Equivalence of Single-Energy 120kVp and Dual-Energy 120kVp-like Virtual Monochromatic CT Images in Treatment Planning Applications

Jude A. Frie[1]; Vicky W. Huang[1]; Jorja Moore[1], and Brennen J. Dobberthien[1]
[1]BC Cancer, Surrey, BC, Canada

ABSTRACT

This project establishes the equivalence of 120 kVp-like virtual monochromatic images to 120kVp single-energy CT images in terms of electron density, image quality, and as applied to clinically representative external beam plans.

Images were acquired on GE Revolution™ Apex CT simulator. Three sets of scans were acquired for each comparison: 1) single energy at 120 kVp and 300 mA, 2) dose-matched (DM) 120 kVp-like with tube current set to produce equivalent $CTDI_{vol}$, and 3) noise-matched (NM) 120 kVp-like with tube current set to produce equivalent sampled standard deviation. Scans of RANDO phantom and MAX-HD™ phantom were used to create representative VMAT plans for brain, lung, and prostate in Varian Eclipse™. The same plan was applied to each scan type and region and compared.

Electron density curves derived from DM and NM, produced sampled relative electron densities 0.6±0.7% and 0.5±0.7%, respectively, of those from 120 kVp. All scans produced similar image quality in terms of geometric distortion (0.4-0.5 mm) and high contrast resolution (6.5-6.8 lp/mm). Low contrast detection was the same for 120 kVp and NM, and slightly better for DM images. Plans produced nearly identical DVHs, and plan sums showed minimal deviations.

This work confirms that plans made with the 120 kVp-like VMI reconstructions produced by the Revolution Apex CT simulator are clinically equivalent to standard scans.

CONTACT

Jude Frie
BC Cancer Surrey
Jude.frie@bccancer.bc.ca
Rm 1093, 13750 96 Ave, Surrey
(604) 930-2098 ext. 654734

BACKGROUND

- Dual-energy Computed Tomography acquires projection data at two distinct energy spectra[1]
- The two data sets enable generation of virtual monoenergetic images (**VMI**), virtual unenhanced images, images with advanced metal artifact reduction, and material density images, all of which have potential benefits in radiotherapy[1,2]
- To leverage these benefits without introducing workflow redundancies or compromising plan quality, image characteristics must be proven equivalent to conventional single energy protocol
- This study establishes equivalence of dual-energy 120 kVp-like VMIs to standard single-energy 120 kVp images using a rapid-kV switching platform. This is an important first step before incorporating further dual energy applications in clinical plans

METHODS

- Three sets of Images were acquired on GE Revolution™ Apex CT sim for each comparison:
  1. Single energy 120 kVp and 300 mA
  2. Dose-matched (**DM**) dual-energy 120 kVp-like with current set to produce equivalent $CTDI_{vol}$
  3. Noise-matched (**NM**) 120 kVp-like scan with tube current set to produce equivalent standard deviation sampled across the scan
- HUs were assessed with Sun Nuclear Advanced Electron Density phantom
- Image quality evaluated with Sun Nuclear IQphan™ and RapidCHECK™ software

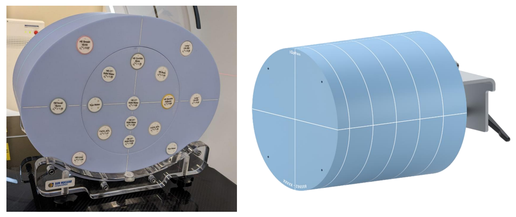

Figure 1: Sun Nuclear Advanced Electron density Phantom (Left) and IQphan™ (Right).

