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Calculation of absorbed dose of stomach tumor labeled with gold and silver nanoparticles using Geant4

Hosseini Sarteshnizi H*. , Jahanbakhsh. O. , Kasani. H.

[1]Faculty of Physics, University of Tabriz, 5166616471, Tabriz, Iran
* *Email: sadrahosseini8@gmail.com*

Abstract

Cancer is one of the main leading causes of death in the modern world and researchers are focusing on finding new methods of diagnostics of cancer and selective therapy. Using ionizing radiations is one of the most effective methods to perish cancerous tumors. Due to increase deposited energy and magnify direct damage to the tumor, the use of high-Z nanoparticles in cancer diagnostics and therapy has been increasing. In this work based on the Monte Carlo simulation toolkit, Geant4, we investigated the local dose enhancement caused by adding gold and silver nanoparticles in a gastric adenocarcinoma tumor tissue. The simulations were carried out for 45-110 photon energies and with gold and silver nanoparticles at 1, 2, and 3 wt% in an adenocarcinoma tumor. The highest dose increase factor was reported for gold nanoparticles in the energy of 90 keV and silver nanoparticles in the energy of 45 keV.

Keywords: Nanoparticles, Human phantom, Geant4, Monte Carlo method, Absorbed dose, adenocarcinoma tumor

Introduction

The most important aim in the cancerous tissue and delivering minimum dose to around normal tissues. In recent decades, the delivery of nanoparticles into tumor tissue is one of the methods that has been widely considered to reduce the adverse effects of radiation on healthy tissues. Accumulated metal nanoparticles in the tumor, can increase absorbed gamma and X-ray photons and cause more damage to the target cell. In this regard, often true experiments are impossible, hence, scientists have turned to simulation programs, like Geant4 code. The MIRD phantom in Geant4 presents a geometric shape of the body parts and identifies their tissue material. In the current study, the Geant4 toolkit was utilized to simulate the interaction of photons with tissues and to evaluate the absorbed dose in a gastric adenocarcinoma tumor and healthy tissues around the tumor.

Materials and method:

The Geant4 is composed of a set of C ++ object-oriented programming classes and functions that can be used to simulate high-energy physics, astrophysics, nuclear physics, and medical physics experiments. In this program, there are a large variety of examples in the program, one of them is Human-Phantom which simulates the real body with organs and compounds such as water, bone, lung tissue, and soft tissue (Fig. 1). Adenocarcinoma is one of the common tumors found in the digestive system and stomach. In the MIRD phantom, the soft-tissue stomach is defined as a solid ellipse. To make it more realistic, we redefined the stomach as a 2cm thick oval shell and located a 1cm radius adenocarcinoma tumor inside it (Fig. 2).

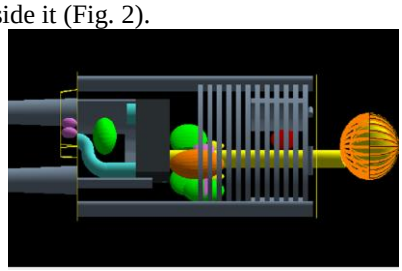

Figure 1. MIRD phantom shape in which the stomach is marked as an oval with a brown color

After that, silver and gold nanoparticles are loaded into the tumor and the body is located in front of an x-ray source. The concentrations of the spherical nanoparticles per medium mass are considered as 1, 2, and 3 wt%, and the size of nanoparticles are varied between 1 to 100 nm with the average diameter of 50 nm. The x-ray source is considered as a flat disk with a radius of 1 cm, which is located outside of the body and at a distance of 54cm from the tumor. It emits X-ray photons rays uniformly in the negative direction of the y-axis, towards the tumor.G4EmStandardPhysics-option3 electromagnetic class is used for the physics of interactions and consequently, absorbed dose in the tumor and other tissues was calculated in the absence and presence of the nanoparticles.

Results and discussion

The results showed that adding nanoparticles to the tumor increases the absorbed dose in the tumor, as expected. Figure 3 demonstrates that in the presence of silver

nanoparticles maximum absorbed dose is belong to concentration 30 mg/g and 45 keV photon energy.

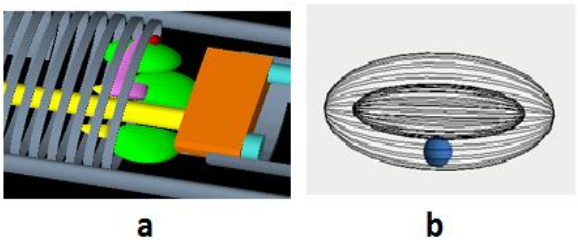

Figure 2. The location of the tumor (a) in the body (red sphere), b stomach wall.

