Absorbed Fractions for Multi-Region Models of the Kidneys in ICRP/ICRU Voxel Phantoms

Sakae KINASE[*], Masanori KIMURA, Shogo TAKAHARA
and Toshimitsu HOMMA
[*]2-4 Shirane, Shirakata, Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan

Kidney dosimetry is indispensable in internal dose evaluations since the kidneys appear to represent radioactivity uptake in both diagnostic and therapeutic nuclear medicine. The Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine has presented multi-region kidney models and evaluated absorbed fractions (AFs) –fraction of energy emitted in a source region which is absorbed in some target regions– for regional kidney doses in the MIRD schema. However, it is needed to update the AFs for the kidneys since the MIRD kidney models, which are stylized models, do not reflect realistic anatomy. The International Commission on Radiological Protection (ICRP) has developed reference computational models i.e. ICRP/ICRU voxel phantoms of the Reference Male and Reference Female, which have more realistic and detailed information about the kidney than the MIRD kidney models. The ICRP/ICRU kidney model consists of 3 regions for each kidney: cortex, medulla and pelvis. In the present study, the ICRP/ICRU kidney models were applied to evaluating AFs for the kidneys. Uniformly distributed photon sources with the energy range from 10 keV to 10 MeV were assumed to be in the cortex, medulla and pelvis. The radiation transport was simulated using a Monte Carlo code. Consequently, it was found that the AFs with the ICRP/ICRU kidney models were consistent with those with the MIRD kidney model for adult. In the case of cross-irradiation AFs, the largest differences between the two kidney models (ICRP/ICRU and MIRD) were found to be 3.3 for the female and 2.6 for the male in the low-energy region. The AFs obtained in the present study would be useful for non-uniformly distributed source of photons in kidney dosimetry.

Key Words: Kidney, ICRP, MIRD, voxel, AF

1. Introduction

The present study is of internal dosimetry for the adult kidneys. Kidney dosimetry is important since the kidneys represent a frequent source of radioactivity uptake. Recent interest in sophisticated approaches in kidney dosimetry with incorporated radionuclides, has spurred a great deal of research into the application of computational models. The Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine has presented the stylized mathematical models of the kidneys for use in regional dose assessment and evaluated absorbed fractions (AFs) –the fraction of the energy emitted by source region that is absorbed in target region– in the radiation energy range from 10 keV to 4 MeV[1]. The MIRD kidney models and the AFs are capable of evaluating regional kidney doses not previously supported by single-region kidney models. However, the MIRD kidney models are not always appropriate in kidney dosimetry since the models represented with ellipsoids are not realistic. The International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) has introduced the anatomical models of Reference Male and Reference Female–ICRP/ICRU voxel phantoms[2]. The ICRP/ICRU voxel phantoms, which are based on medical image data of real people, have multi-region models of the kidneys. The purpose of the present study was to evaluate AFs for photons in the ICRP/ICRU kidney models and to examine the relationship of AFs between those for the ICRP/ICRU kidney models and those for the MIRD kidney model.

2. Materials and Methods

2.1. ICRP/ICRU kidney models

The ICRP/ICRU adult male and female reference voxel phantoms were used in the present study. The voxel phantoms, based on computed tomographic data sets, were developed by the Helmholtz Zentrum München in collaboration with DOCAL of ICRP committee 2 and ICRU. The voxel sizes are 2.137×2.137×8.0 mm^3 for the adult male voxel phantom and 1.775×1.775×4.84 mm^3 for the adult female voxel phantom. Many organs and tissues are segmented and identified. Three regions are segmented in each kidney: cortex, medulla and pelvis. The mass of each kidney region in the voxel phantoms is shown in **Table 1**. The kidneys are adjusted to approximate the reference mass values with high precision. For comparison, the mass of each region for the MIRD kidney model of adult are also shown in the table.

2.2. Absorbed fractions (AFs)

Absorbed fractions for photons were evaluated for the ICRP/ICRU kidney models using the Monte Carlo code, EGS4[3], in conjunction with an EGS4 user code, UCSAF[4]. In the EGS4-UCSAF code, the radiation transport of electrons, positrons and photons in the phantoms was simulated, and correlations between primary and secondary particles are included. In the present study, the sources of the photons were assumed to be mono-energetic in the energy range from 10 keV to 10 MeV and uniformly distributed in the source region. The source regions were cortex, medulla and pelvis in kidneys. Photon histories were selected to be numbers sufficient to reduce statistical uncertainties below 5%. The cutoff energies were set to 1keV for the photons and 10keV for the electrons. The Parameter Reduced Electron-Step Transport Algorithm (PRESTA) [5] to improve the electron transport in the low-energy region was used. The cross-section data for photons were taken from PHOTX[6,7] and the data for electrons are taken from ICRU report 37[8].

