Investigating radical damage on DNA by microscopic Monte Carlo simulation

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Purpose: Detailed tracking of water radiolysis radical diffusion and formation of low-energy electrons in DNA structure is important to calculate different types of radiation-induced DNA lesions. This information, however, might be ignored due to long simulation time. Here, we utilized the accelerated simulation package in our in-house GPU-based microscopic MC simulation package, gMicroMC, to investigate the effect of the hydration shell thickness on the formation of direct-type DNA damage and the number of radicals diffused from the hydration shell into each DNA component.
Method: We developed the hierarchical multi-scale DNA structure of a lymphocyte cell (Figure 1) in physics stage for particle transport and chemical stage for radical generation and diffusion. Tetrahydrofuran and pyrimidine were used for DNA backbone and base. DNA density was set to $1.7 g/cm^3$. Water radiolysis radicals were generated outside the DNA region at different hydration layer thicknesses. During the radical diffusion, DNA structure was overlapped with radicals every 10ps to determine the number of radicals scored into different DNA components. Comparative analysis of DNA damage distributions formed by 4.5-keV electrons were performed.
Results: DNA double strand break (DSB) yield increased with the hydration shell thickness. The number of DSB induced by 1 Gy dose deposition in the cell nucleus was 56, 65 and 76 for the hydration shell thicknesses of 0.08, 0.1 and 0.15 nm, respectively. The contribution of direct-type DSB increased to 56% and 59% at hydration shell thickness of 0.1 and 0.15 nm, compared to 54% at the thickness of 0.08 nm. The number of radicals diffused into different DNA components was linearly proportional to deposited dose but at different yields. G-values for hydrated electrons, hydroxyl, and hydrogen radicals in sugar-phosphate group were 0.28, 0.48, and 0.05, respectively. G-values for corresponding radicals in DNA base were 0.15, 0.11, and 0.02.
Conclusion: Calculation of different types of DNA damage based on stochastic nature of free radical reactions with DNA components is essential for the estimation of radiation biomolecular damage. gMicroMC supports the calculation of radical diffusion at nanoscopic level and estimation of radical yields reacting with each component of DNA molecules.

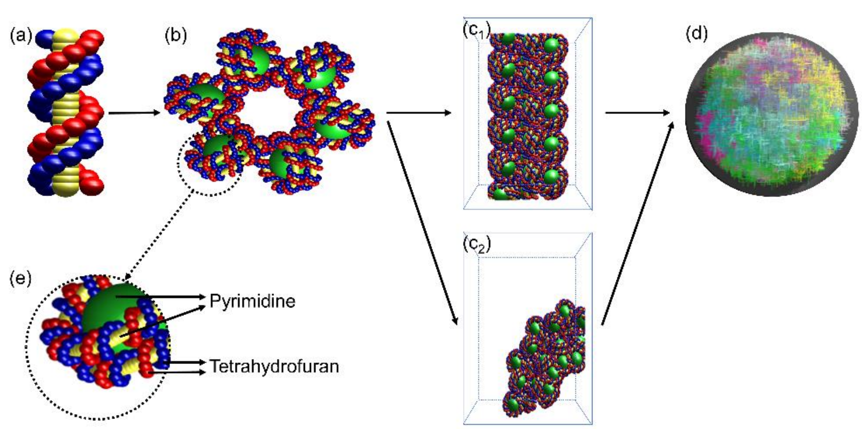

Figure SEQ Figure * ARABIC 1. Illustration of the DNA structure. (a) B-type DNA (b) chromatin fiber unit (c) two types of basic building blocks (d) whole DNA packed in a cell nucleus (e) zoom-in figure to show material assignment. Red and blue region: sugar-phosphate group; Yellow: base pairs; Green: histone protein

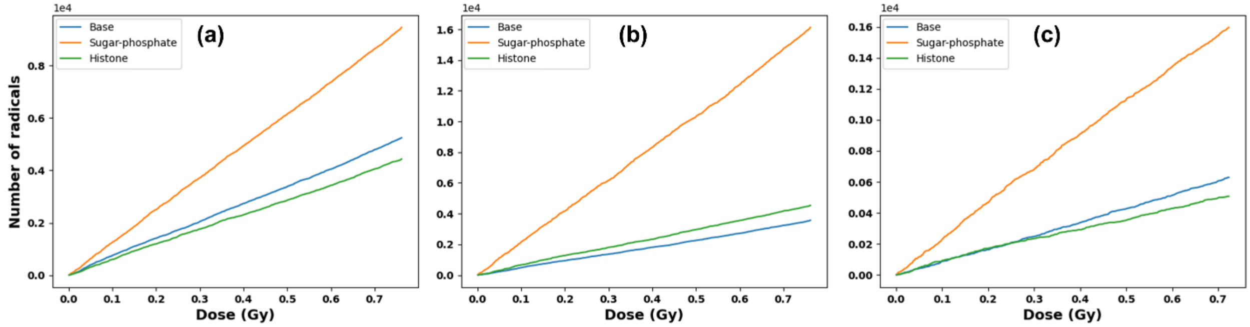

Figure 2. Number of radicals (a) hydrated electrons (b) hydroxyl (c) hydrogen colliding into different DNA components.