Patient Dose From Kilovoltage Radiographic Images During Synchrony Treatments on the Radixact System

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INTRODUCTION

The Radixact system (Accuray, Inc., Sunnyvale, CA) contains an intrafraction motion management system called Synchrony, which uses planar kilovoltage (kV) images to track and compensate for target motion during treatment. These images are acquired at multiple angles every gantry rotation, therefore there is interest in quantifying patient doses associated with these images.

AIMS

1. Measure characteristics (HVL, N_k, point-dose) of three beam qualities commonly used for planar images on Radixact: 100, 120, and 140 kVp.
2. Develop a Monte Carlo (MC) model of the imaging system and benchmark the accuracy of the model using measured point doses.
3. Use the MC model to calculate volumetric dose for patients with disease sites that are likely candidates to be treated with Radixact Synchrony.

METHODS

TG-61 Point-Dose Measurements:

Half-value layers (HVLs) were measured using an A12 ion chamber and used to obtain air-kerma calibration coefficients from the UWADCL. Point doses (central-axis and off-axis) were measured in a water tank for open-field images [1].

Monte Carlo Model:

The Monte Carlo N-Particle (MCNP) transport code 6.2 was used to model the imaging system on Radixact. A point source of photons was used to generate the starting particles and the source was set at depth in the anode to approximate the heel effect. The photon spectra were generated with the MATLAB code Spektr.

Patient Dose Calculations:

Dose was calculated for five patient CT datasets using a mesh energy-deposition tally. Several properties of the calculations:

- CT and mesh dose voxel size <3x3x3 mm^3
- HU values discretized into 6 materials and 38 densities in MCNP
- 100 total images distributed at 4-5 angles
- Couch travel approx. by multiple sources
- Carbon fiber couch included in simulation
- Therapeutic target centered in bore
- Static field size at isocenter: 20x20 cm^2

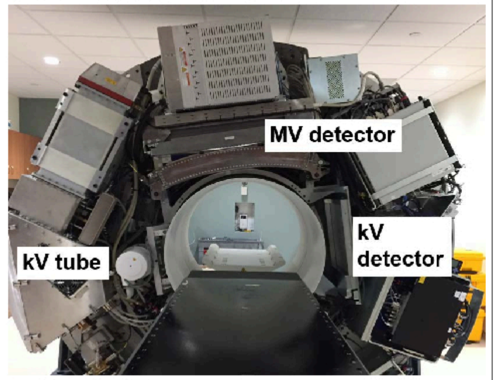

Figure 1. A Radixact system with the cover removed. The kV source is perpendicular to the MV source.

RESULTS

The MCNP model of the imaging system is shown in **Figure 2** and example comparisons between measured and simulated data are shown in **Figure 3**. The median dose difference between the simulated and measured point doses in water was less than 1% and the maximum difference of all points was 6%. The heel effect was sufficiently modelled by placing the photon point source at depth in the anode.

The imaging protocols used for Synchrony treatments on the Radixact have tube potential and time-current ranges of 100-140 kVp and 0.8-4.0 mAs. Reference point dose increases linearly with mAs and was found to increase proportional to tube potential by $kVp^{3.1}$. Therefore, patient dose is highly dependent on imaging protocol.

The calculated organ doses for each of the five patients are shown in **Table 1** and example CT datasets and dose distributions are shown in **Figure 4**. All doses are provided for 100 images, which is a typical number of images per fraction required for a Synchrony treatment. For all simulated patient mesh tallies, the median tally relative error (RE) for voxels with dose greater than 10% of D_{max} was 12% or less.

Chen et al. measured the $CTDI_w$ for the large thorax in a 30 cm phantom to be 8.4 mGy for 100 images distributed among 4 angles on Radixact [2]. The point dose at isocenter for the large lung patient with 100 images of the large thorax protocol was 8.8 mGy which agrees with Chen et al. considering differences in volumes.

The AAPM TG-180 report indicated that typical median organ doses from kV-CBCT images are 11.9-19.9 mGy and that the dose at the isocenter of a 30 cm phantom from a MV Tomo setup scan with normal pitch is 12 mGy [3]. The isocenter doses from 100 kV images of Radixact ranged from 4.1 – 10.9. Therefore, it is expected that dose from kV images during a Synchrony fraction will be less than dose from kV-CBCT or MV Tomo images.