3. Results and Discussions

AFs for mono-energetic photons were evaluated by the EGS4-UCSAF code for the multi-region kidney models in the ICRP/ICRU voxel phantoms and compared with published data[1,9]. **Table 2** compares self-irradiation (source=target) AFs for photon energies of 30 keV, 100 keV and 1 MeV. The result shows that the self-irradiation AFs for photons in the ICRP/ICRU kidney models are consistent with those for the MIRD kidney model. The self-irradiation AFs for the multi-region kidney models are smaller than those for total kidneys–single-region kidney models. It should be noted that kidney dosimetry conducted using single-region kidney models are not always accurate since the radioactivity is concentrated non-uniformly in the kidneys.

Figures 1 (a)-(c) show photon AFs for the multi-region kidney models of the ICRP/ICRU voxel phantoms in the energy range from 10 keV to 10 MeV. AFs for the MIRD kidney model of adult are also plotted in the figures. The self-irradiation AFs decrease with an increase in photon energy on the whole. The cross-iradiation (source≠target) AFs increase up to about 20 keV and then they decrease. From a comparison with the results it can be stated that the AFs for the ICRP/ICRU kidney models are in harmony with those for the MIRD kidney model of adult. However, there are deviations between them in the low-energy region. In the case of cross-irradiation AFs, the largest differences between the two kidney models (ICRP/ICRU and MIRD) were found to be 3.3 for the female and 2.6 for the male in the low-energy region. This is due to the different shape and size of the regional kidneys. Since the mean free path of the photon with low-energy is not large compared with the size of the regional kidneys, low-energy photons could not be considered "pure" penetrating for the dosimetry. From the standpoint of the MIRD schema, the AFs for the MIRD kidney model of adult were validated except for those for low-energy photons and electrons.

4. Conclusions

The AFs for the multi-region kidney models of the ICRP/ICRU voxel phantoms were evaluated using Monte Carlo simulations in the photon energy range from 10 keV to 10 MeV. The obtained AFs were compared with those for the MIRD kidney model. It was found that the AFs for the ICRP/ICRU kidney models are consistent with those for the MIRD kidney model and that the self-irradiation AFs for the multi-region kidney models are smaller than those for single-region kidney models. The AFs obtained in the present study as well as those for the MIRD kidney models would be useful for non-uniformly distributed source of photons in kidney dosimetry.

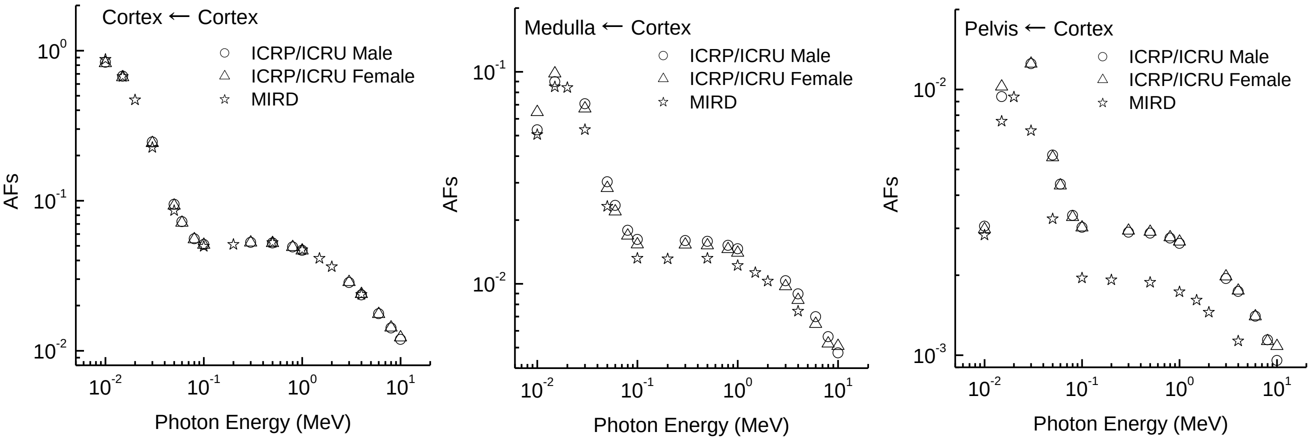
Table 1 Mass of each regional kidney in the ICRP/ICRU and the MIRD models[1]

Suborgan	Mass (kg)		
	ICRP/ICRU male	ICRP/ICRU female	MIRD[1]
Cortex	2.2×10^{-1}	1.9×10^{-1}	2.1×10^{-1}
Medulla	7.8×10^{-2}	6.9×10^{-2}	7.5×10^{-2}
Pelvis	1.6×10^{-2}	1.4×10^{-2}	1.3×10^{-2}
Total kidney	3.1×10^{-1}	2.8×10^{-1}	3.0×10^{-1} *

