Co sources to an Indian reference adult. 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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