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Usability and accuracy of high-resolution detectors for daily quality assurance for robotic radiosurgery

Abstract: For daily CyberKnife QA a Winston-Lutz-Test (Automated-Quality-Assurance, AQA) is used to determine sub-millimeter deviations in beam delivery accuracy. This test is performed using gafchromic film, an extensive and user-dependent method requiring the use of disposables. We therefore analyzed the usability and accuracy of high-resolution detector arrays. We analyzed a liquid-filled ionization-chamber array (Octavius 1000SRS, PTW, Germany), which has a central resolution of 2.5mm. To test sufficient sensitivity, beam profiles with robot shifts of 0.1mm along the arrays' axes were measured. The detected deviation between the shifted and central profile were compared to the real robot's position. We then compared the results to the SRS-Profiler (SunNuclear, USA) with 4.0mm resolution and to the Nonius (QUART, Germany), a single-line diode detector with 2.8mm resolution. Finally, AQA variance and usability were analyzed performing a number of AQA tests over time, which required the use of specially designed fixtures for each array, and the results were compared to film. Concerning sensitivity, the 1000SRS detected the beam profile shifts with a maximum difference of 0.11mm (mean deviation = 0.03mm) compared to the actual robot shift. The Nonius and SRS-Profiler showed differences of up to 0.15mm and 0.69mm with mean deviation of 0.05mm and 0.18mm, respectively. Analyzing the variation of AQA results over time, the 1000SRS showed a comparable standard deviation to film (0.26mm vs. 0.18mm). The SRS-Profiler and the Nonius showed a standard deviation of 0.16mm and 0.24mm, respectively. The 1000SRS seems to provide equivalent accuracy and sensitivity to the gold standard film when performing daily AQA tests. Compared to other detectors in our study the sensitivity as well as the accuracy of the 1000SRS appears to be superior and more user-friendly. Furthermore, no significant modification of the standard AQA procedure is required when introducing 1000SRS for CyberKnife AQA.

Keywords: CyberKnife, Robotic Radiosurgery, Automatic Quality Assurance, High-Resolution Arrays, Gafchromic Film

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1 Introduction

High treatment accuracy with the CyberKnife (Accuray, USA) is achieved by combining a high-precision robotic manipulator with a miniature linear accelerator and stereoscopic x-ray imaging. Using the kV-images the system can calculate the differences of the patient's position during treatment with respect to an alignment center defined on the digitally reconstructed radiographs (DRR) of the planning computer tomography (CT). In contrast to gantry-based systems the CyberKnife can then correct the differences between the actual and planned patient position by moving the robotic manipulator according to the calculated offsets.

The system calibration, i.e. the agreement of the MV-beam reference point and the kV-imaging center, is crucial for the high treatment accuracy, as described in the AAPM Task Group 135 report [1]. Part of the daily quality assurance for the CyberKnife is the Automated-Quality-Assurance (AQA) test [2], a type of Winston-Lutz-Test that allows detecting deviations of the kV-MV-system in comparison to a reference baseline.

Usually the AQA is performed using gafchromic film, inserted into a dedicated phantom with film holding positions, on which two beams are irradiated (one from anterior and one from the left of the phantom). The beams traverse a lead sphere in the middle of the phantom leaving a shadow in the beams profile on the film. The difference between the overall profile center and the shadow center is computed for both films and a 3D offset vector is calculated for the 4 directions with a redundancy in the superior-inferior direction. This offset is compared to a general baseline determined during system calibration. The AQA test is considered an extensive and user-dependent method requiring the use of disposables and we therefore analyzed the usability and accuracy of high-resolution detector arrays as replacement.

2 Materials and methods

We analyzed a liquid-filled ionization-chamber array, the Octavius 1000SRS (PTW, Germany) [3], which offers 977 detectors with a size of 2.3mm x 2.3mm x 0.5mm. The chambers cover a maximum field size of 10cm x 10cm with a resolution of 2.5mm in the inner center (5cm x 5cm) and 5mm in the outer field. The 1000SRS was recently investigated regarding delivery quality assurance for the CyberKnife and demonstrated a high performance in comparison to film [4].

The analysis results were also compared to the SRS-Profiler (SunNuclear, USA) and to the Nonius (QUART, Germany). The SRS-Profiler offers 125 detectors arranged star-like over an area of 12cm x 14cm and a resolution of 4mm. The sensitive area of each detector is 0.64mm². The Nonius is a single-line array of 16 detectors with a resolution of 2.8mm and a sensitive detector area of 0.16mm².

2.1 Sensitivity analysis

To test sufficient sensitivity for the 1000SRS, the robot was positioned vertically above the array's central chamber with a SDD of 80cm and the array's axes aligned along the robot's axes. A reference beam profile of 35mm field size, which is typically used for AQA, was then applied for further testing. To simulate drifts in the kV-MV-system, the robot was shifted along the array's axes in steps of 0.1mm up to a maximum shift of 1.5mm and deviations between the shifted and central profile were compared to the actual robot's position. The same measurement procedure as with the 1000SRS was performed with the SRS-Profiler except a 40mm beam profile was used to increase the number of measuring detectors and robot shifts were adapted to the detector's properties. For the Nonius, due to its maximum field length of 40mm, a 25mm beam profile was used for sensitivity analysis and shift steps were also adapted to the detector's resolution.

