The Use of Beam Fluency to Assure Image-Guided Radiosurgery Accuracy

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Introduction

Routine quality assurance (QA) is vital for maintaining the accuracy of any radiosurgery system. Yet many of the current film, ion chamber, and diode systems are time consuming to use and do not provide individual beam pointing accuracy. In addition, initial beam calibration is often done by laser, rather than directly with the radiation beam. An alternative QA approach featuring a novel configuration of scintillator screen geometry and real-time CCD camera monitoring has been characterized with a CyberKnife (Accuray, Inc.) radiosurgery system.

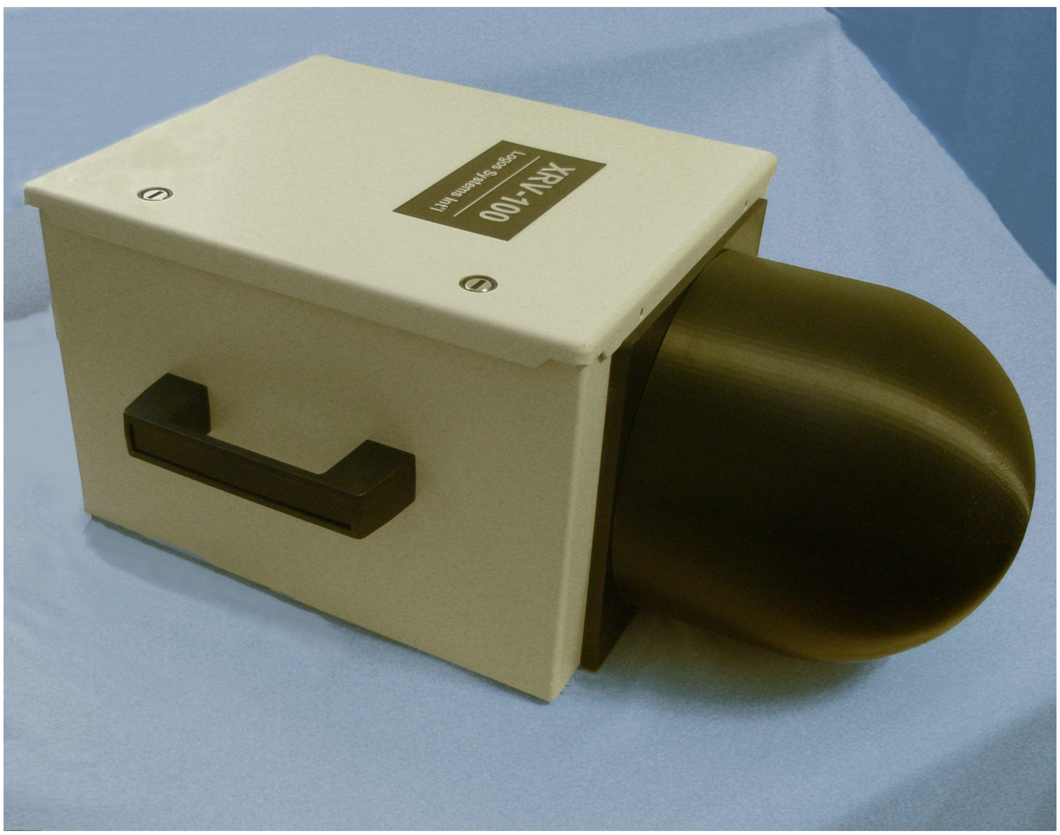

***Figure 1*—the XRV-100 detector enclosure.**

The XRV-100 (Logos Systems, Scotts Valley, CA) system (Figure 1) consists of a 60-degree cone laminated with conventional Gadox X-ray scintillator phosphor. As linear accelerator radiation passes through the cone, two spots of visible light are formed by Compton scattering at the entry and exit points of the beam, as seen in Figure 2. These two beam spots define not only the path of the radiation through three-dimensional (3D) space but also the energy profile of the beam fluence.