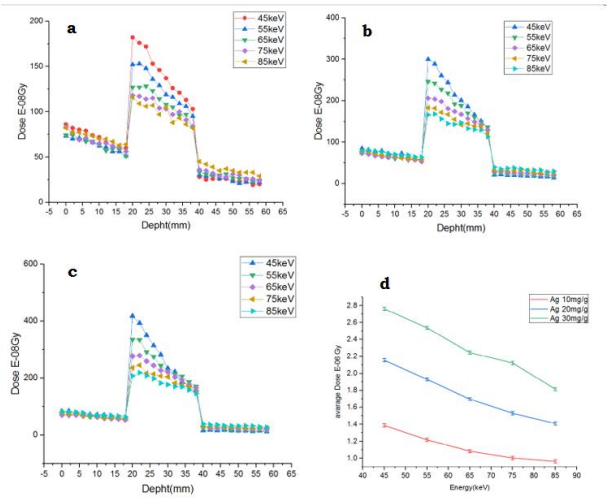

Figure 3. Absorbed dose in the tumor for (a) 10 mg/g, (b) 20 mg/g, (c) 30 mg/g silver nanoparticle. (d) mean absorbed dose in the tumor at all three concentrations.

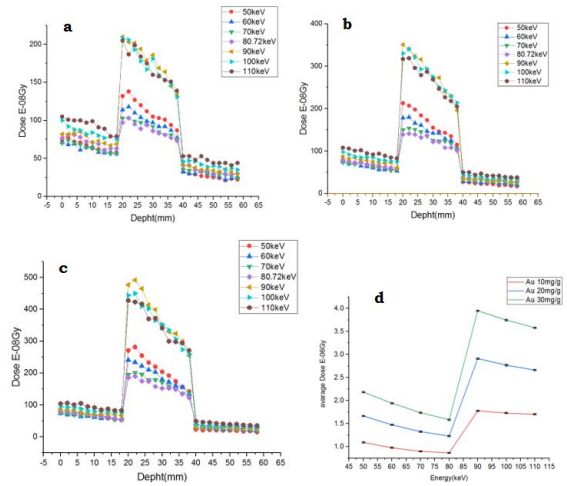

Figure 4. Absorbed dose in the tumor for (a) 10 mg/g, (b) 20 mg/g, (c) 30 mg/g gold nanoparticle. (d) mean absorbed dose in the tumor at all three concentrations.

Moreover, the same calculation has been done for gold nanoparticles in the same situations (Fig.4). After that, the Dose Enhencement Factors or DEFs (defined as following equation) in some other organs of the body for the concentration of 30 mg/g of silver in the tumor were calculated and the results are shown in Table 1. This will give us some information about the effects of peresence of the add nanoparticles in absorbed dose in some other organs.

$$DEf = \frac{Absorbed\ dose\ in\ a\ organs\ with\ Nps}{Absorbed\ dose\ in\ the\ organ\ without\ Nps}$$

Table 1. The DEFS in some organs of the body for 30 mg/g silver concentration at the different energies

	45keV	55keV	65keV	75keV	85keV
Brain	1.089	0.722	0.817	1.086	0.965
Left Kidney	0.74	0.827	0.883	0.921	0.942
Right Kidney	0.866	0.877	0.907	0.954	0.971
Left Adrenal	0.71	0.836	0.896	0.915	0.94
Right Adrenal	0.863	0.744	1.046	1.032	0.98
Upper LargeIntestine	0.839	0.885	0.911	0.93	0.958
Ribcage	0.94	0.951	0.955	0.964	0.975
Bladder	0.982	0.98	0.823	0.879	0.972
Spleen	0.703	0.812	0.874	0.91	0.94
Trunk	0.849	0.889	0.921	0.942	0.958
Stomach	0.856	0.897	0.928	0.948	0.962

Conclusions

because at the lower energies (0 to 100keV) the photoelectric effect is dominant, the highest cross-sectional occurs at the K-edge energies of the elements. The results show that the highest absorbed dose in the tumor for the silver nanoparticles is at the 45 keV and for gold nanoparticles is at the 90 keV incident photon energies, which are in the line with the expectation near the edge energy of the elements. So, the absorbed dose in the tumor is increased, though, the other organs in the body receive more radiation.

References

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