Development of a Phantom for Quality Assurance of Deviceless 4DCT

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose:
Deviceless 4DCT (D4D) reconstruction relies on changes to patient anatomy, such as lung volume or external contour to generate a pseudo respiratory trace which is used to bin 4DCTs for use in radiotherapy planning. This poses a challenge due to the lack of anthropomorphic QA phantoms that undergo physiological motions. Here we present a solution in the form of an in-house constructed phantom.

Methods:
A truncated cone was designed in SolidWorks and 3D printed on a Prusa XL 2T with PLA filament. Once in motion, the phantom's shape provided a longitudinally changing contour needed for D4D. The phantom's centre comprised 3 Catphan CTP504 Modules which allows standard CT tests to be performed as part of our 4DCT QA. The phantom assembly was placed on a CIRS motion platform programmed to move 1 or 3 cm sinusoidally in the cranio-caudal direction with a 4s period, meant to mimic respiratory motion. An RPM marker block was placed on the stage of the motion platform to capture the motion with an external surrogate. A clinical abdomen 4DCT was captured and reconstructed to generate 10 respiratory bins and a static CT was captured for baseline.

Results:
The in-house phantom provided the necessary geometry for D4D to succeed. Catphan analysis showed that all bins, maximum intensity projection (MIP) and average CT were equivalent using D4DCT vs Respiratory Gating for Scanners (RGSC)-based 4DCT. This included HU accuracy, low and high contrast spatial resolution, and positional integrity of moving targets. Visually, D4D exhibited more motion blur and streak artifacts in the phase bins, the clinical impact of which is difficult to quantify.

Conclusion:
A simple yet elegant solution is proposed to complement our QA program that facilitates the use of already established tools for use of D4D QA.

INTRODUCTION

Deviceless 4DCT provides several advantages over systems that rely on an externally generated respiratory trace. This includes no reliance on secondary software and patient devices and potentially better management of reconstructing images with irregular breathing patterns[1]. Deviceless 4DCT (D4D) reconstruction relies on changes to patient anatomy, such as lung volume or external contour to generate a pseudo respiratory trace which is used to bin 4DCTs for use in radiotherapy planning[2]. To facilitate the appropriate respiration-induced geometric changes, this work presents a 3D printed phantom that contains components of a QA phantom used in routine CT QA.

METHODS AND MATERIALS

Phantom Fabrication and Implementation

A truncated cone was designed and 3D printed on a Prusa XL 2T with PLA filament. The design also included a 3D printed ball for use in testing positional accuracy. The 3D printed phantom accommodated the insertion of several modules facilitating various image quality tests that came from an obsolete dismantled Catphan phantom. The phantom was placed on top of a CIRS motion platform, programmed to move 1cm or 3cm sinusoidally in the cranio-caudal direction with a 4s period. The in-house phantom's shape provided a longitudinally changing contour needed for D4D.

