The James
The Ohio State University
Wexner Medical Center

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

Quantitative Quality Assurance of 4DCT Volumetric and Motion Accuracy Using the QUASAR™ Respiratory Motion Platform and a Custom Phantom

Hayden Trent Sobas, Zachary X. Richards, Julia M. Pakela, PhD, Michael D. Weldon and Estelle Batin, PhD, Department of Radiation Oncology, The Ohio State University Wexner Medical Center, Columbus, OH

ABSTRACT

Purpose: Four-dimensional computed tomography (4DCT) is crucial for defining target volumes and calculating plans for motion managed radiation therapy; however, it is susceptible to binning errors, reconstruction artifacts, and motion blurring. A clinically relevant 4DCT quality assurance (QA) protocol was created to assess the uncertainty within the system. The goal of the experiment is to find how well 4DCT can preserve the volumetric accuracy, spatial localization, and system functionality across two identical scanners and 4DCT acquisition types.

Materials and Methods: Two SOMATOM go.Open Pro (Siemens Healthineers) with Respiratory Gating for Scanners (RGSC) (Varian) systems with continuous (helical) and intermittent (axial) 4DCT capabilities were evaluated. A QUASAR Respiratory Motion Platform Phantom (Modus Medical, IBA) was used in conjunction with a custom acrylic insert and a golf ball phantom to simulate a breathing patient with a target volume. Each scanner was assessed for calibration on the infrared (IR) camera system as well as volumetric accuracy and spatial localization consistency of the phantom.

Results: The RGSC IR camera calibration test passed within the manufacturers' recommended tolerance. The spatial localization consistency had a mean value <1 mm from the known range of motion. The average volumetric accuracy was within 5% of the baseline volume.

Conclusion: The collected data reinforced trust in the accuracy of 4DCT while providing valuable insights into underlying uncertainties within the system. Clinically, this information can be used to assess other CT simulators using 4DCT and ensure the fidelity of the reconstructed 4DCT images.

CONTACT

Hayden Trent Sobas
The Ohio State University Wexner Medical Center
460 W. 10th Ave., Columbus, OH 43210
soba06@osumc.edu
865-244-7817

INTRODUCTION

A major source of uncertainty in radiation therapy is intrafraction motion. Four-dimensional computed tomography (4DCT) is the standard for motion management[1,2]. However, inaccuracies in the scans could arise due to binning errors, artifacts, or motion blurring[3]. It is important to account for and quantify these uncertainties[4]. Although 4DCT is frequently used, no AAPM task group exists regarding 4DCT QA on CT scanners[5]. This study presents a framework for assessing the spatial volumetric accuracy of a 4DCT system using commercially available phantoms and software.

METHODS AND MATERIALS

Scans were acquired on two Siemens SOMATOM go.Open Pro scanners equipped with Varian Respiratory Gating for Scanners (RGSC). Continuous helical 4DCT and intermittent axial (i4DCT) acquisition types were both evaluated. All scans were acquired using 2 mm slice thickness to match the existing clinical protocol for the institution. A QUASAR™ Respiratory Motion Platform was used to generate motion in the craniocaudal direction with a synchronized respiratory breathing trace. A golf ball mounted onto a custom acrylic insert was fixed onto the QUASAR platform to serve as a known volume target that mimics a tumor in motion (Figure 1). The platform moves ± 2 cm from its origin, corresponding to a 4 cm total range of motion[6].

A static 3D CT scan was taken to establish a baseline of the reconstructed volume. For repeatability, five helical and five i4DCT acquisitions were performed at 15 breaths per minute (BPM) on each scanner. The results were analyzed and calculated using a user created MIM workflow that automatically identifies and contours the phantom across the static 3D scan, the ten phases of the helical 4DCT, and the ten phases of the i4DCT. The range of motion is calculated using the centroid location of the contour and the volumes are gathered from the contour statistics.

The RGSC system was verified by shifting the surrogate reflector block by a known distance and confirming the console registered the same value[7].

