Acceptance Testing and Evaluation of the RGSC – Respiratory Gating for Scanners

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Abstract

The Respiratory Gating for Scanners (RGSC) system, developed by Varian Medical Systems, is an advanced accessory designed to enhance the precision of diagnostic imaging and radiation therapy by synchronizing image acquisition with the patient's respiratory cycle. By continuously monitoring and recording respiratory motion, RGSC provides essential data for tumor tracking, motion management, and treatment planning. The system is compatible with CT and PET-CT scanners from leading manufacturers, including Canon, GE, Philips, and Siemens, ensuring seamless integration into various clinical workflows. With an intuitive user interface and enhanced gating accuracy, RGSC plays a crucial role in improving tumor targeting, image quality, and overall treatment outcomes. This study presents our experience with acceptance testing and quality assurance (QA) of the RGSC system integrated with a GE Discovery RT Wide Bore (80 cm) CT simulator, outlining key performance evaluations and validation protocols. The findings serve as a reference for optimizing RGSC implementation in clinical practice while ensuring compliance with established motion management guidelines.

Keywords: Tumor Motion Tracking, 4D CT Imaging, Radiation Therapy, Quality Assurance, RGSC System, Motion Management, Computed Tomography, Respiratory Motion Management In Radiotherapy, Respiratory Gating, VCD(Visual Coaching Device).

Introduction

Precise and accurate radiation therapy is essential for successful treatment outcomes, relying on accurate target localization and patient positioning. Quality assurance (QA) of the systems responsible for localization and positioning is therefore of paramount importance. The complexities of radiation oncology treatment are further amplified when managing respiratory motion.

Our institution has recently implemented the Respiratory Gating for Scanners (RGSC) system from Varian Medical Systems. While the American Association of Physicists in Medicine (AAPM) has provided guidance on respiratory motion management QA in reports such as TG-76,[1,3,9] 142, and 147, specific procedures for the RGSC system are currently lacking.

TG-emphasizes the need for regular testing of the respiratory motion management device's functionality and its integration with peripheral equipment, including CT scanners. TG-142 (Klein et al.) recommends testing phase, amplitude, and gating interlocks, and specifies a 100 ms temporal accuracy tolerance for phase/amplitude gating on linear accelerators, though not CT simulators. TG-147 (Willoughby et al.) offers detailed information on testing the integration of the respiratory gating device with other equipment, spatial reproducibility and drift, static and dynamic localization accuracy, and vendor-recommended assessments. Despite this valuable guidance, detailed QA procedures tailored to the RGSC system remain to be developed.

The RGSC system incorporates several design changes compared to the previous Real-time Position Management (RPM) system from Varian. These include a redesigned reflector block for the CT simulator and updated camera hardware and software. These differences necessitate the development of new, specific QA methodologies. Our clinic recently installed an RGSC system on a GE Discovery RT Big Bore 4D CT simulator. Following acceptance testing and subsequent investigation, we present our findings and detailed QA methods for the RGSC system. This study is intended to serve as a valuable reference for future RGSC users.

Methods and Materials[2, 10, 11]:A newly installed Respiratory Gating for Scanners (RGSC) system (Varian Medical Systems) was tested in conjunction with a recently installed GE Discovery RT 4D CT Big Bore 16-slice CT scanner (GE HealthCare Technologies). A Gammex 3 green moving external laser system (Sun Nuclear) provided the alignment reference. The RGSC QA process utilized a dynamic 4D phantom (Varian Breathing Phantom) and a Gating Marker Block.

This study focused on the acceptance and commissioning of the RGSC system specifically for the GE Discovery RT 4D CT Big Bore CT simulator. However, the described procedures should be readily adaptable to other CT scanner models.

Acceptance test[2, 5]: Acceptance testing followed vendor recommendations (Table 1). Initial steps included verifying the RGSC software version (1.7 or higher via the software information button), confirming correct scanner settings and camera type in the software configuration tab, and establishing connectivity with the ARIA (version 16.1) record and verify system. Hardware and software connection with the CT scanner was also tested. Camera motion position accuracy (within 2 mm) was verified by millimeter-scale reflector block movements. Successful export of recorded breathing curves and patient DICOM files to a local or shared drive was confirmed. Finally, the acceptance document was signed by both a local physicist and a Varian representative. These steps ensured proper RGSC system configuration and functionality, establishing a reliable foundation for clinical use.