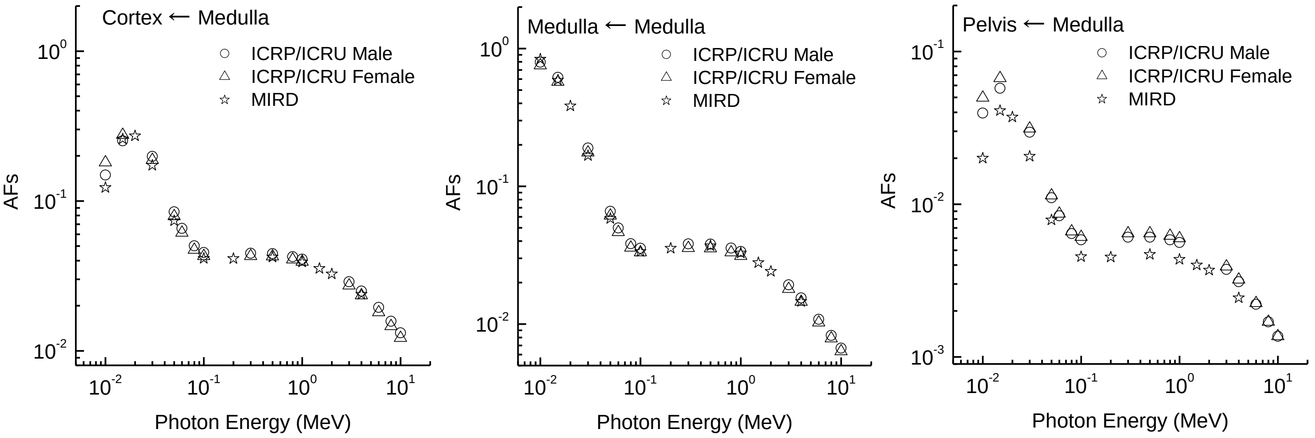
*including the mass of papillae (2.5×10^{-3} kg).

Table 2 Self-irradiation absorbed fractions in ICRP/ICRU kidney models and MIRD kidney model of adult[1] for photon energies of 30 keV, 100 keV and 1 MeV

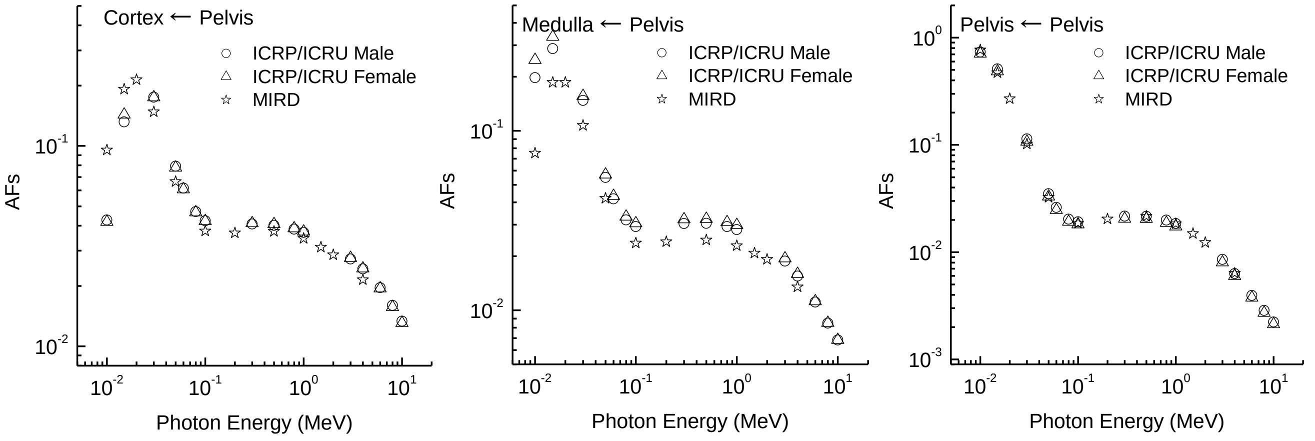
Suborgan	Absorbed fraction		
	ICRP/ICRU male	ICRP/ICRU female	MIRD[1]
Energy, 30 keV			
Cortex	0.25	0.24	0.226
Medulla	0.19	0.18	0.167
Pelvis	0.11	0.11	0.102
Total kidney[9]	0.36	0.35	–
Energy, 100 keV			
Cortex	0.051	0.051	0.0495
Medulla	0.036	0.033	0.0336
Pelvis	0.019	0.018	0.0186
Total kidney[9]	0.076	0.073	–
Energy, 1 MeV			
Cortex	0.047	0.047	0.0471
Medulla	0.034	0.031	0.0328
Pelvis	0.018	0.017	0.0184
Total kidney[9]	0.069	0.068	–



(a) source=cortex



(b) source=medulla



(c) source=pelvis

Figure 1. Comparison of absorbed fractions in the kidneys for the ICRP/ICRU and MIRD models in the photon energy range 10 keV–10MeV.

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