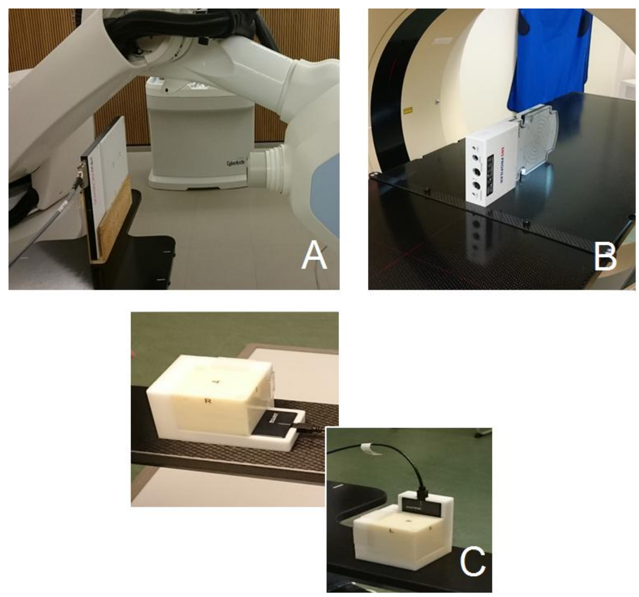

Figure 1: High-resolution detector arrays used in this study with their specially designed fixtures for AQA testing: A) 1000SRS B) SRS Profiler C) Nonius

2.2 AQA accuracy and variance

Having analyzed the detectors' sensitivity, we finally examined AQA variance and usability of all three detector arrays. A number of AQA tests were performed over several months using specially designed fixtures for each array (see **Figure 1**). Different from film, when using detector arrays the two AQA-beams had to be irradiated separately with a repositioning of the array in between. With the Nonius being a single-line detector, a further repositioning had to take place for each of the two AQA-beams. Results of AQA variance for each detector array were compared to the gold standard film.

Figure 2: Results for the radial error in relation to the according baseline reference value of all three high-resolution arrays and film.

3 Results

Concerning sensitivity, the beam profile shifts detected by the 1000SRS and compared to the actual robot shift showed mean deviations of 0.03mm along the array's x-axis and 0.02mm along the y-axis. Maximum differences of 0.11mm and 0.10mm were found, respectively. No dependency on the shift extent or central beam position on the array was observed.

The Nonius and SRS-Profiler showed maximum deviations of up to 0.15mm and 0.69mm between detected and actual robot shift. Mean deviation of 0.05mm and 0.18mm were found, respectively. A position dependency and thus shift limitation could not be observed using the Nonius. The SRS-Profiler, however, showed a higher mean deviation of 0.24mm for shifts ≥ 1mm.

Analyzing the variation of AQA over a time of several months, all three arrays and film showed comparable results. The mean deviation of the radial error to its reference value for gold standard film was 0.07mm with a standard deviation of 0.26mm and a maximum deviation of 0.50mm. AQA performed with the 1000SRS showed a mean difference of the radial error compared to its reference value of 0.11mm (SD = 0.18mm; max dev = 0.42mm). With the Nonius and SRS Profiler a mean deviation of the radial error to the according baseline reference value of 0.30mm (SD = 0.24mm; max dev = 0.72mm) and 0.07mm (SD = 0.16mm; max dev = 0.44mm) was observed (see **Figure 2**).

The results for each of the four analyzed spatial directions (coronal right-left; coronal inf-sup; sagittal ant-post; sagittal inf-sup) showed a standard deviation of up to 0.28mm for film and 0.33mm for the 1000SRS. Using the Nonius and the SRS Profiler results varied with a standard deviation of up to 0.30mm and 0.25mm, respectively.

4 Discussion

The 1000SRS seems to provide a high enough sensitivity to detect sub-millimeter drifts when performing daily CyberKnife QA, confirming initial results previously published [4]. Compared to other arrays a higher conformity of detected drift and actual robot shift could be observed. There appears to be no position dependency when analyzing beam profile shifts using the 1000SRS and the Nonius, confirming previous results [5] now with cylindrical beams. The SRS-Profiler on the other hand shows higher deviations with robot shifts greater than 1mm.

Considering the performance of daily AQA tests, the 1000SRS seems to provide equivalent accuracy and sensitivity to the gold standard film. No significant differences can be observed when analyzing the radial error in relation to the respective reference value. Equally close results were obtained when examining the standard deviation of the four separate spatial directions on film and the 1000SRS. Performance of AQA with the Nonius and the SRS Profiler appears to be equivalent to the 1000SRS and film. However, the application of the 1000SRS for daily CyberKnife AQA seems more user-friendly compared to the other two devices and no significant modification of the standard AQA procedure is required. Furthermore, the 1000SRS may offer absolute dose and multiple profile measurements during AQA potentially overcoming the limits of the current film-based procedure. Further investigation is warranted.

5 Conclusion

As conclusion, for the AQA test the 1000SRS seems to be an equivalent alternative to film and appears to be superior to other detector arrays in our study.

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Author's Statement

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