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Presenting and simulating an innovative model of liver phantom and applying two methods for dosimetry of it in neutron radiation therapy

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ABSTRACT

Aim: A new model of liver phantom is defined, then this model is simulated by MCNPX code for dosimetry in neutron radiation therapy. Additionally, an analytical method is applied based on neutrons collisions and mathematical equations to estimate absorbed doses. Finally, the results obtained from two methods are compared to each other to justify the approach.

Background: The course of treatment by neutron radiation can be implemented to treat cancerous tissues, although this method has not yet been widespread.

The MIRD and the Stylized Family Phantom were the first anthropomorphic phantoms, although the representation of internal organs was quite crude in them. At present, a water phantom is usually used for clinical dosimetry.

Materials and methods: Each of the materials in an adult liver tissue including water and some organic compounds is decomposed into its constituent elements based on mass percentage and density of every element. Then, the accurate mass of every decomposed material of human liver tissue is correlated to masses of the phantom components.

Results: The absorbed doses are computed by MCNPX simulation and analytical method in all components and different layers of this phantom.

Conclusions: Within neutron energy range of 0.001 eV–15 MeV, the calculated doses by MCNPX code are approximately similar to results obtained by analytical method, and the derived graphs of both methods approve one another. It is also concluded that through increasing the incident neutron energy, water receives the largest amounts of absorbed doses, and carbon, nitrogen and sulfur receive correspondingly less amounts, respectively.

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Nomenclature

E_1	the energy of emitted neutron before collision
E_2	the energy of emitted neutron after collision
E_R	absorbed dose (transferred energy)
$\Sigma^H_{s(elastic)}$	macroscopic elastic scattering cross section for hydrogen
$\Sigma^C_{s(elastic)}$	macroscopic elastic scattering cross section for carbon
$\Sigma^C_{s_1(inelastic)}$	macroscopic nonelastic scattering cross section for the first excitation level of carbon
$\Sigma^C_{s_2(inelastic)}$	macroscopic nonelastic scattering cross section for the second excitation level of carbon
Σ_s	macroscopic scattering cross section
Σ^H_a	macroscopic absorption cross section for hydrogen
Σ^C_a	macroscopic absorption cross section for carbon
Σ_t	macroscopic total cross section
Ω	space angle
θ	collision angle of incident neutron
T	temperature
k	the Boltzmann constant
E_U	upper limit of integration for neutron energy
E_L	lower limit of integration for neutron energy

1. Background

Applying the neutrons is a new method in radiotherapy course for the treatment of cancerous tumors. First, the concept of neutron radiation therapy was shortly proposed after the discovery of the neutron by Chadwick in 1932.[1]

The neutron radiation therapy may be implemented in a patient through two types of neutrons. One type of neutron radiation therapy is Boron Neutron Capture Therapy (BNCT) that applies epithermal neutrons. It is considered that the available neutron beams in the epithermal-based reactors can mostly be an eligible source to produce epithermal neutrons to be applied in the BNCT. In the BNCT, the thermal reactors which provide low energy neutrons, might be used as a neutron source.[2]

Another type is Neutron Capture Therapy (NCT) that is relative to fast neutrons. In that case, it is suggested that the mono-energy neutrons be used. One choice is D-T source which produces 14 MeV neutrons. As Am-Be source produces a wide spectrum of neutron energies, it is not appropriate for this purpose.[3,4]

During radiotherapy by any radiation, it is always indispensable to stop the absorption of the excess dose by a normal tissue. On the other hand, measurement and assessment of absorbed dose is an important matter.[5] Thus, before practical treatment, a new phantom modeling might be very helpful for the sake of dose calculation. An appropriate software tool for this aim is the MCNPX code.[6]

One of the liver models which has already been applied in dosimetry is a small-scale dosimetry model for various source-target combinations within the micro-architecture of human liver and using Monte Carlo simulations. In this model, the ratio of local absorbed dose has been calculated to the whole-organ average absorbed dose.[7]

Another model is the simulation of a homeostatic liver lobule in which cell death, cell division, and changes in vasculature are all present. This model consists of a single classical hepatic lobule. The morphology and function of this lobule represents all lobules within the liver. In this model, a synthesized lobule is used for flow in histomorphometry data.[8]

At present, one of the most common phantom models is the "Water Phantom" that is used for clinical dosimetry. This phantom contains a water chamber such that a counter is placed at various points of it. In this phantom, the amount of transferred dose from existing water in tissue to tissue is calculated according to the following equation:

$$D_{tissue} = D_{water}\left(\frac{\tilde{\mu}_{en}}{\rho}\right) \quad (1)$$

In the "Dose Volume Histogram" (DVH) calculations, the phantom named "Test Phantom" is used in such a way that they have specified dimensions. These phantoms are mainly comprised of cubes and isocenter circles that are applied for testing the dose calculation accuracy.[9]

A crude model of phantom is MIRD phantom that has been developed in 1960 with 22 internal organs and more than 100 sub-regions. It is the first anthropomorphic phantom representing a hermaphrodite adult for internal dosimetry. The major type of phantom named "Stylized Family Phantom" series were also developed, although the representation of internal organs was quite crude in these phantoms, as it had many inherent limitations in definition of geometry and material of each organ.[10]

The liver is the second largest single organ in the body (after the skin), weighing on average 2 kg in an average adult. In actual state, the average width of the liver tissue across for an adult human is approximately 21–22.5 cm, the vertical height of this organ at the greatest height is estimated to be 15–17.5 cm, and the depth is 10–12.5 cm from the front to back.[11] The liver tissue is located in the right upper quadrant of the abdominal cavity, resting just below the diaphragm. The liver lies to the right of the stomach, and its left lobe is accessible for radiation, although, the liver is wider.[12]

2. Aim

There are three prime objectives of this investigation:

a) The first objective is to define a new model of a liver phantom and simulation of it by the MCNPX code. This phantom has identical compositions compared with existing compositions in a human liver tissue; so, in this study, each of the materials in an adult liver tissue (including water, protein, glucose and glycogen) is decomposed to its constituent elements. This decomposition is carried out based on the mass percentage and density of every element, then the accurate mass of every analyzed element (such as H, O, C, N and S), which exists in constituent materials of the