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Real-Time, Ray Casting Based Scatter Dose Estimation for kV X-Ray Systems

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Radiation protection is very important part of modern medicine and involves not only the patient, but the staff as well. With new studies the understanding of tissue interactions with radiation increases and recommendations about occupational doses received by the staff change accordingly. Currently, there is no satisfying way to predict the dose to the staff before or while the medical treatment. A simulation of the dose distribution for different procedures can enable these predictions. Dosimetric control of staff exposure during interventional procedures under fluoroscopy is of high relevance. In this work, a novel ray-casting approximation (RCA) of radiation transport is presented and the potential and limitation vs. a full Monte Carlo (MC) transport and dose measurements are discussed.

The x-ray sources of a Siemens Axiom Artix C-arm and Elekta XVI CBCT are modelled by a virtual source model using Gaussian-shaped sources. Geant4-based Monte Carlo determines the radiation transport from the source to compute scatter from patient, intervention table, ceil and floor. A phase space around these scatter objects is erected, storing only photon information. In the ray-casting approximation (RCA), only those photons (from the phase spaces) are considered that hit the surface of a staff-representing phantom placed in the treatment room. Hereby, indirect scattering is ignored; and as approximation of the dose deposited on the phantom surface the complete photon energy is considered (ignoring partial absorption of this photon energy). In order to evaluate the accuracy of RCA, both experimental measurements using Thermoluminescent dosimeters (TLDs) and a Geant4-based Monte Carlo simulation of dose depositioning for different angulations of the C-arm and XVI CBCT from cranial-caudal angle 0° and from LAO 0°-90° are realized. Since the measurements are performed on both sides of the table, using the symmetry of the setup, RAO measurements are not necessary. The Geant4-Monte Carlo simulation agreed within 3% with measured data, which is within the accuracy of measurement and simulation. On average and for C-arm, x-ray head angulations between 45°-90°, RCA achieved a percentage difference of -5% with standard deviation of $\sigma = 0.00016$ vs. a Monte Carlo simulation. For LAO 90°, the percentage differences were between 0.5 - 3% on the side of the x-ray source where the highest dose usually detected was mainly from primary scattering (Photons), while a percentage differences between 2.8 – 20% on the side opposite to the x-ray source where the lowest doses detected. Dose calculation time of our approach was 0.85 seconds. The proposed RCA approach yields results that are approximating the Monte Carlo reference dose distribution in high-dose regions of ≥ 0.8 mGy within ≤ 3%. In low-dose regions, where multiple scatter events dominate, the approximation is not valid. However, in these low-dose regions, an accurate dose estimate is not really necessary since it is negligible relative to the exposure in the high-dose areas. Hence, RCA represents the option for real-time dose estimate for radiation control and radiation hygiene during an intervention. Since the dose distribution depends on a validated model of the x-ray source and uses concrete patient and treatment table as primary scatterers for the offline computed phase spaces, an individual dose scoring for each intervention is possible.