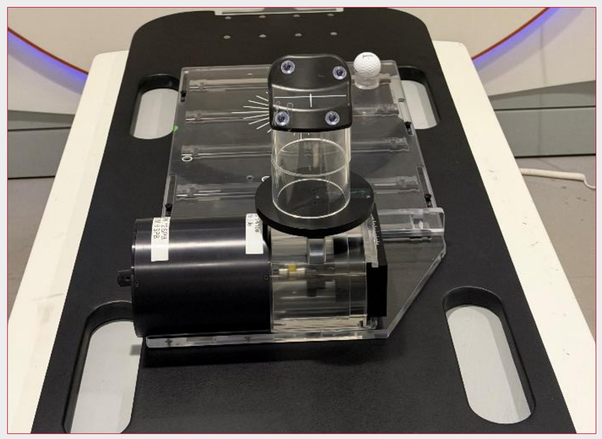

Figure 1. Setup of the golf ball phantom and QUASAR respiratory motion platform.

RESULTS

Spatial Localization

- **Figure 2** displays results for the individual trials in the spatial localization consistency test.
- The mean measured range of motion across the five trials was **3.93 ± 0.02 cm** for helical 4DCT and **3.91 ± 0.03 cm** for i4DCT.
- The largest errors that occurred were **0.12 cm** for helical 4DCT and **0.15 cm** for i4DCT.

Volumetric Accuracy

- **Figure 3** displays results for the volumetric reconstruction accuracy test.
- The mean static baseline volume was **42.53 ± 0.01 cm³**.
- The mean reconstructed volume was **42.63 ± 2.59 cm³** for helical and **42.76 ± 2.18 cm³** for i4DCT.
- The average absolute difference in individual phases from the static baseline was **4.11 ± 1.62%** for helical 4DCT and **3.71 ± 0.97%** for i4DCT.
- The largest measured percent differences from the baseline volume were **18.76%** and **5.04%** for the helical and i4DCT scans respectively.

RGSC Functionality

- Five RGSC infrared (IR) camera validation measurements were performed on each scanner.
- Every measurement was within the manufacturer's recommended tolerance of 2 mm[8].

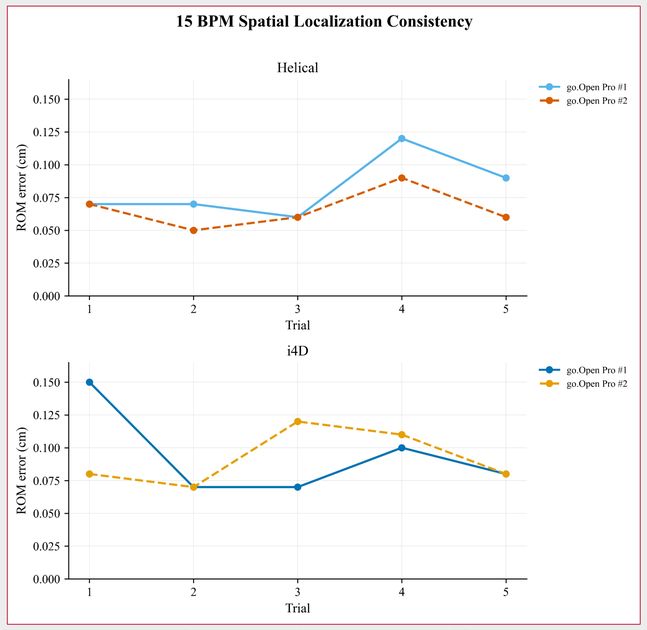

Figure 2. The range of motion (ROM) error on every trial for both 4DCT acquisition types and scanners from the spatial localization consistency test.

