Calculation of Local Skin Dose Coefficients with ICRP Mesh-type Reference Computational Phantoms

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1. Introduction

The International Commission on Radiological Protection (ICRP) recommended the annual limit on skin dose of 500 mSv for occupational exposure and 50 mSv for public exposure in the ICRP Publication 103 [1]. The annual skin dose limit corresponds to the equivalent dose averaged over 1 cm^2 area of skin, regardless of the area exposed, at the basal cell layer, the depth of which is recommend as 50-100 μm at the nominal depth of 70 μm [2-5].

The 50-μm-thick basal layer, however, cannot be included in the ICRP adult reference voxel phantoms described in ICRP Publication 110 [6] due to their limited voxel resolutions (i.e., male: 2.137 × 2.137 × 8 mm^3 and female: 1.775 × 1.775 × 4.84 mm^3). Instead of using the ICRP-110 reference phantoms, the ICRP separately used a simple tissue-equivalent cube model (10 × 10 × 10 cm^3), including the cylindrical-shape target region of 1 cm^2 area and 50 μm height located 50 μm below the cube surface, to calculate local skin dose coefficients (LSDCs) for electrons and alpha particles, which were provided in the ICRP Publication 116 [2].

In 2016, the ICRP formulated a new Task Group (i.e., Task Group 103) within Committee 2 in order to develop mesh-type reference computational phantoms (MRCPs) that can address the dosimetric limitations of the currently used voxel-type reference phantoms due to the limited voxel resolutions and the nature of voxel geometry [7-11]. Recently, the TG 103 have completed the development of the adult male and female MRCPs, and are now preparing a report for distribution. The adult MRCPs, in contrast with the ICRP-110 reference phantoms, include the 50-μm-thick skin basal layer; however, a calculation method of local skin dose (LSD) with the adult MRCPs has not been developed yet.

In the present study, we developed a LSD calculation method based on the mean shift algorithm [12]. Then, by using the developed method, LSDCs for electrons and alpha particles were calculated with the adult MRCPs, and the calculated LSDCs were compared with the values in the ICRP Publication 116 that were produced with the simple cube model.

2. Material and Methods

2.1 Local Skin Dose Calculation Method

Figure 1 shows the overall procedure for the LSD calculation method developed in the present study. First, the interaction position and deposited energy for each step of particles within the skin basal layer of the adult MRCPs are recorded. The recorded data are then used to calculate the dose distribution in the skin basal layer with the dose grid resolution of 1 × 1 × 1 cm^3. From the dose distribution, a sufficient number of cube volumes (i.e. 150–200 cubes depending on particles and energies) showing highest dose values are selected, assuming that the LSD exists in or near one of these cube volumes. Then, the LSD is found by using the mean shift algorithm [12], the well-known method to search local maxima. Specifically, a center of kernel sphere (cross-sectional area at center: 1 cm^2), starting from the center of the selected cube volume, is moved to the center of energy of the interaction positions within the sphere, calculated by using the equation:

$$\boldsymbol{E}_{center} = \frac{\sum_{i=1}^{n} \boldsymbol{x_i} \cdot E(x_i)}{\sum_{i=1}^{n} E(x_i)} \qquad (1)$$

where E_{center} is the center of energy of the interaction positions within the sphere, x_i is a coordinate of an i^{th} interaction position, and $E(x_i)$ is a deposited energy for the i^{th} position. This movement is repeated until the moving distance of the sphere is less than 1 μm. At the location, a local maximum dose is calculated averaged from 1 cm^2 area of the skin, which is considered as a candidate for the LSD. This process is repeated for all of the selected cube volumes, and finally the largest value among the calculated local maximum doses is considered as the LSD.

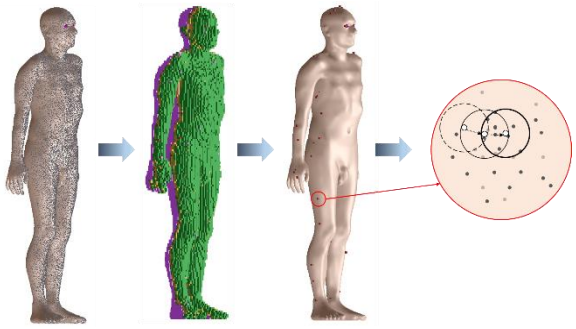

Figure 1. The overall procedure for the calculation of the local skin dose.

2.2 Monte Carlo Simulation with Geant4

The developed LSD computation method was used to calculate LSDCs for the broad parallel beam of electrons and alpha particles with the adult MRCPs. For the calculation, the Geant4 code [13] was used and the broad parallel beam was delivered to the MRCPs in the antero-posterior (AP), postero-anterior (PA), left-lateral (LLAT), and right-lateral (RLAT) with the same energy points considered in the ICRP Publication 116. The physics library of the *G4EmLivermorePhysics* was used to transport electrons and alpha particles as well as photons. The secondary production cut value of 1 μm was applied for all particles considering the 50-μm-thick skin basal layer of the MRCPs. The statistical errors of the calculated LSDCs were all less than 5%.

3. Results and Discussions

In the present study, the LSDCs calculated with adult MRCPs for electrons and alpha particles were compared with those of the ICRP Publication 116. Figure 2 shows that the LSDCs of the MRCPs along with the values of the ICRP Publication 116 for electrons. It can be seen that for the energies less than 0.1 MeV, the calculated LSDCs were not much different from the ICRP Publication 116 values; the differences were less than 25%, except for the 0.06 MeV where the maximum difference was 46% in the PA geometry for the female. These differences were due mainly to the different electron physics models between MCNPX (ver. 2.6.0) used in the ICRP Publication 116 and Geant4 (ver. 10.02) used in the present study.