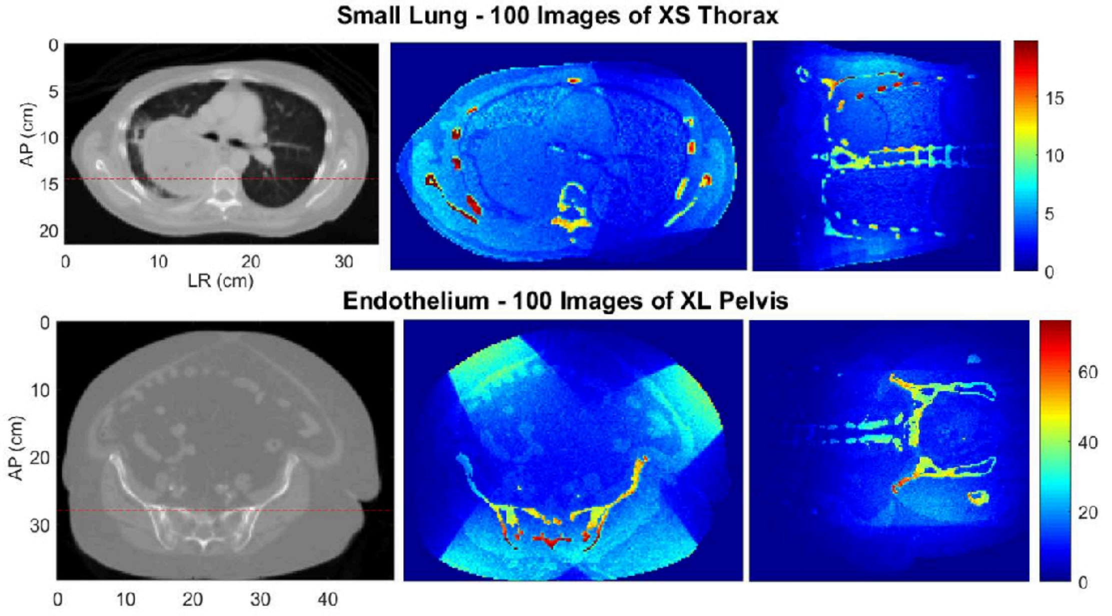

Figure 4. Example CT datasets and dose distributions in mGy from 100 images on the Radixact, calculated using MCNP. Four imaging angles centered around the target were simulated.

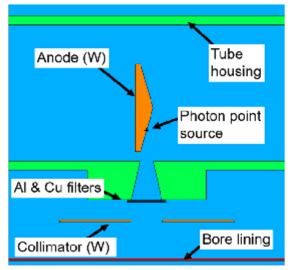

Figure 2. MCNP model of the imaging tube. The anode/cathode axis is parallel to the direction of table travel. The field size is 20x20 cm^2 at a source-to-axis distance of 57.5 cm.

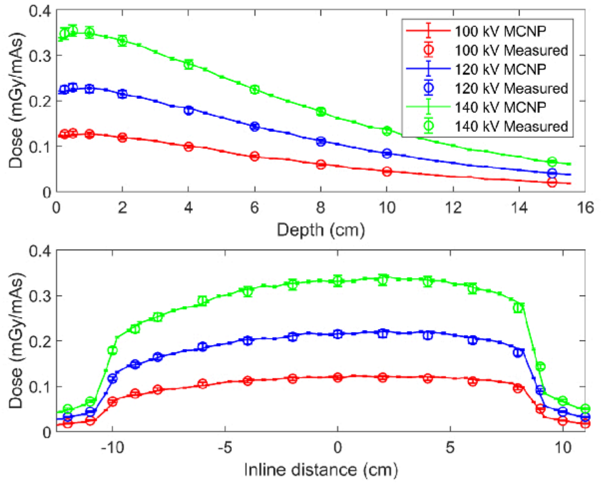

Figure 3. Comparison of measured and simulated point-doses. The heel effect can be observed in the inline profile. The crossline profile is symmetric.

Table 1. Patient dose from 100 images on Radixact calculated in MCNP. Imaging protocol is in italics.

Patient	D_{iso} (mGy)	Volume	$D_{50\%}$ (mGy)	$D_{10\%}$ (mGy)
Large Lung *L Thorax* *120kV, 1.6 mAs*	8.8	Heart	6.9	8.7
		Lungs	7.2	11.8
		Ribs	8.9	33.4
		Skin	1.5	11.3
		Soft tiss.	3.5	10.2
Small Lung *XS Thorax* *100 kV, 1 mAs*	4.1	Heart	3.2	4.4
		Lungs	3.1	4.8
		Ribs	4.7	15.0
		Skin	1.1	4.2
		Soft tiss.	2.0	4.4
Prostate *M Pelvis* *120 kV, 1.25 mAs*	6.3	Pub. Bone	12.6	19.6
		Prostate	5.3	6.3
		Rectum	6.1	7.4
		Skin	1.8	7.0
		Soft tiss.	2.6	6.6
Endothelium *XL Pelvis* *140 kV, 4 mAs*	10.9	Femurs	6.8	29.9
		Pub. Bone	25.4	52.0
		Rectum	12.6	16.5
		Skin	1.8	21.6
		Soft tiss.	4.6	18.4
Pancreas *L Pelvis* *120 kV, 2 mAs*	6.9	Liver	8.3	10.6
		Pancreas	10.5	12.2
		Skin	1.5	11.7
		Soft tiss.	3.0	10.7
		S. Cord	5.9	9.7

CONCLUSION

A MC model of the kV imaging system on the Radixact was created to calculate imaging doses for various subjects. The MC model accurately reproduced measured point doses. This work expanded the literature on patient kV doses on Radixact, which was previously limited to one measurement of $CTDI_w$ for one beam quality [2].

Patient dose was found to be highly dependent on imaging protocol and patient geometry. Median doses from 100 images were on the order of 2.0-4.6 mGy for soft tissue organs and 4.7-25.4 mGy for bony structures. Maximum dose ($D_{1\%}$) to bone reached up to 72.0 mGy. These doses are intended to be scalable estimates of patient doses for these treatments. Doses from 100 kV images on Radixact are expected to be less than typical doses from kV-CBCT images or from MV Tomo setup scans used on the Radixact.

Total patient dose may reach more than a gray for a large number of fractions and a large number of images per fraction at the high dose protocol. Careful planning and choice of imaging protocol can be used to minimize patient dose from kV images from these treatments.

REFERENCES

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