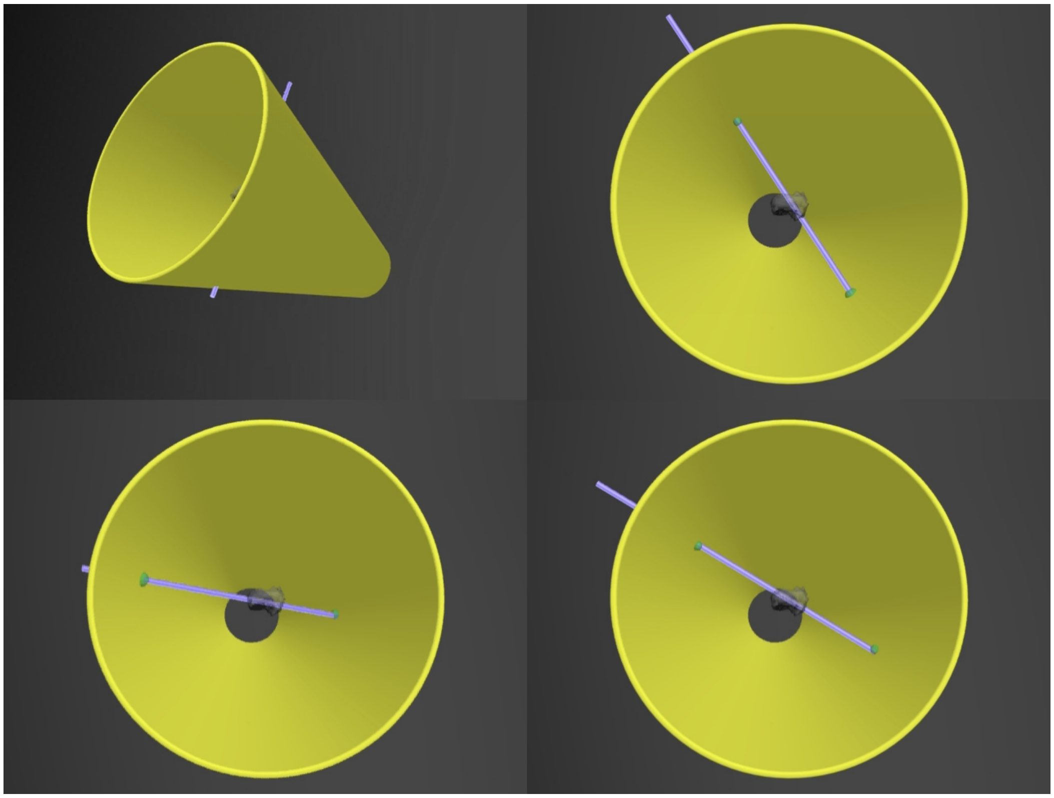

***Figure 2*—Beam entry and exit points are detected by the XRV scintillator cone.**

High-density fiducials mounted in proximity to the scintillator allow the radiosurgery imaging system to precisely target treatment plans within the cone volume. While QA treatment plans are administered by the radiosurgery system, the CCD camera and monitoring software view the interior of the scintillator cone and record the position of each beam in real-time.

Materials and Methods

The XRV scintillator cone is located in a plastic shroud in order to keep ambient light from affecting beam measurements. The orientation of the cone and its XYZ coordinate system with respect to the CyberKnife robot is shown in Figure 3.

***Figure 3*—The XRV is positioned on the treatment couch with the cone positioned near where the patient's head would be located.**

Data Representation

The XRV beam capture software is shown in Figure 4 with two beam spots delivered along the Y-axis of the scintillator cone. The X-axis of the cone goes from left to right and the Z-axis of the cone is perpendicular to the screen center. The concentric circles overlaying the beam spots correspond to calibrated 10 mm distances along the Z-axis. The inner circle represents a distance of 60 mm from the cone apex, and the outer circle represents a distance of 120 mm from the cone apex.

