Building a Comprehensive 4DCT QA Program

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Introduction

Following the upgrade of one of our GE CT simulators to enable 4DCT acquisition, a comprehensive review of our institution's 4DCT QA program was done. Our center has 2 GE lightspeed RT 16 CT simulator as well as a one 4D PET/CT (GE Discovery 690) system all equipped with Varian's Real Time Position Management (RPM) system. All 4DCTs are binned in 10 phases for clinical purposes. While obtaining baseline data for the newly-commissioned 4DCT acquisition system, we compared results from the 3 CTs and established new quality control tests based on CPQR guidelines.

Methods

Two phantoms were scanned to determine the recommended quality metrics for all 3 scanners. Phantom scans were acquired with a thorax clinical protocol (120kVp) that consist of a helical static scan and a cine mode scan (with 5.6s cine duration and 0.3s cine time between images). 4DCTs retrospective reconstruction was performed with Advantage software (GE) resulting in 10 phase-binned CTs, a MIP and an average CT. All 4D phase binned images were compared with 3D static scans taken on each scanner as a reference. The results of three CTs were also compared with each other.

Quasar respiratory motion phantom (Modus QA) with a 30mm cedar insert was scanned in either static mode or set to move in a sinusoidal pattern with amplitude ±1cm and period of 3s and 4s. Figure 1 shows the phantom setup, and the insert with a mock tumour target. All of the scans were analysed as follows:

1) To determine the amplitude of a moving target as measured with 4DCT, the mock tumour within the cedar insert was contoured on all of the phase CTs in Eclipse (Varian, v13). The centre of mass of the ROI was then plotted for each phase to assess the total target motion.
2) Eclipse was also used to determine the mean CT number and standard deviation of moving target at each respiratory phase
3) To examine the spatial integrity and positioning of the moving target at each respiratory phase, an isotropic inner margin of 4mm was applied reducing the previously manually contoured ROI to avoid encompassing any ambiguous Hounsfield Unit (HU) regions at the edge of mock target as recommended by CPQR.
4) To determine whether Maximum and Average intensity projection (MIP and Ave-IP) captured the induced motion, a line profile was drawn in Eclipse to measure the diameter of the target in all 3 directions and compare it to the actual dimensions including motion. Expected values: 3cm in Ant/Post and Right/Left direction and 5cm in the Sup/Inf direction.

Catphan 504 (The Phantom laboratory) phantom was placed on an in-house moving platform as seen in Figure 2 and scanned static and with a ± 5mm amplitude and period of 3.5s. These scans were used for the following tests:

1) The low contrast resolution at each respiratory phase
2) The high contrast spatial resolution at each respiratory phase
3) 4D slice thickness (sensitivity profile) at each respiratory phase

Analysis was manually performed on Eclipse for the first 2 tests while an in-house software for Catphan image quality analysis was used to measure the slice thickness.

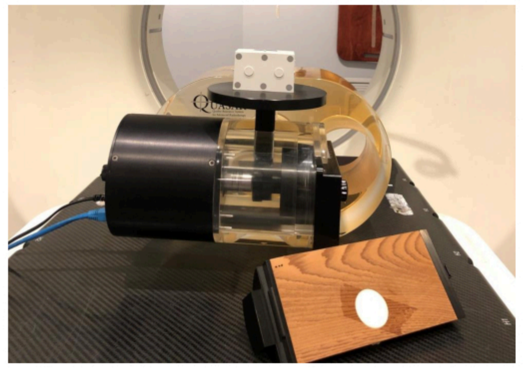

Figure 1. Quasar respiratory motion phantom with a 30mm cedar insert

Figure 2. Catphan 504 phantom on an in-house moving platform

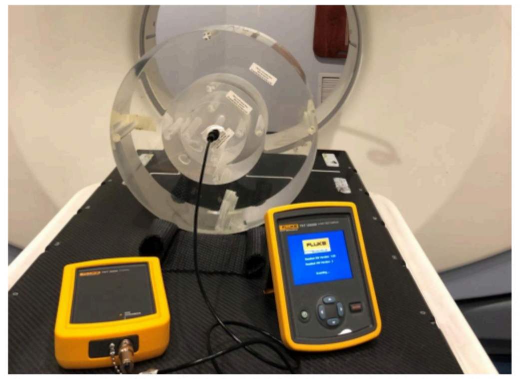

Figure 3. 32cm CTDI phantom with Fluke TNT 12000 Dosemate

Both phantom scans were used to assess the following 3 tests:
1) Functionality of the 4D reconstruction
2) Functionality of the data import into the treatment planning system
3) The amplitude and periodicity of surrogate with monitoring software and/or CT console