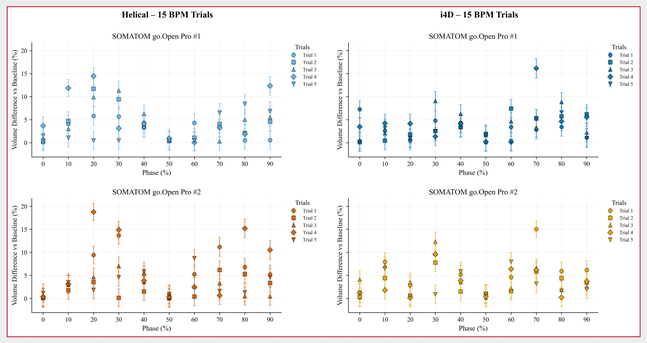

Figure 3. The volume difference from the baseline for each phase across the trials for both 4DCT acquisition types and scanner

DISCUSSION

The developed 4DCT QA demonstrated reproducible results between two different Siemens SOMATOM go.Open Pro scanners for both helical and i4DCT acquisition types. Spatial localization consistency demonstrated excellent performance across scanners and acquisition types with the mean range of motion found to be within 1 mm of the known range of motion. For the volumetric reconstruction accuracy test, the results highlighted that the mean percent difference from the baseline volume was about 5%. These findings support the accuracy of 4DCT derived target volumes. Some individual respiratory phases exhibited increased variability and occasional outliers, particularly during periods of high velocity. However, these deviations were largely averaged out across the full respiratory cycle, resulting in accurate overall volume representation for the average. The RGSC IR camera validation test met the manufacturer tolerance of ±2 mm on both scanners. Overall, these findings establish confidence in the clinical use of 4DCT while providing an assessment of system performance. The recommended QA tests, tolerances, and frequencies are shown in **Table 1**.

Test	Tolerance	Frequency
Spatial Localization Consistency	±1.5 mm	Commissioning/Annual
Volumetric Reconstruction Accuracy	5%	Commissioning/Annual
IR Camera Validation	±2 mm	Monthly

Table 1. 4DCT quality assurance program tests, tolerances, and frequency.

CONCLUSIONS

An efficient QA protocol with automated analysis was developed to assess different types of 4DCT scans performance across spatial localization, volumetric reconstruction accuracy, as well as the functionality of the system. The results showcased reliable performance that enforces confidence in the use of 4DCT. After multiple trials and cross-validation between two different scanners with identical configurations, tolerances and frequencies for the test were estimated. This framework provides a practical method for routine QA that may be adapted.

REFERENCES

1. Y. Yang, et al., "A streamlined workflow for comprehensive 4DCT imaging QA with automated analysis of spatial integrity and image quality," J. Appl. Clin. Med. Phys., vol. 26, no. 8, p. e70168, 2025.
2. P. J. Keall, G. S. Mageras, J. M. Balter, et al., "The management of respiratory motion in radiation oncology: Report of AAPM Task Group 76," Med. Phys., vol. 33, no. 10, pp. 3874–3900, 2006, doi: 10.1118/1.2349696.
3. M. Burghelea, J. Bakkali Tahiri, J. Dhont, et al., "Results of a multicenter 4D computed tomography quality assurance audit: Evaluating image accuracy and consistency," Phys. Imaging Radiat. Oncol., vol. 28, p. 100479, 2023, doi: 10.1016/j.phro.2023.100479.
4. J. I. Choi, et al., "Sharpening the particle knife: The evolution of ultra-precise proton therapy," Ther. Radiol. Oncol., vol. 5, 2020.
5. Modus QA, QUASAR Programmable Respiratory Motion Platform HD – User's Guide, Mar. 2022.
6. C. Shi, X. Tang, and M. Chan, "Evaluation of the new respiratory gating system," Precis. Radiat. Oncol., vol. 1, pp. 127–133, 2017, doi: 10.1002/pro6.34.
7. Varian Medical Systems, Respiratory Gating for Scanners (RGSC) – Instructions for Use, Version 2.0, P1047784-003-C, Apr. 2024.
8. J. Bakkali Tahiri, M. Kyndt, J. Dhont, et al., "A comprehensive quality assurance program for four-dimensional computed tomography in radiotherapy," Phys. Imaging Radiat. Oncol., vol. 27, p. 100475, 2023, doi: 10.1016/j.phro.2023.100475.

© Poster Template by Genigraphics® 1.800.790.4001 www.genigraphics.com