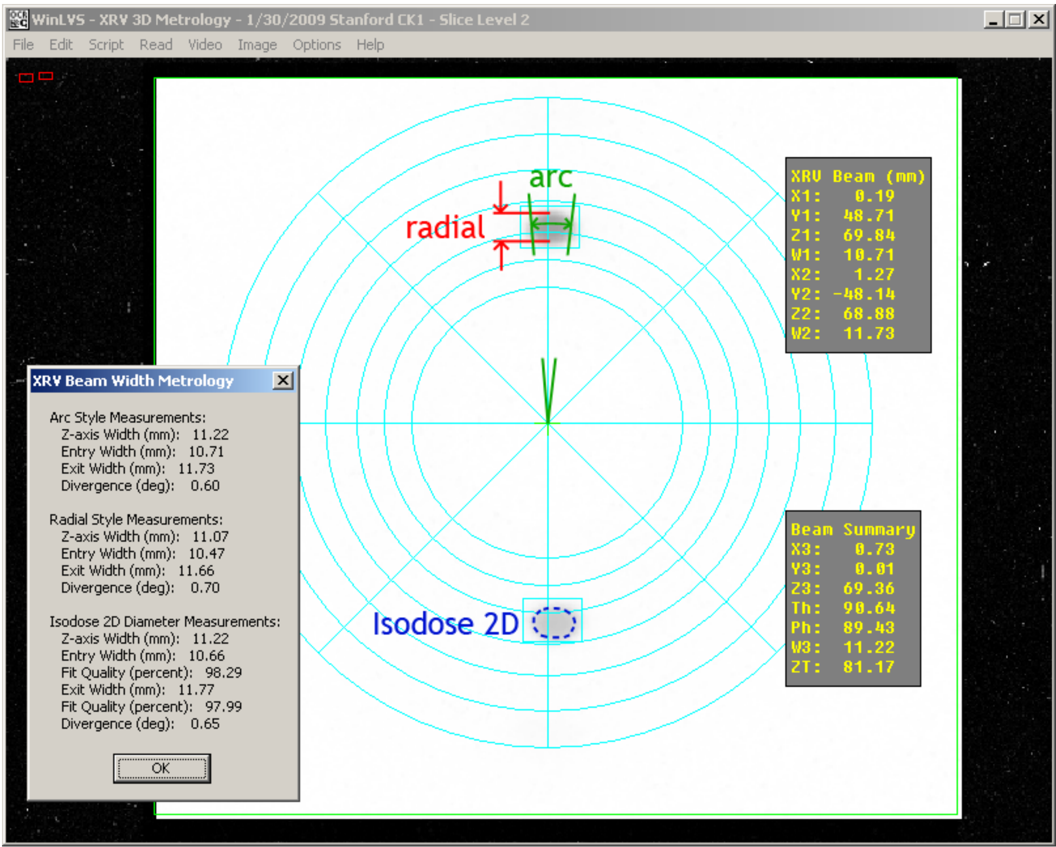

***Figure 4*—Beam metrology data is displayed over the captured cone image.**

Beam path vectors are determined by calculating the XYZ locations on the cone where the beam enters and exits. The beam vector can then be expressed as the XYZ point along the path where the beam makes its closest approach to the cone central Z-axis. Theta and Phi are the polar coordinate system angles that describe the vector path from that location.

Beam widths are measured at the 20%, 50%, and 80% fluence intensity levels between the background and the brightest intensity in the spot. The Isodose 2D width measurement algorithm follows the contour of the fluence level, fits a circle to that contour, and then calculates the diameter of the circle.

