Feasibility Assessment of Using SRS MapCHECK® for CyberKnife®'s Automatic Quality Assurance (AQA) Test

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INTRODUCTION

The CyberKnife® Robotic Radiosurgery System (CK) is a dedicated SRS/SBRT treatment machine that delivers multiple non-isocentric radiation beams. The set of possible positions that the robot stops around the patient is called a "path." The accurate and safe delivery of radiotherapy treatments depends on verifying the robot mastering calibration and path calibration; this daily verification is usually accomplished by performing the Automatic Quality Assurance (AQA) test, as recommended the manufacturer and by AAPM Task Group 135[1].

The AQA test, which is analogous to a Winston-Lutz test, is typically done using films placed inside a phantom containing a 2 cm tungsten ball. The use of films make this test both time consuming and (in the long run) costly. Array-based methods have been used to perform filmless AQA test. Yang et.al.[2] have shown error detection capability of 0.3 mm using the Sun Nuclear ArcCHECK®, but it required a hand-made styrofoam phantom for tracking and correlation curve analysis using an in-house Matlab® software. Gersh et.al.[3] reported detection of 0.5 mm errors using the Standard Imaging QAStereoChecker™, which analyzes a modified AQA test called "PANDA" test. This commercial solution, however, is dedicated to machine QA and lacks applications on delivery quality assurance (DQA) and patient-specific quality assurance (PSQA).

In our institution, the Sun Nuclear SRS MapCHECK® is routinely used for DQA and PSQA on CK, but there is no study evaluating its potential application in routine machine QA. This study aims to assess the feasibility of performing filmless CK's AQA test using SRS MapCHECK® through a process-based analysis following TG218[4].

METHODS

- AQA plans creation: The SRS MapCHECK was scanned with the detector planes oriented horizontally and vertically with a 0.625 mm slice thickness with no buildup material. An independent isocentric AQA plan was created for each detector orientation with a single field perpendicular to the detector plane targeting the central detector. The plans delivered 200 MU using the 30 mm fixed collimator.

Figure 1 AQA test setup. The robot delivers circular radiation beams that are perpendicular to the detector plane in the same way as the film-based method. Left: anterior radiation with the detector lying horizontally in the couch. Right: lateral irradiation with the detector lying on its side.

- AQA test execution: The SRS MapCHECK® was positioned using its embedded fiducials until residual corrections were no greater than 0.2 mm/0.1 °. Array calibration was applied to all measurements. The results were saved as text files and analyzed in Excel®. The analysis routine calculated the beam profile center on the three centermost detector rows in both X and Y directions using linear interpolation in the beam penumbra.
- Repeatability: Irradiations were repeated under identical geometric conditions (without repositioning the phantom of the robot) to evaluate the repeatability of the results.
- Process-based analysis: Irradiations were performed randomly over the course of 4 weeks. The results were plotted in chronological order and used for the calculation of tolerance and action limits following the AAPM Task Group 218[4] methodology to evaluate the process' behavior.
- Sensitivity to induced errors: Offsets of 0.5 mm and 1 mm were introduced by turning off the beam near the end of a standard test execution (used as baseline) and manually moving the robot by discrete steps using the hand pendant.

RESULTS AND DISCUSSION

The results for the sequence of identical irradiations showed a mean deviation of 0.01 mm and a maximum deviation of 0.03 mm, demonstrating that the method is highly repeatable.

SRS MapCHECK®'s dual-layer of detectors provides results with an effective resolution of 1.75 mm; however, due to the steep and monotonic dose gradient of the penumbra region, we expect to detect errors that are much smaller than the resolution. Manually induced errors were detected with an average difference of less than 0.1 mm, as shown in *Table 1*. A maximum difference of 0.22mm and 0.14 mm were obtained for offsets of 0.5 mm and 1 mm, respectively. These differences are considered acceptable for the purpose of the test, although there is evidence that the device's sensitivity is even higher. For instance, Becker et.al.[5] reported error detection in GammaPod® within 0.1 mm using SRS MapCHECK®, and Jordan et.al[6] reported a detection sensitivity of 0.1 mm on induced errors in the AQA test using the Sun Nuclear SRS PROFILER™ despite its larger detector spacing of 4 mm. A possible explanation would be in the accuracy of manually shifting the robot using the hand pendant; although we have seen the positioning reproducibility of the robotic arm to be of the order of 0.1 mm, the manual positioning accuracy has not been investigated, and visual inspection of the pointing laser displacement during such very small shifts indicates that they may not be accurate enough for this evaluation. Alternative methods would be to create AQA plans with known offsets or to introduce errors directly into the path calibration; this is left for future assessments.