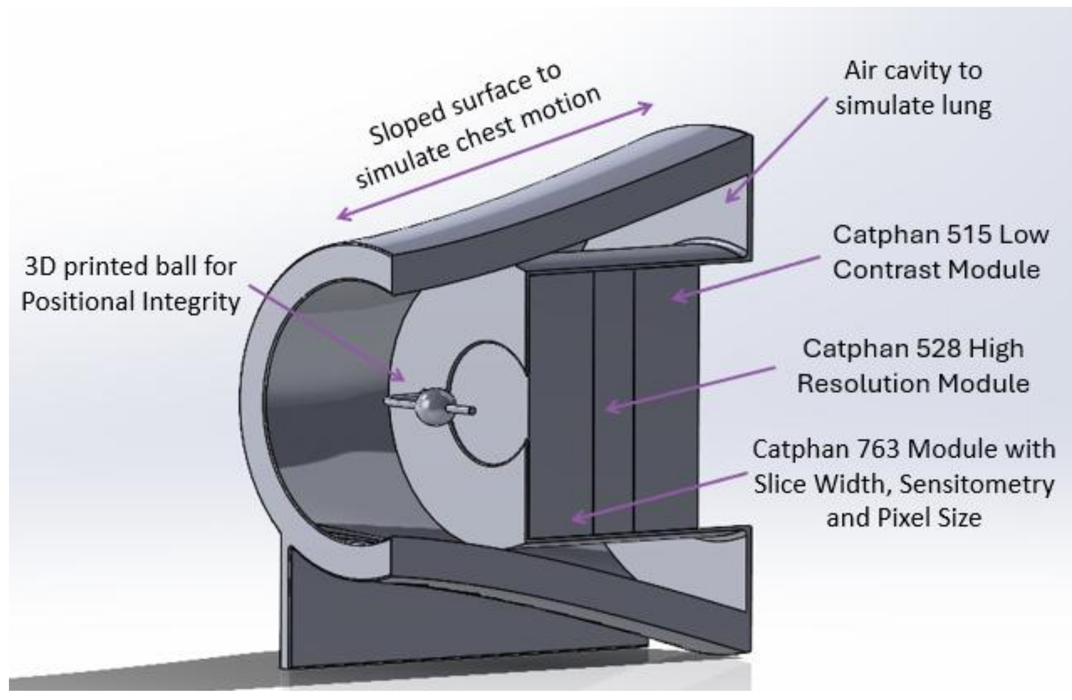

Figure 1. CAD image of in-house created phantom with Catphan modules and positional accuracy insert.

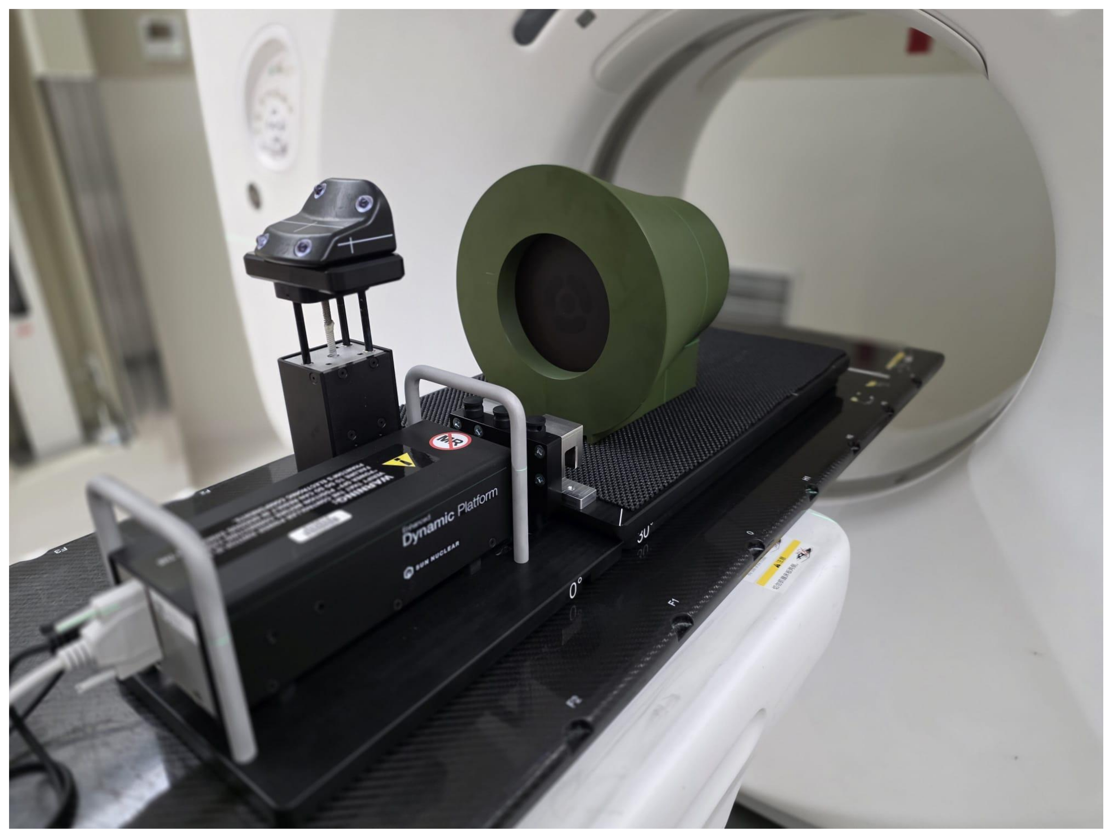

Figure 2. In-house phantom on top of the CIRS motion platform.

CT Scan

A GE Discovery RT CT Simulator was used to acquire all CTs with 2.5mm slice thickness. A static CT was performed in addition to 4DCTs reconstructed in two ways:

1. Using retrospectively binned data based on a externally captured trace, using Varian RGSC software. Images were binned using GE's Advantage 4D software that incorporates RGSC trace
2. Using the *Deviceless* module of GE's Advantage4D software that relies on changes in external and internal anatomy of the object scanned to bin data.

A MIP and AVE were generated in addition to 10 respiratory phase binned images for both reconstruction types.

Analysis

Images were imported into Eclipse (Varian, v18) for a part of the analysis. The variable density inserts were assessed in Eclipse to determine average HU (Air, Teflon, Delrin, Acrylic, Air, Poly, LDPE, PMP).

