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Internal dosimetry for paediatric patients: a GATE Monte Carlo study on UF/NCI phantoms

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Internal dosimetry has an increasing and crucial role in nuclear medicine. Though radiation detection through tomographic imaging permits to reconstruct patient's morphology via CT scans and the biodistribution of radionuclide inside the body via PET or SPECT scans, directly detecting the distribution of deposited energy inside the body is not feasible. Consequently, dedicated calculation methods are necessary to estimate the radiation absorbed dose internally imparted to organs and tissues by radionuclides. Internal dosimetry enables to potentially optimize the injected activity for safer diagnostic acquisitions and effective therapeutic treatments, maximizing the damage to lesions while minimizing complications to healthy tissues. Particular care is required in nuclear medicine practice and related dosimetry for paediatric patients, constituting a radiosensitive cohort [1].

The standard model-based approach for internal dosimetry is the MIRD organ S-factors formalism, widely applied to various adult computational phantoms, such as the ICRP110 ones, for different emitted particles and energies. Instead, to date there is still lack of studies on paediatric phantoms. The aim of this work was to perform a dosimetric study on the UF/NCI voxelized paediatric phantoms [2] through GATE Monte Carlo simulations. The Specific Absorbed Fractions (SAF) due to photons and electrons at different energies were estimated for pairs of organs of major interest for clinical practice.

The geometries and organ compositions of the whole UF/NCI series, which includes phantoms for newborn, 1, 5, 10, 15 and 35 years old of age, were reproduced on the GATE simulation environment, and a set of organs, including thyroid, liver and brain among others, were each set as a homogeneous source of emitted particles. A wide set of monoenergetic values of energy, from 5 keV to 10 MeV, was simulated, scoring for each combination of phantom, particle, energy and source organ the average absorbed dose in all the organ volumes of the phantoms; the respective SAFs were then calculated.

The simulations were carried out on the Marconi 100 CINECA HPC cluster, within the INFN MIRACLE project, exploiting a parallelization into 62 runs per node, thus strongly reducing the overall simulation time. 10^7 primary events were run for each simulation, requiring a further parallelization on multiple runs for high-energy electrons. These specifics guaranteed the selection of photon SAFs with statistical uncertainties below 5% for most of the organ pairs examined. Instead, for the electrons, given their short range, we focused on auto-SAFs (i.e., source = target), which showed uncertainties below 1%.

The obtained SAFs exhibit trends depending on the emitted particle energy, on the organs'size and reciprocal distances and in some cases on phantoms'age. Photon SAFs decrease in the source organ and in the nearby target organs as the energy increases; the same behaviour is found for electron auto-SAFs. SAFs for the same organ pairs show a decreasing trend for increasing age of the phantoms, evidence justified by the increase of body size, and consequently of the organ volumes and of the reciprocal distances, causing a lower relative energy deposition than for younger ages. Comparing the results for phantoms of the same age but different sex, the differences are way lower than for adult phantoms, and not significant for ages below 10 years; this reflects the more similar body dimensions and proportions between male and female newborns and children with respect to adults.

Future perspectives foresee the extension of the dosimetric analysis to additional pair of organs, and the comparison of the SAFs obtained with different Monte Carlo codes.

References

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