Table 1: Acceptance tests of RGSC

Task	Purpose	Expected result
1	Camera Mount Installation Verification for Wall/Ceiling Mounted	verified
2	Software version	Software version ≥1.7
2	Scanner vendor and camera type	Scanner manufacturer should be verified and camera type is correct
3	Integration with ARIA system	ARIA is higher than version 13
4	Calibration of camera	Pass
5	Integration with scanner	Hardware connection and software control
6	Camera motion position	accuracy in 3D ≤2 mm

7	File can be exported to destination	File can be exported to destination
8	Export patient into database	File can be exported into the database
9	DICOM file can be exported	DICOM file can be exported
10	Documents	User related documents are available from vendor
11.	VCD(Visual Coaching Device) Couch Mount can be attached to the CT couch top. VCD shows the course of the tracked marker block.	Pass

Camera Mount Installation Verification for Wall/Ceiling Mounted[2,5,6]

Camera (for GE Scanner Installation only):it is important to verify that the wall- and ceiling-mount camera is firmly mounted, and that the camera bracket and anchoring screws have paint marks applied.

Wall-Mounted Camera Verification: After launching the RGSC application and logging in with authorized user credentials, select Verification > Calibration from the main menu. Place the marker block without the breathing phantom at the isocenter and click OK on the RGSC Verification procedure. Verify that the RGSC application prompts "Verification passed" and record the results in the data table.

Camera Calibration:Launch the RGSC application and log in with user credentials. Select Calibration from the main menu. Place the marker block without the breathing phantom on the couch top within the camera's view and align the marker block to the lasers. Click OK on the RGSC Calibration procedure. Verify that the RGSC application prompts "Calibration passed" and record the results in the data table.

QA of integration with peripheral Equipment: The integration of the RGSC system with peripheral equipment, including the R&V system and CT scanner, should be thoroughly checked. A dry run test was conducted by scanning a breathing phantom and sending the images through the Digital Imaging and Communications in Medicine (DICOM) protocol to the R&V system.

The RGSC system offers four different scanning modes: "4D Scan[8]," "Phase Gating," "Amplitude Gating," and "Breath-hold Gating." The "4D Scan" mode was tested by programming a breathing phantom with a reflector block to follow a sinusoidal breathing cycle with a 5-second period, then performing a CT scan. The trigger signal from the RGSC system was synchronized with the CT scanner, allowing the 4D scan to be carried out. The CT scanner was able to reconstruct images with the correct breathing phases using the breathing curve file recorded by the RGSC system.
For "Phase Gating" and "Amplitude Gating," similar procedures were followed. The breathing phantom with the reflector block was used, and the trigger signal was synchronized with the CT scanner during scanning. The CT software then generated the correct image set using the trigger signal file.All these CT scans were successfully completed with the RGSC system, and the intended image sets were reconstructed.

Motion Position Indicator Accuracy for CT with Wall/Ceiling Mounted Camera[4,6,7]:
The RGSC system will accurately display a marker block positional shift as follows:

AP axis: ± 10%(2.0 cm move = 1.8 – 2.2 cm indication)
LAT axis: ± 10% (2.0 cm move = 1.8 – 2.2 cm indication)
LNG axis: ± 10% (2.0 cm move = 1.8 – 2.2 cm indication)

To test this, launch the RGSC application and log in with the appropriate user credentials. Select Verification > Calibration from the main menu. Position the marker block without the breathing phantom on the couch top at the isocenter and press OK. Note the VRT, LNG, and LAT averaged positions of the isocenter on a separate sheet of paper. Move the couch top 2.0 cm lower (vertical), press Restart, and click OK on the following screen without moving the marker block to the isocenter. The message "Verification failed" is expected, as the marker block is intentionally not placed at the isocenter. Calculate the VRT axis difference (current VRT reading minus the isocenter VRT position noted) and record the results in the data table.

Next, move the couch top 2.0 cm to the back (longitudinal), press Restart, and click OK on the following screen without moving the marker block to the isocenter. Calculate the LNG axis difference (current LNG reading minus the isocenter LNG position noted) and record the results in the data table. Then, move the couch 2.0 cm to the left (lateral), press Restart, and click OK on the following screen without moving the marker block to the isocenter. If the couch top cannot be moved laterally, move the marker block manually on the graph paper in the lateral direction, using the lines on the graph paper as a reference to move the marker block exactly 2 cm. Calculate the LAT axis difference (current LAT reading minus the isocenter LAT position noted) and record the results in the data table. Figure 2 shows the test setups.