For the energies higher than 0.1 MeV, the calculated LSDCs were significantly different from the ICRP Publication 116 values; the calculated LSDCs were greater by as large as ~2.7 times at 10 MeV in the AP geometry for the female. These significant differences were mainly due to the different curvature between the

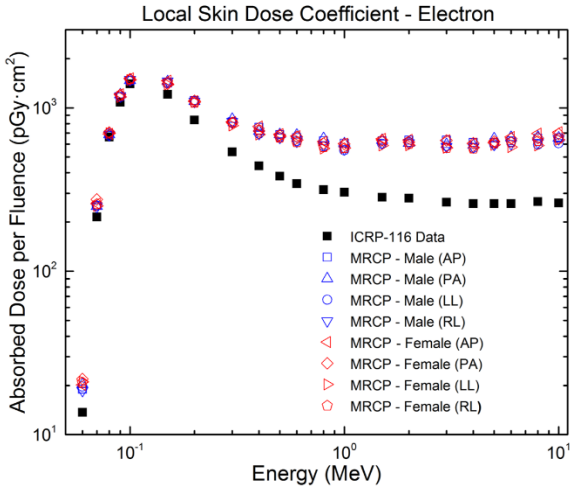

Figure 2. Local skin dose coefficients of the adult MRCPs calculated in this study and the ICRP Publication 116 values for electrons.

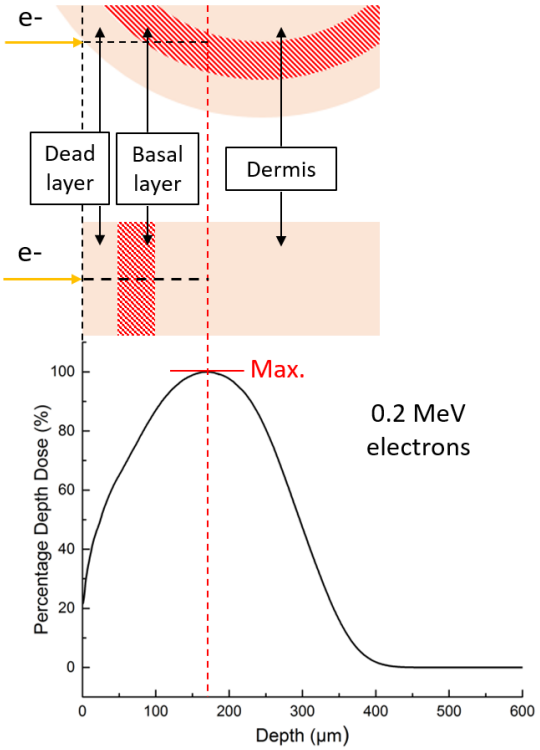

Figure 3. Percentage depth dose distribution of 0.2 MeV in the skin (bottom) and the projectile depth for flat (middle) and curved (top) skin.

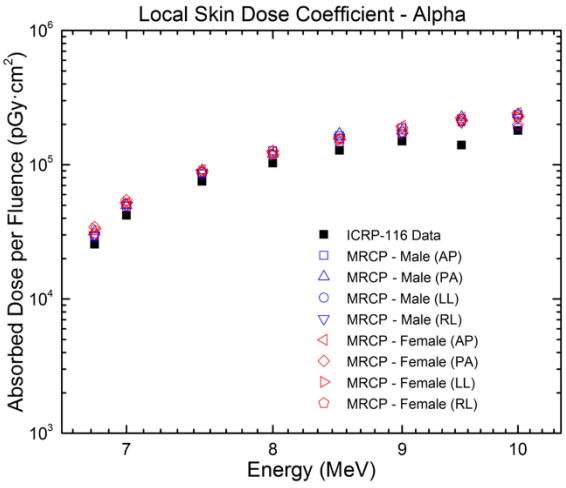

Figure 4. Local skin dose coefficients of the adult MRCPs calculated in this study and the ICRP Publication 116 values for alpha particles.

MRCPs and the tissue-equivalent cube model used in the ICRP Publication 116. Considering that the continuous slowing down approximation (CSDA) range of the electrons (> 0.1 MeV) in the skin is greater than 100 μm, these electron beams, normally incident to the cube model, establish a maximum dose at a depth deeper than the skin basal layer (see Figure 3). On the other hand, the

same beams incident to the MRCPs can establish the maximum dose within the skin basal layer of the MRCPs due to the fact that the projected depth along with the beam direction to the basal layer from the surface of the curved phantom is increased depending on a part of the skin (see Figure 3).

Figure 4 shows the LSDCs of the MRCPs along with the ICRP Publication 116 values for alpha particles. It can be seen that the LSDCs of the MRCPs were generally not much different from the ICRP Publication 116 values with the maximum difference of ~1.6 times at 9.5 MeV. These differences were mainly due to the different alpha particle physics models between MCNPX (i.e., the ICRP Publication 116) and Geant4 (i.e., the present study).

4. Conclusions

In the present study, the LSD calculation method based on the mean shift algorithm was developed and used to calculate the LSDCs of the adult MRCPs for electrons and alpha particles. The calculated LSDCs were then compared with the ICRP Publication 116 values produced with a simple cube model. The results of the present study show that the LSDCs of the MRCPs are generally in good agreement with the ICRP Publication 116 values for alpha particles, but for electrons, there are significant differences at the energies higher than 0.1 MeV. The ICRP Publication 116 values are smaller by as large as ~2.7 times at 10 MeV, which is due mainly to the effect of the curvature of the phantoms. Considering that the MRCPs are anatomically more realistic than the simple cube model, we believe that the LSDCs of the MRCPs are more reliable than the ICRP Publication 116 values.

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