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Short Communication Open Access

Short Note on Our Research in Cancer: Cell and DNA Damage from the Point of View of a Medical Physicist

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Currently, there are approximately 80 million CT examinations [1] performed in the United States annually. This means that each patient is exposed to about 10^{13} photons/cm^2 during the CT scan and most photon and their secondary electrons have a kinetic energy, which is higher than the ionization potential of patients DNA in cells. To date, due to the increasing number of CT examinations worldwide, the risk of getting cancer has been further increased. According to the literature, direct action of ionizing radiation (e.g. direct cell hits) is seen as less important, because about 2/3 of DNA damage is originated by indirect action of ionizing radiation (e.g. hydroxyl radicals). However, the damage to human DNA by X-ray imaging is a stochastic and also a quantum mechanical process.Therefore, more theoretical and medical physicists should investigate this topic.

In our study on the direct action of ionizing radiation using the Monte Carlo (MC) simulation, target theory and probability rules, we found this branch of science plays a more important role as generally assumed, because the higher the number of cell hits in tissue the higher the risk of cancer would be. In contrast to the study on mummified cells [2], in this work the research was on the direct action of ionizing radiation on normal cells. To date, the different risks of cancer following CT examination can be calculated [3] as a function of age and sex. However, it is not yet clear which role the change of the tissue type around the cells, cell size or spacing plays in causing cancer.This study is focused on the following research question: what is the probability of hitting a cell and its DNA two or more times to produce irreparable breaks?

To quantify the risk of DNA damage we simulated CT scans at 80 and 120 kVp using MC methods. Eighty-five cell models (ellipsoids) were distributed by 3D self-avoiding random walks and placed in the isocenter of a CT scanner model [2]. The cell cluster was embedded in three different phantom tissues, for example, normal tissue (e.g. muscle tissue), dry tissue and cortical bone. We calculated the relationship between direct cell hits and risks of DNA damage using the extended multi-hit, single-target model (MHST) [4] under the assumption that DNA double-strand breaks (DSBs) take place by two radiation tracks.

Surprisingly, the calculated probability for DNA damage at 120 kVp X-ray tube voltage lies in the range of the additional cancer risk from 0.01 to 0.4% by CT imaging according to the online X-ray risk calculator [3]. Simulations at 80 kVp shows that cells embedded in cortical bone undergo significantly fewer hits (risk level ≈ 1 ppm) than cells in normal tissue. The reason for this phenomenon is the superficial build-up effect (maximum dose absorption), which protects deeper lying cells for radiation damage. It is important to note that, the risk of DNA damage depends also on the cell size and the tissue type around the cell. For example, the risk of DNA damage is p=0.0006 for larger cells (e.g. cell size 6×6×10 μm^3) and p=0.0001 for smaller cells (e.g. cell size 4×4×6 μm^3) in normal tissue at 120 kVp, where the Compton process is more dominant. Lowering of the tube voltage to 80 kVp however demonstrates that the risk of DNA damage depends mainly on the tissue density around the cells due to the dominant photoelectric process in this energy range.

Our study revealed that lowering the tube voltage to 80 kVp may reduce the risk of DNA damage significantly, however, only for deeper lying cells or cells embedded in high Z-tissue (e.g. cortical bone). Superficial cells (e.g. in muscle tissue) have a slightly higher risk of DNA damage (p_{80kVp} = 0.001, p_{120kVp} = 0.0006) at 80 kVp than exposed cells at 120 kVp. Oikarinen pointed out that 30% of all CT examinations were not justified [5] because they could be replaced by non-ionizing imaging modalities. The responsible use of CT scans in diagnostic radiology and the consideration of the ALARA principle (as low as reasonable achievable) may further reduce the risk of cancer following CT imaging.

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