MONTE CARLO MODELING OF THE SCANNING BEAM DIGITAL X-RAY SOURCE (SBDX)

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INTRODUCTION

Planar x-ray imaging is widely used for diagnosing problems of the digestive tract, kidneys and gallbladder and for radiological interventions. Due to possible long imaging times, the dose to the patient from a single frame should be minimal. The scanning beam x-ray source (SBDX, Triple Ring Technologies, Fremont, CA) system uses the so-called inverse beam geometry, which employs a large-area x-ray source and a small detector position at a distance from the isocenter (**Figure 1**). The patient imaging dose of such a system is lower than that of a conventional geometry system[1,2]. The goal of this work was to develop a Monte Carlo (MC) model of the SBDX source and to evaluate the imaging dose to the patient. The MC method was used for dose calculations as it is the most accurate technique for estimating dose from kilovoltage x-ray beams.

METHODS AND MATERIALS

The SBDX source (**Figure 2**) was modeled for 80, 100, and 120 kV energies in the EGSnrc BEAMnrc MC code. The source consisted of 71×71 electron beams impinging on a tungsten transmission target and a tungsten/brass collimator with 100×100 circular collimator holes (**Figure 2**). All 5041 electron beams were simulated in separate runs, and the transmission target was modeled using the SLABS component module (CM). The collimator holes were approximated by octagonal openings and their divergence was modeled using 5 layers of BLOCK CMs. To shorten the simulation time, only 11×11 collimator holes in the vicinity of the electron beam of interest were modeled in each beamlet simulation (**Figure 3**). The model was validated against EBT Gafchromic film measurements. Three films were placed in between blocks of solid water at 1, 6, and 11 cm depths and measurements taken at 80, 100, and 120 kV. The irradiation times were adjusted in order to deliver approximately 1 Gy in the 1 cm-deep film for each tube voltage. A patient Monte Carlo simulation was performed in the EGSnrc/DOSXYZnrc code to evaluate imaging dose from the SBDX system.

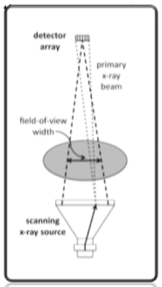

Figure 1: A schematic drawing of the SBDX source as used for fluoroscopic imaging.

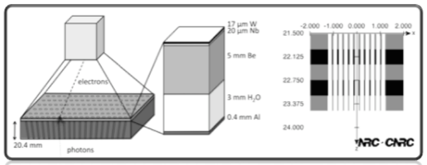

Figure 2: A schematic view of the SBDX source. The source is under a vacuum and enclosed with a 3.1 mm thick polyetherimide window. The collimator consists of divergent holes approximated by octagonal openings and five brass/lead layers of BLOCK component modules.

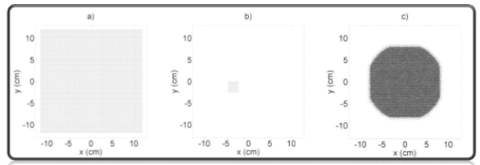

Figure 3: Full collimator geometry with 100×100 collimator holes (a) and with only 121 holes for more efficient simulations (b). The beam is incident on the central collimator hole in (b). The final distribution of the 120 kV photons in the phase-space file (c).

RESULTS

Simulated and measured dose distributions are presented in **Figure 4**. Dose profiles and depth dose curves are compared in **Figure 5** and **Figure 6**. The modeled spectra are shown in **Figure 7**. **Table 1** summarizes simulated and measured beam output values and half-value-layers (HVL). MC imaging dose in a patient is shown in **Figure 8**.