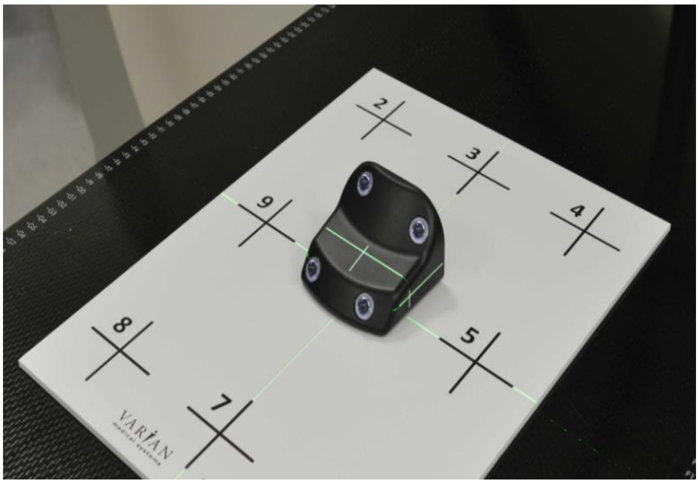
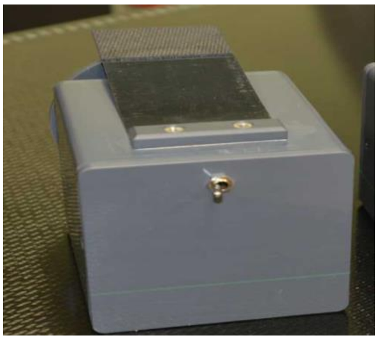


Fig.2: Marker Block

QA of dynamic localization accuracy[4, 6, 7, 10]:Dynamic localization accuracy was assessed by programming the breathing phantom to move sinusoidally with periods from 1 to 10 seconds. The RGSC software measured and recorded inspiration and expiration values for comparison. Figure 3 shows the breathing phantom setup and a screenshot of the measured values.



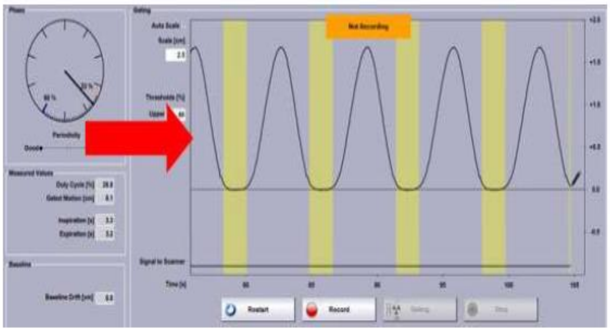


Figure 3: a) Breathing Phantom Figure 3: b) Gating Window displays breathing pattern

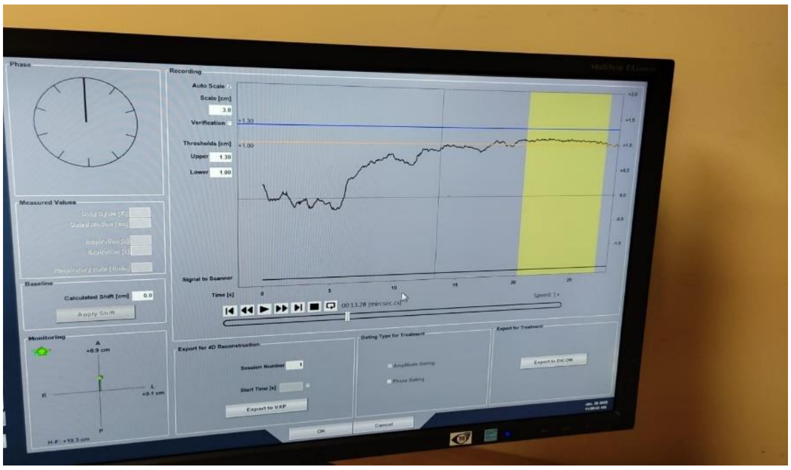


Figure 3:c) DIBH Scan.

Verification of the VCD:The VCD shows the course of the tracked breathing pattern. To test this, place the marker block on the breathing phantom in the CT scanner room and align it within the camera's view. Turn on the breathing phantom. Instead of attaching the VCD and couch mount to the couch, place the VCD on the couch top. Attach the VCD Couch Mount, including the VCD, to the CT couch top. Turn on the VCD and wait for it to start up.