Finally 4D-CTDI measurements were performed using a 32cm **CTDI phantom** (Figure 3) with a Fluke TNT 12000 DoseMate and a 10cc Pencil Chamber system with 4D scan settings as above. 4D-CTDI values were compared among scanners as well as with those calculated by GE under scan parameters.

Results

Amplitude of a moving target measured with 4DCT

The amplitude of motion of the ROI as contoured in Eclipse was 2cm ± 2mm (range 1.8-1.94), which is within CPQR guideline for a breathing period of 4s on all the scanners. Figure 4 shows position of the ROI in all directions for the binned images.

The scan with a breathing period of 3s reported a maximum motion discrepancy of 4mm on one scanner which is more than the recommended accuracy of 2mm indicating possible limitations of the scanner for fast breathers.

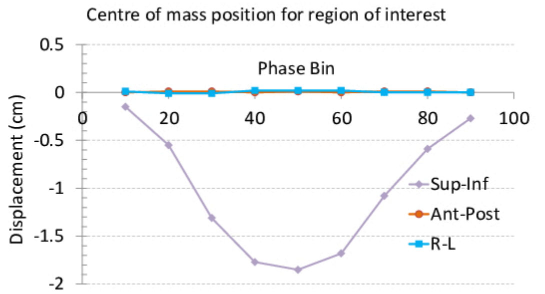

Figure 4. Motion of the center of mass of the lung insert ROI manually contoured in 4DCT for all 10 phases for a moving platform of ± 1cm

Mean CT number and standard deviation of moving target at each respiratory phase

For 4D scans with T=4s, for all scanners the differences in the mean HU of an ROI on the static scan and the same ROI contoured on a phase scan were within the CPQR recommendation of 10HU or 10% variation for phase bins: 0,10,40,50,60 and 90. Conversely, variations up to 25HU were seen in phases: 20, 30, 70 & 80. This is expected as these bins include images where the ROI velocity is highest.

Spatial integrity and positioning of the moving target at each respiratory phase

The maximum difference between the measured and actual amplitude was 3mm for two scanners and 4mm on the third scanner. The average difference in expected versus measured position over all phases was 1.4 mm ±0.1mm for all 3 scanners. The CPQR guideline of 2mm discrepancy from baseline was not met in CT20 phase image for one scanner, CT90 for the 2nd scanned and CT10 and CT90 phase images for the third scanner.

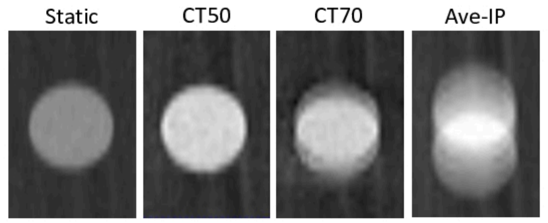

Figure 5. ROI in different reconstructions

4D-CT intensity projection image reconstruction (MIP, Ave-IP)

MIP and Average scan for all 3 scanners for both breathing periods showed the expected size in all the directions which included the sup-inf motion, as seen in Figure 5, within 1mm accuracy. This was well within the 2mm CPQR recommendation.

Low contrast resolution at each respiratory phase

Low contrast resolution could only be detected at the supra-slice 1.0% level but that level was maintained in all respiratory phases as recommended by CPQR for all scanners compared to the helical scan used as baseline. No significant difference in low contrast resolution was observed between the scanners.

