Estimation of 3D Imaging Dose for kV-MV-STR CBCT

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Introduction

•KV-MV scan time reduction (kV-MV-STR) is a cone-beam CT (CBCT) technique that reduces scan time by simultaneous acquisition with orthogonal kV and MV beams.

•The kV-MV-STR has comparable image quality while simultaneously reducing scan time. This could have important consequences for patient workflow, considering the frequent use of CBCT for setup and monitoring throughout a full course of radiation therapy. It also has potential application in breath-hold CBCT for motion management.

•However, the impact on dose of mixing an MV sub-arc with a kV sub-arc needs to be carefully evaluated along with image quality.

•This study compared the dose of conventional kV-CBCT with kV-MV-STR using Monte Carlo simulations.

METHOD

- A diagnostic CT scan of a thorax phantom was used to create a digital phantom volume for simulations.
- The Monte Carlo simulation software, GATE v7.2 (Geant4 application for tomographic emission), was used to execute the dose calculations.
- A 200° kV-MV-STR scan of a digitized thorax phantom was simulated (figure 2 left). The MV portion was simulated with a 2.5 MV source acquiring 181 projections over a 90° arc. The kV portion was simulated using a 125 kVp source acquiring 272 projections over the remaining 110° arc. Each projection was simulated with a number of primary photons equivalent to either 0.0025 MU for the MV arc or 1.5 mAs for the kV arc.
- A conventional kV-CBCT scan of the same thorax phantom was simulated using a 125 kVp source and 498 projections distributed over the same 200° total arc as kV-MV-STR (figure 2 right).
- 2.5 MV phase space source files generated from Varian's VirtuaLinac were used as the MV beam model. The equivalence between MU and the number of photons was established by simulating the experimental MU calibration process.
- The kV source model, shown in figure 1, consisted of an x-ray point source with a 125 kVp spectrum, blades for lateral and longitudinal collimation, a beam hardening filter, a bowtie, and detector housing. Real and simulated CTDI measurements were compared to find the equivalence between mAs and the number of simulated photons.
- The phantom dose maps were recorded for both scans, kV-MV-STR vs. kV-only, and compared.
- Measured versions of the simulated scans were also experimentally acquired on a Varian TrueBeam Linac equipped with a high-DQE four-layer imager, following the same scan protocols as in simulation.
- FDK reconstructions of the scans were compared. A previously proposed beam hardening correction algorithm with edge-preserving sinogram denoising was applied to the kV-MV-STR data set. Conventional water-equivalent beam hardening correction was applied to the kV-only data set.

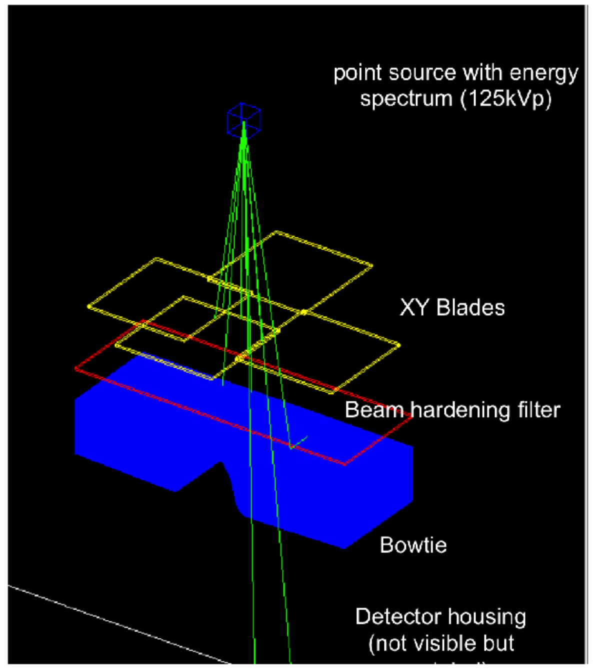

Figure 1. kV source model

Results

- The Monte-Carlo ***dose map calculation results*** are shown in figure 3. Imaging dose of two regions of interest (indicated by arrows in figure 3), one in the heart and one in lung, are listed in table 1.
- Dose profiles (indicated by dash lines in figure 3) across the ROIs are plotted on figure 3 right.
- The ***reconstructed images*** of the real acquisitions are shown in figure 4. Similar image quality is observed in the two reconstructions, with a slight reduction in bone contrast for kV-MV-STR. Both images showed approximately the same background noise at matched blur of the lung wall. The noise was 15 HU as measured in an ROI in the heart. Blur was equivalent to a gaussian filtering of an ROI at the lung wall with sigma=0.3 mm.
- The kV-MV-STR technique generally delivered lower dose than the kV-only scan.
- The reconstructed image quality for the two scans was comparable, with a minor reduction in bone contrast for kV-MV-STR.

