Evaluation of Electron Specific Absorbed Fractions in Organs of Digimouse Voxel Phantom Using Monte Carlo Simulation Code FLUKA

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ABSTRACT

Background: For preclinical evaluations of radiopharmaceuticals, most studies are carried out on mice. Electron specific absorbed fractions (SAF) values have had vital role in the assessment of absorbed dose. In past studies, electron SAFs were given for limited source target pairs using older reports of human organ compositions.

Objective: Electron specific absorbed fraction values for monoenergetic electrons of energies 15, 50, 100, 500, 1000 & 4000 keV were evaluated for the Digimouse voxel phantom incorporated in Monte Carlo code FLUKA. From the latest report (International Commission on Radiological Protection ICRP) 110, organ compositions and densities were adopted.

Material and Methods: We have used the Digimouse voxel phantom which was incorporated in Monte Carlo code FLUKA. Simulation studies were performed using FLUKA. The organ sources considered in this study were lungs, skeleton, heart, bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal, eye and brain. The considered target organs were lungs, skeleton, heart, bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal and brain. Eye and brain were considered as target organs only for eye and brain as source organs.

Results: The electron SAF values for self-irradiation decreases with increasing electron energy. The electron SAF values for cross-irradiation are also found to be dependent on the electron energy and the geometries of source and target. Organ masses and electron SAF values are presented in tabular form.

Conclusion: The results of this study will be useful in evaluating the absorbed dose to various organs of mice similar in size to the present study.

Keywords

Electron specific Absorbed Fraction, Digimouse Voxel Phantom, Monte Carlo Simulation, FLUKA

Introduction

To improve the estimation of organ doses, mice are frequently used. Mouse models can help to assess the potential interest of new radiopharmaceuticals. Bio-distribution and radiation toxicity studies are performed on mice and based on success of these studies, human clinical trials will be carried out. The earliest methods adopted for estimation of electron specific absorbed fraction values involved using point kernel method [1-2] in conjunction with stylized phantoms [2-4] with mouse organs represented by ellipsoids, spheroids and cylinders. With time, approximate point kernel methods were replaced by full Monte Carlo simulations [2-6] using the particle transport which are

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more accurate. Similarly, stylized phantoms were having the issue of non realistic representation of internal organs due to their simple mathematical form and non-overlapping organs. Mouse volume pixel (voxel) phantoms are the modern computational phantoms based on medical imaging of mouse. Most studies use older organ compositions based on International Commission on Radiological Protection (ICRP) publication number 23 [7] or International Commission on Radiation Units and Measurements (ICRU) report number 44 [8]. Previous studies also lack the aspect that electron specific absorbed fraction values are not provided for all source target pairs, which will be useful for computing all organ doses.

In this study, we present electron SAF as they are evaluated for the digimouse voxel phantom [9] using Monte carlo code FLUKA at six electron energies from 15 keV to 4000 keV. Electron SAF were evaluated and tabulated for all source target pairs as considered. The effect of various parameters on SAF values were also analyzed. The comparison between electron SAF values of this study and contemporary study which used voxelized phantom were also performed.

Material And Methods

Digimouse Voxel Phantom in FLUKA Code

The Digimouse voxel phantom used in this study which was downloaded [9] is a three-dimensional representation of whole body of a mouse. This phantom was developed by biomedical imaging group of the University of South California using medical image data such as x-ray, CT and color cryosection images of a normal nude male mouse. The phantom is a matrix of 380 columns, 992 rows and 208 slices or 78407680 voxels. The structures which are segmented and labeled with distinct organ identification numbers in this phantom are: medulla, cerebellum, olfactory bulbs, external cerebrum, striatum, rest of the brain, massetter muscles, eyes, lachrymal glands, heart, lungs, liver, stomach, spleen, pancreas, adrenal glands, kidneys, testes, bladder, skeleton and skin. The whole brain in this phantom consists of medulla, cerebellum, olfactory bulbs, external cerebrum, striatum and the rest of the brain.

