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Monte Carlo simulation of dose efficiency and image quality in X-ray Luminescence Optical Tomography

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A new hybrid imaging modality, x-ray luminescence optical tomography (XLOT), has been proposed to study problems related to deep-tissue preclinical imaging. In this technique luminescent nanoparticles emit optical photons when irradiated with a collimated x-ray beam. XLOT combines the high sensitivity of optical imaging and the high spatial resolution of x-ray imaging. We are currently building an XLOT prototype using SiPM photodetectors and a low energy x-ray tube. It uses submillimeter diameter collimators to produce an X-ray pencil beam to achieve high spatial localization of the luminescent nanoparticles. The use of this technique for small-animal imaging requires the determination of the dose delivered to the subject. Also, accurate knowledge of the energy deposition map inside the subject is useful for optimization of the optical imaging model used in the tomographic reconstruction. However, the use of a narrow beam of low energy X-rays complicates the use of traditional methods for the determination of the absorbed dose. In this work we report the calculation of the deposited energy distribution map by means of Monte Carlo simulation (PENELOPE v.2011) in the energy range 30-90 kVp. The results show that the dose scales linearly with kVp for a fixed concentration of luminescent nanoparticles and air-kerma rate and that the dose ratio for a 3 mm diameter insert containing 10 mg/ml Gd2O2S embedded in a 30 mm diameter water phantom is 6:1. This ratio drops to less than 2:1 for a 1 mg/ml concentration. The imaging performance of the system has been evaluated by means of simulations of the NEMA NU4 image quality and micro-Derenzo phantoms. The results indicate that quantification of the luminescent particle concentration deteriorates with object size, up to 80% when going from 5 to 1 mm diameter objects at 1 mg/ml concentration. The optical spatial resolution using 1 mm step size and 10 degrees angular step is of the order of 1.5 mm.
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Primary author: Dr MARTINEZ-DAVALOS, Arnulfo (Instituto de Fisica, UNAM)

Co-authors: Dr RODRIGUEZ-VILLAFUERTE, Mercedes (Instituto de Fisica, UNAM); Mrs ROSAS-GONZALEZ, Sarahi (Instituto de Fisica, UNAM)

Presenters: Dr MARTINEZ-DAVALOS, Arnulfo (Instituto de Fisica, UNAM); Dr RODRIGUEZ-VILLAFUERTE, Mercedes (Instituto de Fisica, UNAM)

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