- Alderson RANDO phantom and Tecnosan MAX-HD™ phantom were used to create clinically representative VMAT plans for brain, lung, and prostate in Eclipse™
- The same plan was applied to each scan type and region and compared via plan subtraction and dose volume histogram (**DVH**) metrics

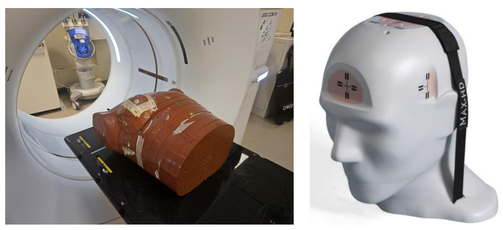

Figure 2: Alderson Rando phantom (chest and abdominal section; Left) and Tecnosan MAX-HD SRS Phantom (Right)

RESULTS

ELECTRON DENSITY

- Dose and noise matched scans produced curves that did not differ significantly (extra sum of squares F-test; F=-1.890, *p*=1.000), producing sampled electron densities within 0.6±0.7% and 0.5±0.7% of the single energy scan, respectively

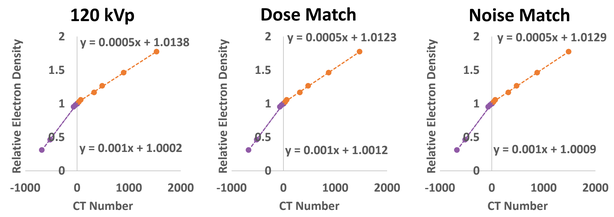

Figure 3: Electron density curves.

- Using the same 120 kVp curve, the DM and NM electron density values resulted in average error of 0.5%±0.7% and 0.5%±0.6% compared to 120 kVp
- Compared to true Electron densities, the 120 kVp curve already resulted in average error of 1.1% ± 1.2% for sampled values

IMAGE QUALITY

- Image quality was comparable between all scan, with slightly improved low contrast detection, noise, and uniformity in the dose matched scan

Table 1: Summary of selected image quality results. LCD – Low Contrast Detection.

Scan Type	$CTDI_{vol}$	Distortion (mm)	MTF (10%) Freq. (lp/mm)	Uniformity	Noise	LCD 0.3% (mm)	LCD 1% (mm)	LCD 2% (mm)
120 kVp	46.88	0.38	6.80	0.79	6.04	Not visible	7.3	3.5
Dose Match	46.98	0.44	6.63	0.65	5.66	22.4	6.5	3.1
Noise Match	42.68	0.45	6.46	1.19	6.16	Not visible	7.3	3.5

PLAN COMPARISONS

- Plans produced with all three image sets produced nearly identical DVH curves and dose differences

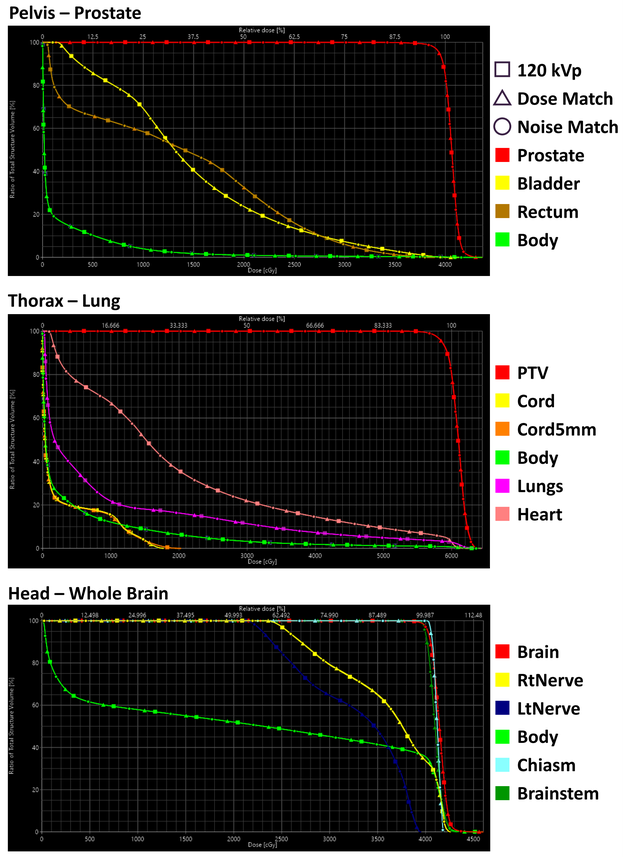

Figure 4: DVH curves.

Table 2: Summary of DVH metrics.