High contrast spatial resolution at each respiratory phase

The standard helical scan had 7 line pairs/cm for two of the scanners for both static CT and phase-binned 4DCT scans (Figure 6). The PET/CT helical scan had a spatial resolution of 6 lp/cm while the 4DCT phases spatial resolution varied from 6 to 7lp/cm. All scanners met CPQR guideline.

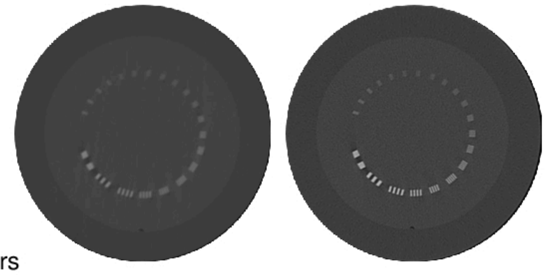

Figure 6. Line pairs indicating spatial resolution in the static (left) and CT0 binned CTs

4D slice thickness (sensitivity profile) at each respiratory phase

Results obtained for slice thickness are plotted in figure 7. Measurements were accurate within the recommended ±0.5 mm CPQR guideline for all 3 scanners at only phase 0 while the maximum difference was up to 5.9mm for other phases.

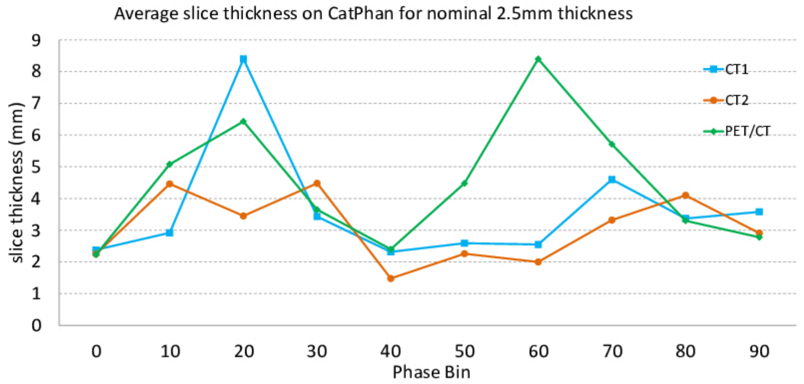

Figure 7. Slice thickness for 4DCT phases calculated using Catphan geometry slice

Amplitude and periodicity of surrogate with monitoring software and/or CT console

The RPM surrogate system reported the motion amplitude and breathing period for all the acquired scans within the 1mm and 0.1s CPQR recommendation.

4D-CTDI Measurement

CTDI measurements on the 3 scanners differ by an average of 3.34% (range: 0.18-8.5%) compared to the manufacturer value. CTDI values were within expected limits of ±10% as per CPQR recommendation.

Conclusions

A comprehensive 4DCT program was successfully implemented, however adhering to all CPQR guidelines proved challenging for the some metrics. The uniformity of HU within a specific region did not adhere to CPQR guidelines as well as the slice thickness accuracy that could not be maintained in all 4D phases.

Some metrics had mixed results, such as the amplitude of the moving target which was accurately represented for a breathing period of 4s but could not meet CPQR guidelines for a 3s period.

In addition the spatial integrity and positioning of the moving target was only accurate in 7/10 phases for all the scanners.

Other metrics met all the CPQR recommendation: the low contrast resolution, the high contrast spatial resolution, the amplitude and periodicity of the surrogate system and all the CTDI measurements.

Further interrogation of HU noise in 4D scans along with a possible change in cine parameters for shorter breathing periods is warranted. CPQR recommendations are difficult to comply with but metrics recorded can be used as future baseline for periodic monitoring.

References

Després P, Gaede S. COMP report: CPQR technical quality control guidelines for CT simulators. *J Appl Clin Med Phys.* 2018;19(2):12-17. doi:10.1002/acm2.12213

Mutic S, Palta JR, Butker EK, et al. Quality assurance for computed-tomography simulators and the computed-tomography-simulation process: report of the AAPM Radiation Therapy Committee Task Group No. 66. *Med Phys.* 2003;30(10):2762-2792. doi:10.1118/1.1609271

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