Digimouse voxel phantom was converted into a suitable format for use in FLUKA code which was discussed in authors' previous work [10]. The figure of Digimouse voxel phantom was incorporated in FLUKA code (different planes) as shown in Figure 1. The elemental compositions and densities used for Monte Carlo simulation of Digimouse phantom are based on the most recent human anatomical data provided in ICRP publication number 110 [11]. ICRP 110 contains fifty three different organ compositions where various soft tissue compositions are based on ICRU 46 [12] and various skeleton tissue compositions are based on ICRP 70 [13].
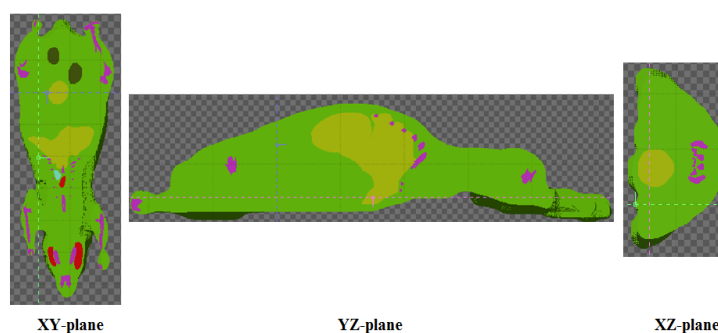

XY-plane   **YZ-plane**   **XZ-plane**

Figure 1: Digimouse Phantom incorporated in FLUKA code (different views)

Simulations and Estimation of Electron Specific Absorbed Fractions

Masses of simulated organs (in Supporting documents) in phantom were calculated by multiplying the total volume of organs (product of number of voxels and volume of voxel and related density). The organ sources considered in the present study are: lungs, skeleton, heart, bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal, eye and brain. The target organs considered are: lungs, skeleton, heart, bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal and brain. As stated above, eye and brain were considered as the target only when eye and brain were source organs. Six electron energies (15, 50, 100, 500, 1000 and 4000 keV) were considered in these simulations. In FLUKA code, USERBIN card was used to evaluate the energy deposited in the target organs due to the activity in the source organ. The electron SAF value [14] used as a common parameter in our study and can be calculated by the following formula:

$$SAF = \frac{\text{Average Energy Deposited in the Target Organ}}{\text{Primary Energy Emitted in the Source Organ x mass of target organ}} \quad (1)$$

For a particular energy and source-target combination, 2×10^7 histories were run to reduce the relative error

(RE) in the estimated energy deposited in target organ due to the activity in source organ.

Results and Discussion

The computed electron SAF values (from equation 1) for various source-target combinations and their REs at different energies are presented in in Supporting documents. The reported electron SAF values have REs less than 10%. The results of electron SAF values show that these values are dependent on the following factors:

Primary electron energy, mass of target organs, density of organ in case of self irradiation and effect of geometry in the case of cross-irradiation.

Primary Electron Energy

Because of low penetrating power of electrons, previous ICRP and MIRD [15, 16] assumption model supposed the electrons are fully absorbed in the source organ and electron AFs are recommended to be 1, AFs and SAFs are recommended to be 0 when the source and target are different. From Figure 2, we can see that electrons have the ability to leave the source organ with electron energy above 0.5 MeV which proves that it is certainly not always appropriate to assume 100% localized electron energy absorption.

Mass of Target Organs

We can see the dependence of mass of target organs in case of self-irradiation from Figure 2. The self-absorption SAFs agree with the inverse organ mass for electron energy. For self irradiation, liver has the smaller electron SAF values that is due to energy deposition per mass unit less for larger size organs. The organ with similar masses (difference ~0.2%) such as stomach and heart have very small differences (<5%) in SAF values at all energies.

Effect of Density in case of Self-irradiation

Based on Figure 2, the difference between electron SAF values in lung and spleen, the organs having close masses, shows that the electron SAFs were dependent on organ density. Electron SAF values in lung and spleen show a variation of approximately 10% at lower energies and 80% at higher energies.

