Practical application of NIPAM kV-CBCT dosimetry to determine kV-MV isocenter alignment

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INTRODUCTION

Spatial accuracy of the radiation and kV-CBCT systems is of great importance in SRS and SBRT cases. Spatial accuracy is determined via specific QA tests ("star shots," Winston-Lutz test, Varian MPC), while co-incidence of the radiotherapy isocenter and kV-CBCT imaging coordinate system is typically determined through separate QA tests[1].

Three-dimensional (3D) dosimetry systems may offer more comprehensive QA tests and provide information about the dose distributions achieved by techniques such as SBRT/SRS. In this study, we demonstrate the use of N-Isopropylacrylamide (NIPAM) kV-CBCT dosimetry[2] to verify the spatial accuracy of the kV-MV isocenters.

AIM

We have previously demonstrated a fast and comprehensive isocenter verification technique in which the radiation isocenter is imaged and quantified directly using the on-board kV-CBCT[3]. Here, we report practical clinical scenarios in which a NIPAM kV-CBCT gel dosimeter was used to detect kV-MV isocenter alignment on a Varian TrueBeam STx.

METHOD

NIPAM dosimeter fabrication → Pre-CBCT images acquired → Isocenter verification test performed → Post-CBCT images acquired

Isocenter verification was performed using a NIPAM 3D gel dosimeter, irradiated at eight unique couch/gantry angles (~16Gy). Pre- and post- irradiated CBCTs were acquired. Because a density change was observed in the dosimeter as dose is deposited, the dose signal was extracted as the difference between the pre- and post-irradiation CBCTs. CBCT acquisition parameters were 125 kVp, 1080 mAs, smooth reconstruction filter, 1mm slice thickness. We demonstrate two cases in which this method was able to determine kV-MV isocenter misalignment on a TrueBeam STx linear accelerator: (1) a misalignment was simulated by introducing a 0.5mm shift applied in the direction of leaf travel for 5mm diameter MLC field, and (2) the test was carried out before and after a scheduled isocenter adjustment made by the manufacturer.

Matlab code developed in house detects beam geometry within the CBCTs and quantifies the isocenter uncertainty and coincidence with the imaging system. Accuracy of couch and gantry angles were also quantified.

RESULTS

Imaging, Irradiation, and Analysis

(1) Setup, irradiation, and imaging could be carried out within 45 minutes.

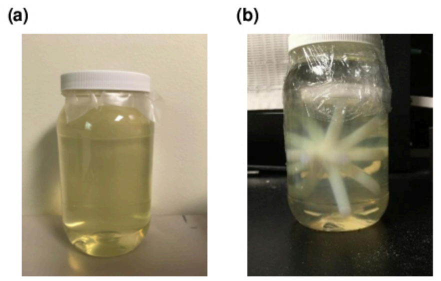

Figure 1. Photos of an (a) unirradiated dosimeter, and (b) irradiated dosimeter.

(2) Matlab analysis could be completed in under 15 minutes.

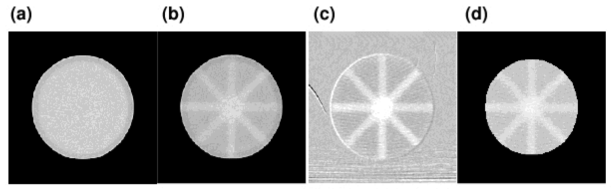

Figure 2. (a) Axial slice of the pre-irradiation, (b) axial slice of the post-irradiation, (c) subtracted CBCT image, and (d) the dosimeter after applying a mask to eliminate the background.

Detecting a Misalignment

The Matlab code was able to detect the 0.5mm alignment error. With the shift applied to each MLC field, the vector difference between the radiation isocenter and CBCT origin increased from 0.4mm to 0.6mm, and the radiation isocenter radius increased from 0.4mm to 0.9mm.

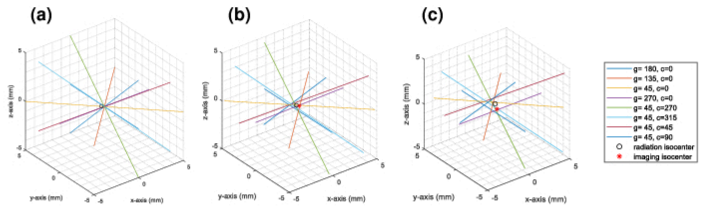

Figure 3. 3D plots of the (A) ideal gantry and couch combinations that directly cross the radiation and imaging isocenter, (B) displacement of the beams for the 10mm MLC field test, and (C) displacement of the beams for the 0.5mm shift applied to the 10mm MLC plan.

Detecting a Scheduled Isocenter Adjustment

The isocenter verification test was able to detect an isocenter adjustment made by the manufacturer. The following tables show the results of the isocenter diameter size as determined from the vendor and using the NIPAM isocenter verification test, as well as the results of the smallest radius to intersect all beams using the isocenter verification test.

Table 1. Results of the isocenter diameter size (mm) provided by the vendor.

	Prior to maintenance	After maintenance
Isocenter diameter (mm)	0.976	0.519

Table 2. Results of the isocenter diameter size (mm) using the NIPAM isocenter verification test.

	Prior to maintenance	After maintenance
Isocenter radius (mm)	0.45	0.31
Smallest radius intersecting all beams (mm)	0.46	0.43

Prior to maintenance, the machine isocenter diameter measured by the vendor was 0.976mm. After maintenance, this value decreased to 0.519mm. Our results using the NIPAM isocenter verification test with a 10mm MLC field before maintenance showed the radial distance from the radiation isocenter to the CBCT origin was 0.45mm. After repair, the isocenter verification test with 5mm MLCs showed this value to be 0.31mm. The smallest radius to intersect all beams decreased from 0.46mm to 0.43mm before and after maintenance, respectively.

CONCLUSIONS

This work demonstrates the clinical applications of using the comprehensive isocenter verification test with NIPAM kV-CBCT dosimetry to detect kV-MV isocenter alignment. We successfully demonstrated the ability to detect an intentional misalignment and a scheduled isocenter adjustment by the manufacturer using the novel isocenter verification test.

The fast acquisition and analysis, unique ability to directly visualize dose in the CBCT image, and comprehensive analysis of radiation uncertainty and coincidence with the kV-CBCT imaging coordinate system make NIPAM kV-MV isocenter verification a unique tool for a clinical radiosurgery program, and is especially useful in clinical settings where the isocenter is expected to change.

ACKNOWLEDGEMENTS

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