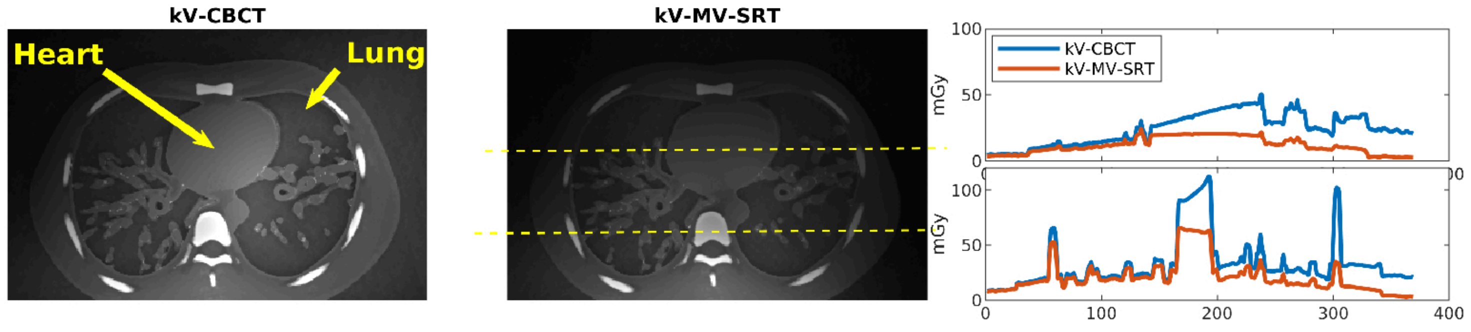

Figure 3. ***Simulated dose maps*** of the kV-CBCT (left) and the kV-MV-STR (middle) displayed under the same window level. Dose profiles across the heart and the bone are plotted on the right.

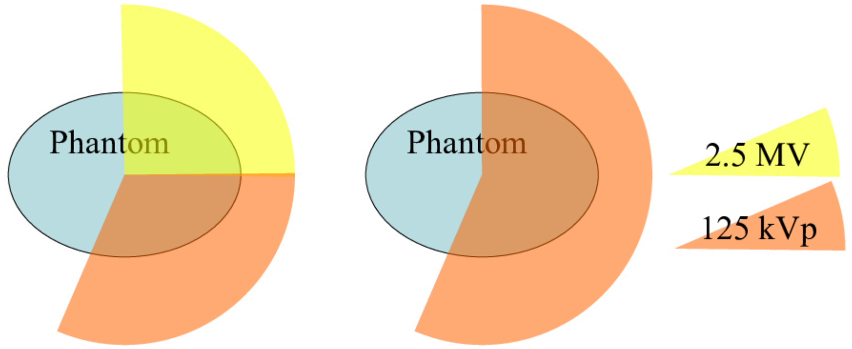

Figure 2. kV-MV-STR scan (left) and kV-only scan (right)

CONCLUSIONS

With comparable image quality, kV-MV-STR delivers less dose to the lung and the heart while simultaneously reducing scan time.

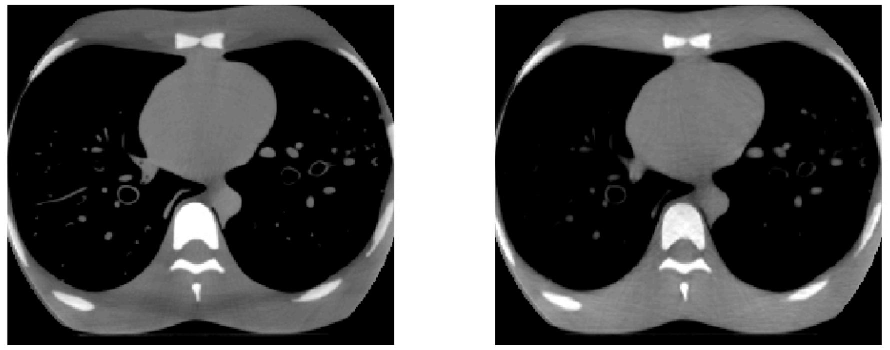

Figure 4 ***Reconstructed images*** of the kV-CBCT (left) and the kV-MV-STR (right)

Table 1. Image dose at different regions of interest

	Heart	Lung
kV-CBCT	36.85 mGy	26.6 mGy
kV-MV-STR CBCT	21.37 mGy	11.15 mGy

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