The ball ROI was consistently contoured on all phase binned images to determine estimated peak-to-peak motion and total amplitude as well as the amplitude within each bin compared to programmed phantom motion.

Images were also visually analysed to determine the low and high contrast resolution. Finally general image quality was assessed for streaking or artifacts.

RESULTS

D4D was successfully performed with our in-house phantom. The ball ROI contouring resulted in a total amplitude of 0.9cm and 2.7cm for the two reconstructions when a 1cm and 3cm motion was applied to the platform. The 3cm amplitude fails the TG179[3] ±1mm tolerance equally for both reconstructions. The positional integrity of the ball ROI results are displayed in Figure 3. For reference, the expected motion range in each bin, based on the surrogate, is shown in green.

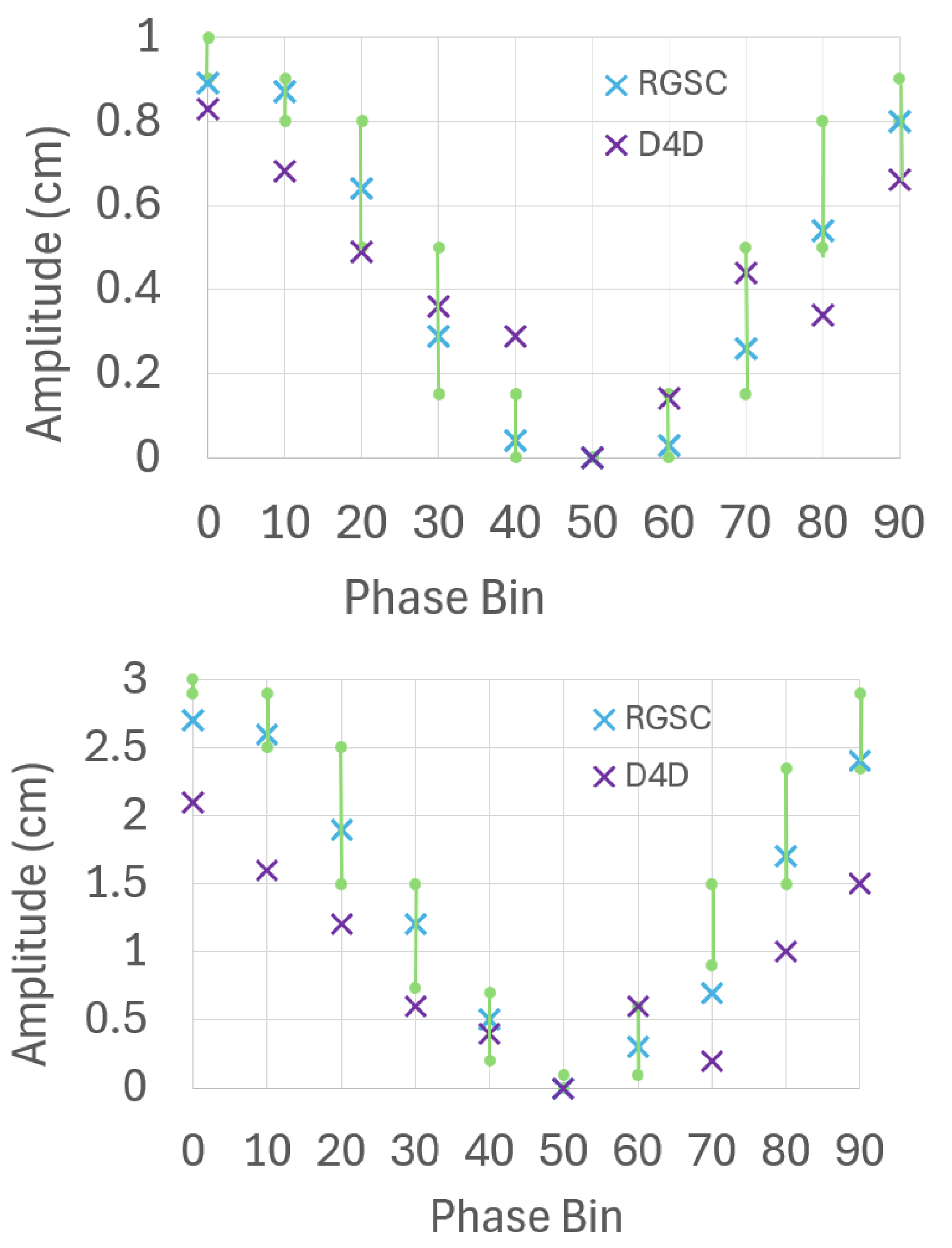

Figure 3. Contoured ROI centroid position as based on Eclipse. Green bars show expected position based on external RGSC surrogate position in bins 10-90.