Effect of Geometry in case of Cross-irradiation

We can explain the independence of electron SAF values from mass of target organs

in case of cross irradiation while taking spleen as a source organ. Figure 3 shows SAF values for organ cross-fire in adjacent organs such as stomach, pancreas, liver, kidney and heart with spleen as source organ. SAF values are different at all energies for stomach and heart (difference more than 100%) regardless of having the same mass. We can conclude from these examples that SAF values for cross-irradiation depend on energy and geometrical fac-

tors such as size of source and target.

Comparison with Contemporary Studies using Digimouse Voxel Phantom

A comparison of electron AF values for self irradiation in liver reported by Mohammadi et al [17] and with those observed in the present study is shown in Figure 4. The difference in AF values of liver between our study and the reference study is less than 2% at 100 keV as
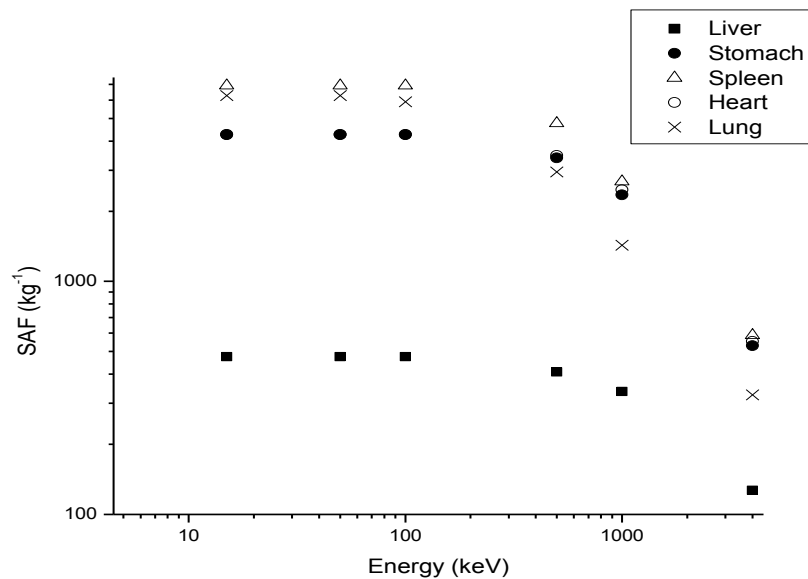

Figure 2: Self-irradiation in organs such as liver, stomach, spleen, heart and lung
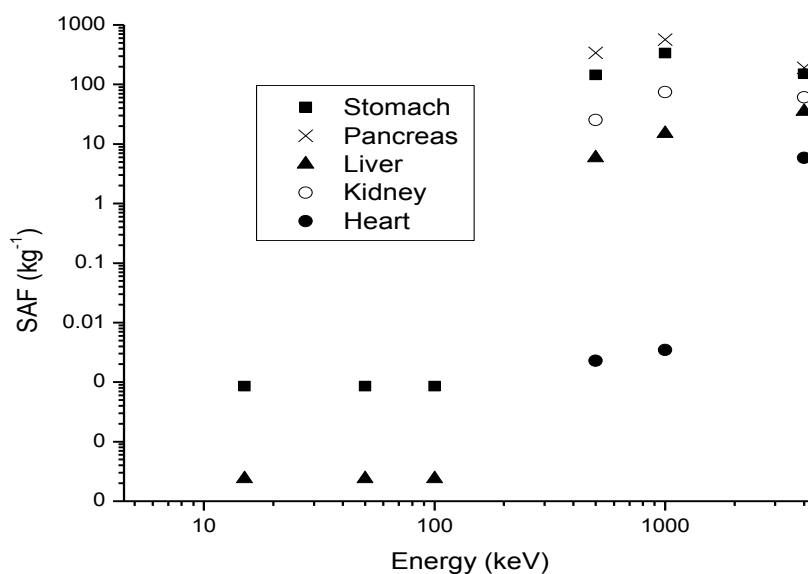

Figure 3: Cross-irradiation in organs such as stomach, pancreas, liver, kidney and heart (source: spleen)

well as very smaller differences at higher energies (<2.69%). The AF values for cross irradiation in spleen, while taking liver as source organ between our study and the reference study, are shown in Figure 5, which have the minimum difference of 2.27% and maximum difference of 1%.

