Radiation Risk Assessment of using Gold Nanoparticles as Contrast Agent in Image-guided Radiotherapy: A Monte Carlo Study

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INTRODUCTION

In this study, we performed a radiation risk assessment regarding the increase of imaging dose with the incorporation of gold nanoparticles (AuNPs) in the kilovoltage cone-beam computed tomography (kV-CBCT) guided radiotherapy. This is important because variations of higher imaging doses are anticipated due to the enhancement of the photoelectric effect caused by the kV photon beams, predominantly when using heavy-atom or high atomic number materials. Although there are studies on the imaging dose estimation with variations of photon beam energy from the CBCT, and patient setup uncertainty without NP addition using Monte Carlo simulation [1-3], there is no related study on the increase of imaging dose due to applying AuNPs as contrast agent in the CBCT imaging. In this work, photon beams from the CBCT with various energies of 120, 130 and 140 kVp were stimulated using Monte Carlo method [4]. This was carried out to make accurate calculations of imaging dose enhancement for a phantom based on patient geometry and configuration with the addition of various NP concentrations in an IGRT system.

AIMS

The aims of this work are to (1) find out the relationship between the imaging dose enhancement and AuNPs incorporated into the phantom; (2) evaluate the relationship between the imaging dose enhancement and various AuNP concentrations; and (3) investigate the relationship between the imaging dose enhancement and various photon beam energies from the CBCT with AuNP addition.

METHOD

An oval shaped phantom with a horizontal radius of 28 cm, vertical radius of 20 cm, and thickness of 20 cm, was stimulated. The Monte Carlo simulation was performed using the EGSnrc code [5].

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- The Monte Carlo geometry included phase-space beams from a CBCT (XVI system, Elekta) irradiating a phantom [6] is shown in Figure 1.
- The concentration of AuNPs added into the phantom were 3, 7, 18, 30, and 40 mg/ml ,respectively.
- The 120-,130-, and 140-kVp photon beams were used in the stimulation.
- The absorbed imaging dose in the phantom was determined, and the imaging dose enhancement ratio (IDER), defined as the ratio of the imaging dose with addition of AuNPs to the dose without addition of NPs, was calculated using the following equation.

$$IDER = \frac{D_{(water+nanoparticles)}}{D_{(water)}}$$

RESULTS AND DISCUSSION

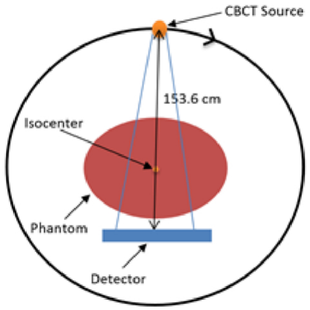

Figure 1: Schematic diagram showing the simulation setup of the phantom and CBCT X-ray source.

Figure 2: It is seen that the IDER increased with an increase of NP concentration. It should be noted that when the IDER is equal to 1, there is no NP added to the phantom.

Figures 3 and 4: Similar results and trend of variation between the IDER and NP concentration can be found in Figures 3 and 4 compared to Figure 2. In Figures 2, 3 and 4, it is found that the IDER increased with a decrease of photon beam energy from the CBCT.

In Figures 2, 3 and 4, the maximum IDER was found to be about 1.59 using the 120-kVp photon beam with concentration equal to 40 mg/ml. Based on the experimental imaging dosimetry of similar phantom irradiated by the CBCT beam [7], 0.67% increase of imaging dose was estimated as per the typical therapeutic dose of 2 Gy per fraction in radiotherapy. This radiation exposure is well within the standard uncertainty of delivery (±5%) [8].

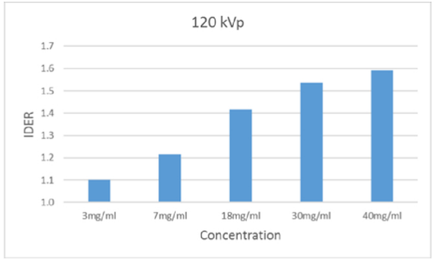

Figure 2: Relationship between the IDER and AuNP concentration with the delivery of 120-kVp photon beam from the CBCT.

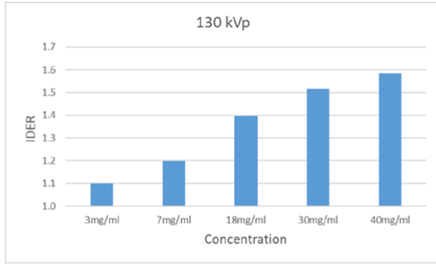

Figure 3: Relationship between the IDER and AuNP concentration with the delivery of 130-kVp photon beam from the CBCT.

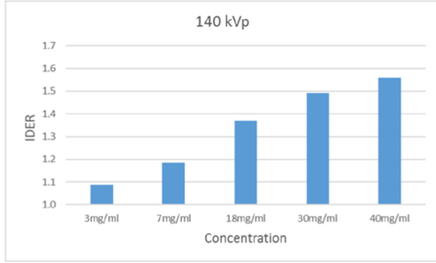

Figure 4: Relationship between the IDER and AuNP concentration with the delivery of 140-kVp photon beam from the CBCT.

CONCLUSIONS

The increase of imaging dose from the CBCT in NP-enhanced IGRT was determined using Monte Carlo simulation. The IDERs were calculated as a function of photon beam energy and NP concentration. It was ascertained that the higher the NP concentration, the higher the IDER there will be; and the lower the photon beam energy, the higher the imaging dose will be. Considering the maximum IDER of 1.59 for AuNPs with concentration of 40 mg/ml using the 120-kVp photon beam in this study, the increase of imaging dose was only about 0.63% to the prescription dose of 2 Gy in one fraction of delivery. This is within the uncertainty of a clinical radiation dose delivery (±5%).

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