Plan Region	DVH Metric	120 kVp	Dose match	Noise match
Prostate	PTV V95% (%)	99.2	99.2	99.2
	Bladder V18Gy (%)	29.3	29.2	29.2
	Bladder V33Gy (%)	4.6	4.5	4.5
	Bladder V36Gy (%)	2.3	2.2	2.2
	Rectum V18Gy (%)	40.0	40.2	40.2
	Rectum V29Gy (%)	7.5	7.6	7.6
	Rectum V33Gy (%)	2.7	2.7	2.7
Lung	PTV V90 (%)	100.0	100.0	100.0
	Heart V30Gy (%)	25.3	25.2	25.2
	LungSubIGTV V20Gy (%)	16.3	16.3	16.3
	LungSubIGTV Dmean (Gy)	15.3	15.3	15.3
	Spinal Cord Dmax (Gy)	29.6	29.7	29.7
Brain	PTV V95 (%)	99.9	99.9	99.9
	Brainstem Dmax (Gy)	43.4	43.4	43.3
	Chiasm Dmax (Gy)	41.9	42.0	42.0
	RtNerve Dmax (Gy)	42.6	42.6	42.6
	LtNerve Dmax (Gy)	39.5	39.5	39.5

Table 3: Maximum plan subtraction differences. Greatest differences always observed at surface.

Region	Comparison	Difference (cGy)	Total Dose (cGy)	% of Total Dose
Prostate	120-DM	96.0	4000	2.4
Prostate	120-NM	42.1	4000	1.1
Lung	120-DM	232.8	6000	3.9
Lung	120-NM	187.8	6000	3.1
Brain	120-DM	342.4	4000	8.6
Brain	120-NM	341.4	4000	8.5

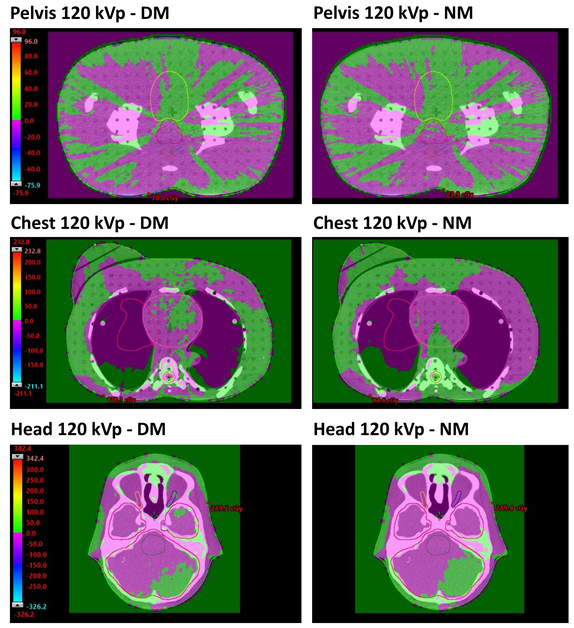

Figure 5: Plan subtraction dose colour washes.

CONCLUSIONS

- Compared to 120 kVp single energy conventional scans, 120 kVp-like virtual monoenergetic images show equivalent electron densities, image quality, and produce nearly identical plans
- This gives us confidence to investigate dual-energy for other potential clinical benefits without compromising plan quality or dose

REFERENCES

1. Slavic, S., Madhav, P., Profio, M., Crotty, D., Nett, E., Hsieh, J., & Liu, E. (2017). *GSI Xtream on Revolution™ CT. Volume. Spectral. Simplified.* [White paper]. GE Healthcare. Slavic, S., Madhav, P., Profio, M., Crotty, D., Nett, E., Hsieh, J., & Liu, E. (2017). *GSI Xtream on Revolution™ CT. Volume. Spectral. Simplified.* [White paper]. GE Healthcare.
2. Matsumoto, K., Jinzaki, M., Tanami, Y., Ueno, A., Yamada, M., & Kuribayashi, S. (2011). Virtual Monochromatic Spectral Imaging with Fast Kilovoltage Switching: Improved Image Quality as Compared with That Obtained with Conventional 120-kVp CT. *Radiology*, *259*(1), 257-262.