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Monochromatic X-ray imaging and diagnostics using nanomoities for biomedical applications

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Abstract

Conventional medical x-rays are produced by accelerating electrons through a cathode tube at a high-Z anode target metal, where they collide with atoms and emit photons in a broadband of energies up to the maximum potential energy as bremsstrahlung spectrum. However, the broadband output lacks specificity and precision; low-energy x-rays are likely to be absorbed by the skin or intervening tissue up to the targeted site inside the body for imaging or therapy, while the high energy x-rays in the broadband spectrum, typically close to 100 keV, become decreasingly efficient with energy since their interaction cross sections fall off rapidly [1]. New monochromatic and quasi-monochromatic x-ray devices, that have a single dominant energy rather than a broad range of energies, are now being developed. These devices would be a vast improvement over conventional x-ray machines because they would have the advantage of producing specific energies needed to activate electronic transitions in high-Z elements that may be employed for imaging or therapy, such as gadolinium and gold nanoparticles or platinum-based compounds such as cisplatin or carboplatin for chemotherapy.

In this study, broadband, monochromatic, and quasi-monochromatic x-ray sources and propagation through low and high-Z (atomic number) media were examined numerically and experimentally. To compare monochromatic and quasi-monochromatic x-ray sources against conventional broadband medical x-rays, we performed numerical simulations using Geant4 to study image contrast, depth of penetration, and total attenuation. Monochromatic and quasi-monochromatic x-rays achieved improved contrast at lower absorbed radiation doses compared to conventional broadband 120 kV or CT scans. In addition, physical processes responsible for X-ray photo-excitation and absorption were numerically modeled, including a novel mechanism for accelerating the Auger effect, which occurs when electrons drop from the outer 2p shell to the inner 1s shell and emit photons at characteristic Ka energy [2]. The schematics entail twin monochromatic x-ray beams tuned to inner-shell transition energies of high-Z atoms. Our data suggests this method increases the flux of emitted characteristic Kα photons and, when targeted at nanoparticles attached to cancer cells, may be capable of single- and double-strand breakups of the DNA and cell killing.

These studies also highlight the need for nanobiotechnological developments necessary for targeting and delivery of nanomoities to malignant cancer cells in particular, and for imaging and diagnostics in general, using high-Z contrast agents. Issues related to both therapy and diagnostics (theranostics) may therefore be addressed, such as chemo-radiation therapy using platinum nanovehicles.

[1] Lim, Sara N., et al. 2015. "Tumoricidal activity of low-energy 160-KV versus 6-MV X-rays against platinum-sensitized F98 glioma cells". J. Radiat. Res. 56:77-89.

[2] Nahar, Sultana N., and Anil K. Pradhan. 2015. "Kα resonance fluorescence in Al, Ti, Cu and potential applications for X-ray sources". Journal of Quantitative Spectroscopy and Radiative Transfer. 155: 32-48.