Launch the RGSC application and log in with the appropriate user credentials. Select New Scan > Open, then create or open the patient ID1: TestRGSC{SN}IPA, with the last name "Acceptance" and first name "Acceptance," and click Create. Enter "RGSCVCDVerification" for the session name and click Create. On the next screen, click on Phase Gating, leave the Gating Settings at their default values (Breathing Predictive Filter: 20%, Upper Threshold: 60%, and Lower Threshold: 33%), and click on the Coaching tab at the bottom. Enable Visual Coaching in the Visual Coaching area and select Slider from the Visual Prompt Style, then click OK.
Click Start to begin learning the breathing curve. Once the breathing pattern has been learned, the sliding bar will be visible in the Coaching area of the RGSC application. Click Record to start recording. Inside the treatment room, verify on the VCD that the sliding bar is visible and moves up when the marker block moves up and down when the marker block moves down. Press Stop in the Scan workspace, close the patient, and then close the RGSC application. Record the results in the data table. Figure 4 shows the test setups.

Fig 4:VCD

Camera thermal drifting test:Although the camera is shielded in a box and the room temperature is stable in the CT simulation room, it is still necessary to verify the camera's thermal drifting initially to establish a baseline. The “Breath-hold Gating” mode was selected for this test. For the first 30 minutes after the camera was plugged in, the breathing curves were recorded. The MATLAB program was used to analyze the recorded “*.vxp” data.

Using the “Breath-hold Gating” mode, the recorded breathing curve was generally flat. However, with thermal drifting, the breathing curve showed fluctuations and systematically decreased over time. To compare the thermal drifting, the average amplitude value in the first 15 minutes was compared with the averaged amplitude value in the second 15 minutes.

RESULTS:

All the tasks listed in Table 1 met the manufacturer's specifications. Since our system used a wall-mounted camera, the tasks for a couch camera did not apply.

QA of integration with Peripheral Equipment:The integration of the RGSC system with the GE CT scanner has been verified. The functionalities of “4D Scan,” “Phase Gating,” “Amplitude Gating,” and “Breath-hold Gating” were tested, and the results met the manufacturer's specifications. The RGSC system can generate correct gating signals and control the GE CT scanner accurately.

QA of spatial reproducibility:Table 2 shows the results for the spatial reproducibility and accuracy tests using the GE CT coordinate system. When a patient lies on the couch in a head-first supine position, the positive Z direction points to the patient’s anterior, the positive X direction to the patient’s left side, and the positive Y direction to the patient’s feet. The RGSC system recommends a temporal accuracy of less than 3 seconds or an amplitude accuracy of less than 4 mm. If these tolerances are not met, other clinical choices, such as using a breath control device, should be considered.

Table:2 Motion Position Indicator Accuracy For CT/PET with Wall/Ceiling Mounted Camera

AXIS MOTION POSITION ACCURACY	SPECIFICATION	RESULT
VRT axis difference	2.0 cm (±0.2 cm)	OK
LNG axis difference	2.0 cm (±0.2 cm)	OK
LAT axis difference	2.0 cm (±0.2 cm)	OK

The RGSC system's superiority over the RPM system may be attributed to improved camera resolution and better predictive functionality from the software design. To enhance the performance of the RGSC system, audiovisual biofeedback information might be beneficial. Clinical physicists can implement these QA tasks according to their clinic's needs. The provided tolerances should be reasonably achievable in the clinic and satisfy the requirements of the TG-142 and TG-147 recommendations.
This study serves as a reference guideline for the acceptance test, commissioning, and routine QA of the RGSC system installed in a radiotherapy clinic. However, clinical physicists are encouraged to establish their own clinical QA standards optimized for their clinic's needs and available tools. This work presents our experience with the new RGSC system acceptance and QA tests.

Conclusions

The RGSC system presents several advantages over the older RPM system, including a 3D infrared reflector block, a shielded camera design, and a fully integrated software platform with ARIA. These enhancements lead to better spatial information, reduced background interference, and more streamlined workflows. The RGSC system also shows improved dynamic accuracy, particularly with irregular breathing patterns. Although there are limitations on breathing period and amplitude for QA purposes, these are generally acceptable for clinical use. The system has received FDA clearance, and its superior camera resolution and software design contribute to its enhanced performance, especially with irregular breathing.

While the RGSC performs comparably to the RPM system for regular breathing, it may benefit from the addition of audiovisual biofeedback. The authors recommend QA tasks based on TG-142 and TG-147 reports and their initial experience, emphasizing the importance of clinics establishing their own tailored QA standards. This study provides a valuable reference for RGSC acceptance testing, commissioning, and QA, highlighting the system's improved dynamic treatment precision and the need for further investigation of its performance with linear accelerators. New functions and positioning accuracy enhance the RGSC system's ability to achieve higher dynamic treatment precision. A 4D phantom is useful for QA tests, and further investigation is required for comprehensive RGSC system performance QA.

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