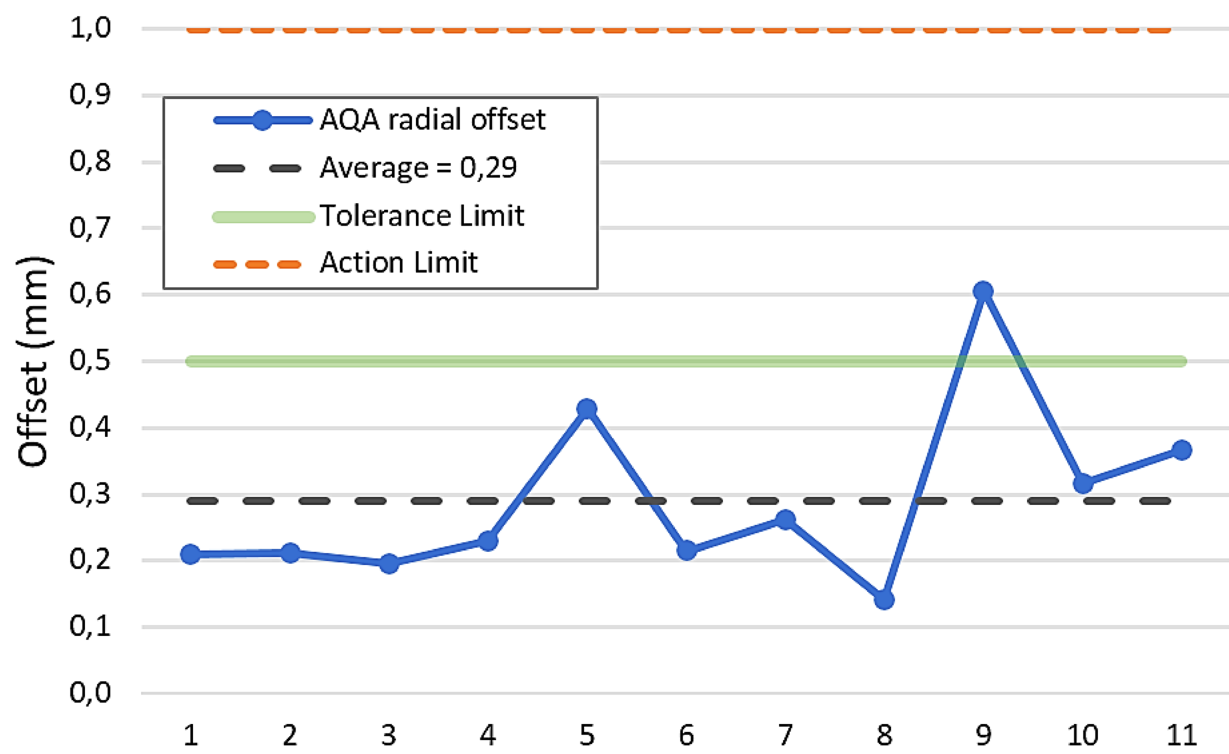

Figure 2 Historical data of AQA test results using SRS MapCHECK®

Table 1 Detection of induced manual offsets in the robot

Manual offset (mm)	Detected offset difference (mm)	
	Average	Maximum
0,50	0,07	0,22
1,00	0,06	0,14

Table 2 Tolerance and action limits (in mm)

Limits	Calculated	Considered
Tolerance	0,43	0,50
Action	0,80*	1,00**

*ideal scenario in which the target value is set to the average
**universal action limit from AAPM TG 135[1]

Figure 2 shows the results of 11 AQA analysis. The average radial offset was 0.29 mm. Unlike a Winston-Lutz test, this value is not representative of the overall treatment accuracy, since path calibrations are done independently for AQA and treatment paths and corrections could be done to bring the average AQA results closer to zero without affecting treatment paths. Thus, identifying large deviations and out-of-control behavior is more important than the baseline value. With this in mind, the process-based action limit was calculated, considering that the target value is equal to the average value (i.e. based only on the standard deviation of the results), making it independent of the path calibration. The resulting process-based action limit was 0.8 mm, which is smaller than the universal action limit of 1 mm recommended by AAPM TG135[1].

The chronological behaviour of the results displayed in *Figure 2* yielded a process-based tolerance limit of 0.43 mm. No more than 5 consecutive results lied below or above the average value, and no more than 2 consecutive measurements lied outside the tolerance limit; this behavior indicates that the process is not out-of-control. One result lied above the tolerance limit, which grants an investigation (perhaps it should have been remeasured) but does not undermine the method. A better understanding of the process behavior will be obtained with a longer follow-up and larger sample size, but the initial results are encouraging. For the time, we set the tolerance limit to 0.5 mm close to the calculated value and equal to half of the universal action limit. The limits are summarized in *Table 2.*

CONCLUSIONS

A processed-based analysis of our method employing SRS MapCHECK® to perform CK's AQA test has demonstrated that is it a feasible alternative to the film-based method. The method was able to detect manual offsets of 0.5 mm and 1 mm to within 0.2 mm, which is sufficient for the purpose of the test. It has the advantage of using a device that is used routinely for DQA and PSQA with a straightforward implementation. Future work is planned to make the analysis process faster, apply it to the IRIS and MLC collimators, and explore other potential applications of SRS MapCHECK® for other routine CK machine QA tests such as laser alignment, IRIS field size verification and MLC QA.

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