Low contrast resolution as well as high contrast spatial resolution for 4D phase binned images was equivalent to the static 3DCT for both RGSC and D4D 4DCTs. All scans static and 4D for both 1cm & 3cm motion using both reconstruction resulted in measured HU for all the density modules within ±50 HU of the expected HU except for Teflon that failed in all scans. The MIP and Average scan equally passed the ±50 HU tolerance for the RGSC and Deviceless reconstruction for the 1cm motion and equally failed for the 3cm motion. Visual Image quality assessment resulting in D4D with slightly more reconstruction artifact for both 1 and 3cm as shown in Fig 3 and 4.

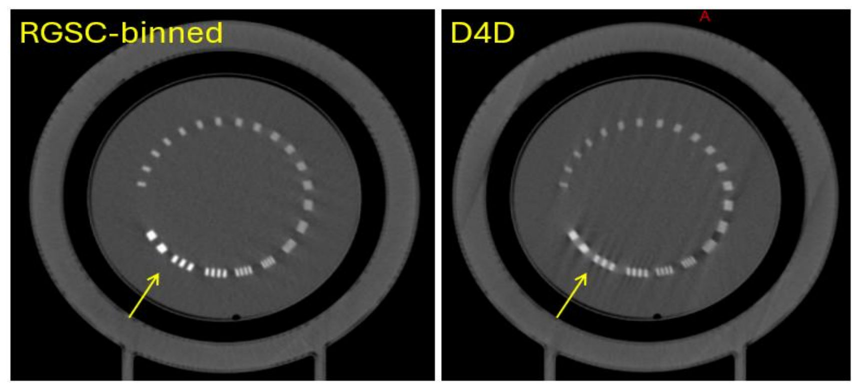

Figure 4. CT50 binned image reconstructed with RGSC and D4D showing increased streaking in D4D reconstructed image for 1cm of motion

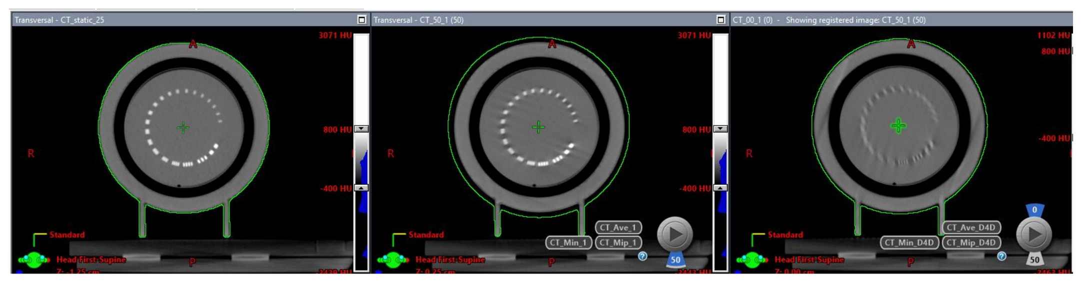

Figure 5. Helical scan (left) and CT50 binned image reconstructed with RGSC (centre) and D4D (right) showing increased streaking in D4D reconstructed image for 3cm motion

DISCUSSION

Annual Quality control of 4DCT scans is recommended as per TG179[3], however this task wasn't possible at our institution when scans were reconstructed with Deviceless 4DCT and no commercial phantom solutions were available at the time. Other groups have demonstrated the feasibility of creating in-house phantoms that enable D4D[1]. To our knowledge, this is the first D4D phantom that incorporates a well established image quality device (Catphan) to enable easy QA testing of imaging systems. Although our analysis was manual, commercially available Catphan analysis software could be utilized for quick analysis.

CONCLUSION

A successful prototype device was designed in our institution allowing for annual quality control to be performed on Deviceless 4DCT scans as per TG179[3] recommendation. Further work will focus on automating analysis. Image quality was non-inferior to RGSC-reconstructed 4DCTs and comparable to 3DCTs. Spatial position integrity remains hard to assess due to the D4D algorithm using its own trace and binning system. D4D artifacts warrant further exploration.

REFERENCES

1. Tillery H, Windsor C, Aguilera C. Commissioning evaluation of a deviceless 4DCT scanner. J Appl Clin Med Phys. 2025;26(5):e70048. doi:10.1002/acm2.70048
2. Smart Deviceless 4D : GE white paper on deviceless reconstruction
3. Bissonnette JP, Balter PA, Dong L, et al. Quality assurance for image-guided radiation therapy utilizing CT-based technologies: a report of the AAPM TG-179. *Med Phys.* 2012;39(4):1946-1963. doi:10.1118/1.3690466

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