Conclusion

The authors derived a new set of SAF values for electrons at 15, 50, 100, 500, 1000 and 4000 keV in the organs of the Digimouse voxel phantom using FLUKA code. Studies on SAF values have used older standard human organ compositions and these values were for limited source target pairs. In this study, organ compositions and densities for photon SAF estimation in Digimouse voxelized phantom are based on ICRP publication number 110. The organ sources were lungs, skeleton, heart,
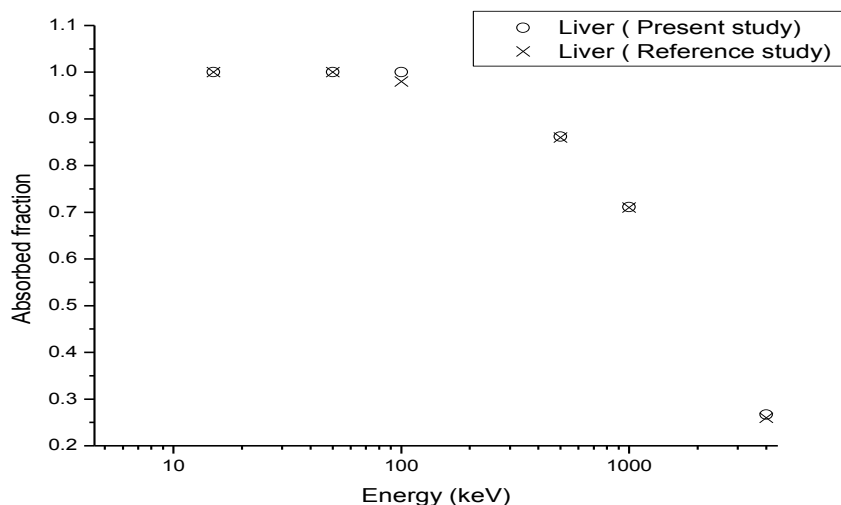

Figure 4: The comparison of absorbed fractions for self irradiation in liver between present study and Mohammadi et al. (reference study)
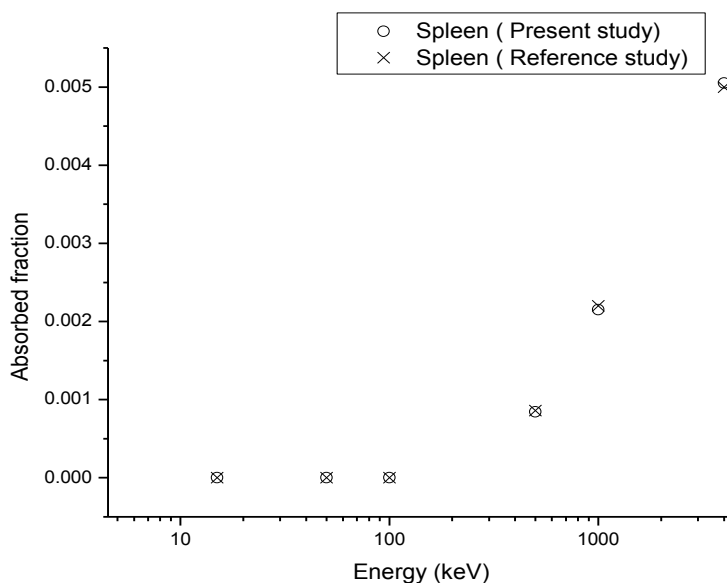

Figure 5: The comparison of absorbed fractions for cross irradiation in spleen between present study and Mohammadi et al. (reference study)[Source-Liver]

bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal, eye and brain. The target organs were lungs, skeleton, heart, bladder, testis, stomach, spleen, pancreas, liver, kidney, adrenal, eye and brain. The SAF values obtained from this study are in agreement with other studies which used Digmouse voxelized phantom. In case of self irradiation, electron SAF values depend on energy, mass and density of organs and for cross-irradiation, it depends on geometry of the organs.

Acknowledgment

Conflict of Interest

None

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