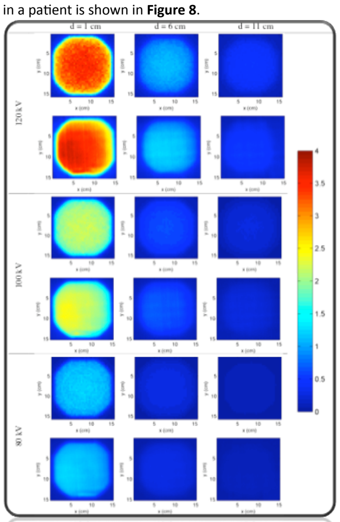

Figure 4: Figure: MC (upper row) and film (lower row) dose distributions at 1 cm (left), 6 cm (center), and 11 cm (right) depth for the 120 (top), 100 (middle), and 80 kV (bottom) beams.

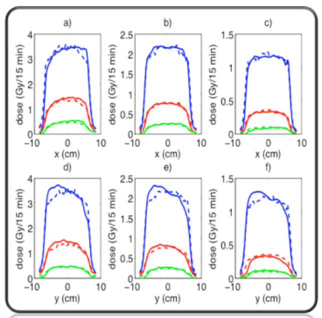

Figure 5: In-plane (a,b,c) and cross-plane (d,e,f) beam profiles for 120 kV (a,d), 100 kV (b,e) and 80 kV (c,f) at 1 cm, 6 cm and 11 cm depth for film measurements (solid line) and MC simulations (dashed line).

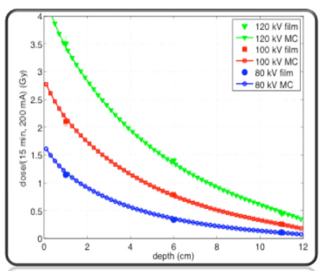

Figure 6: Central axis depth dose for a 15 min irradiation time with 200 mA as measured by films (markers) and as calculated by MC (lines) for 120, 100 and 80 kV.

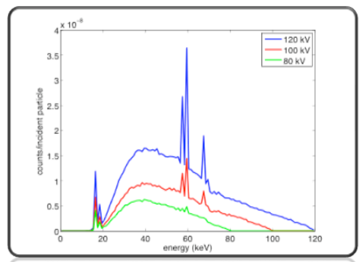

Figure 7: MC modeled energy spectra behind the polyetherimide window for 120, 100, and 80 kV beams. Note the K-lines of Nb at 16 and 18 keV.

Table 1: Simulated and measured HVL values. Measurements are for a previous version of the system with 14 μm target, simulations are for a 17 μm target.

	HVL (mm Al)		exposure rate (mR/min/mAp)	
	MC simulated	measured	MC simulated	measured
80 kV	3.29	3.03	24.5	23.0
100 kV	3.98	3.58	38.2	37.5
120 kV	4.56	4.06	53.0	56.5

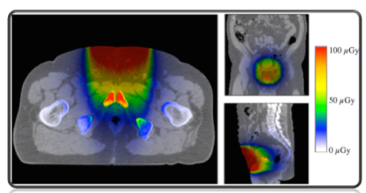

Figure 8: Fluoroscopy imaging dose distribution from a single frame image acquired with 120 kV, 23 kWp, and 15 frames/s.

CONCLUSIONS

The SBDX source has been modeled with the Monte Carlo method and validated against film measurement. The dose delivered to a patient with this low-dose imaging system has been evaluated. The skin dose for a single frame acquired with 120 kV was found to be 100 μGy, which is 3-6 times lower than a typical cineradiography.

ACKNOWLEDGMENTS

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REFERENCES

1. M. A. Speidel, B. P. Wilfley, J. M. Star-Lack, J. A. Heanue, T. D. Betts and M. S. Van Lysel, "Comparison of entrance exposure and signal-to-noise ratio between an SBDX prototype and a wide-beam cardiac angiographic system," Medical Physics **33**, 2728-2743 (2006).
2. M. A. Speidel, B. P. Wilfley, J. M. Star-Lack, J. A. Heanue and M. S. Van Lysel, "Scanning-beam digital x-ray (SBDX) technology for interventional and diagnostic cardiac angiography," Medical Physics **33**, 2714-2727 (2006).