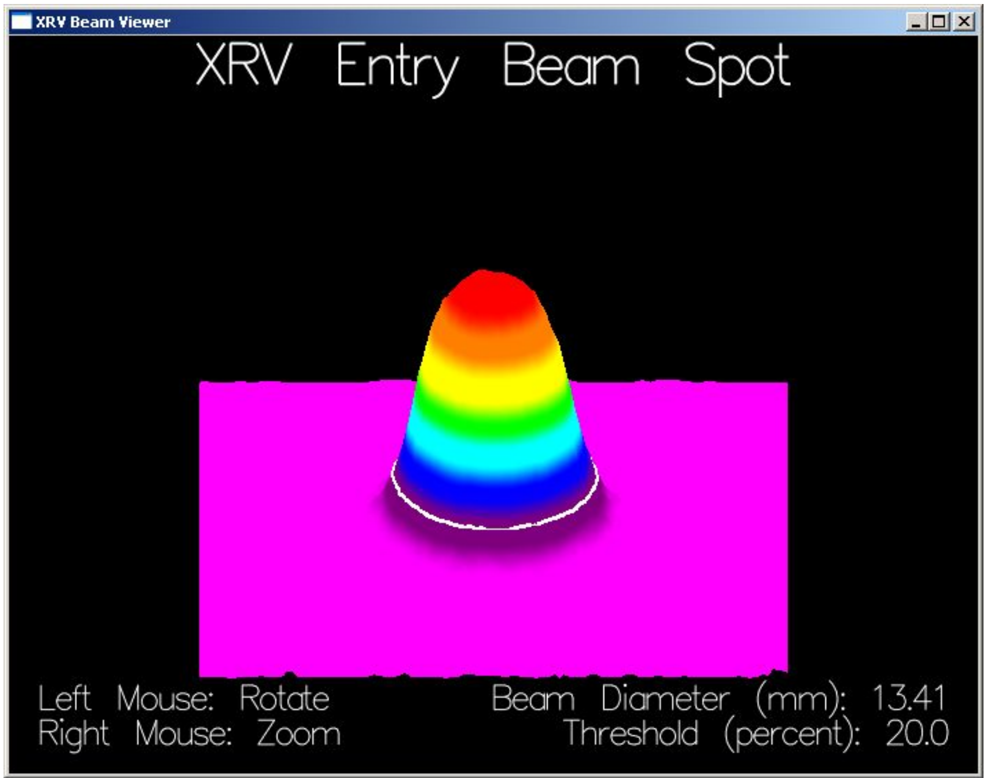

***Figure 5a*--The Beam Viewer measures the beam width at the 20% intensity level for penumbra calculations.**

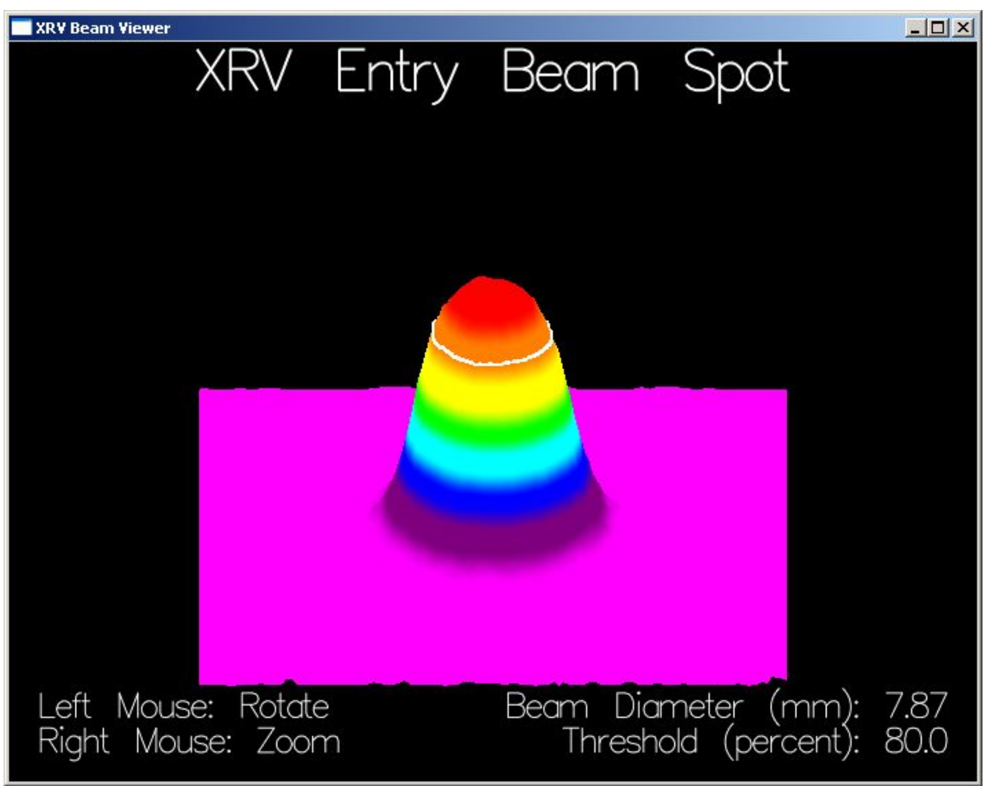

***Figure 5b*--The Beam Viewer measures the beam width at the 80% intensity level for penumbra calculations.**

End-to-End Isocenter Test Plan

The treatment plan shown in Figure 6 places the intersection of 5 mm wide beams 79.89 mm from the plane of the fiducial spheres embedded in the base of the XRV scintillator cone.

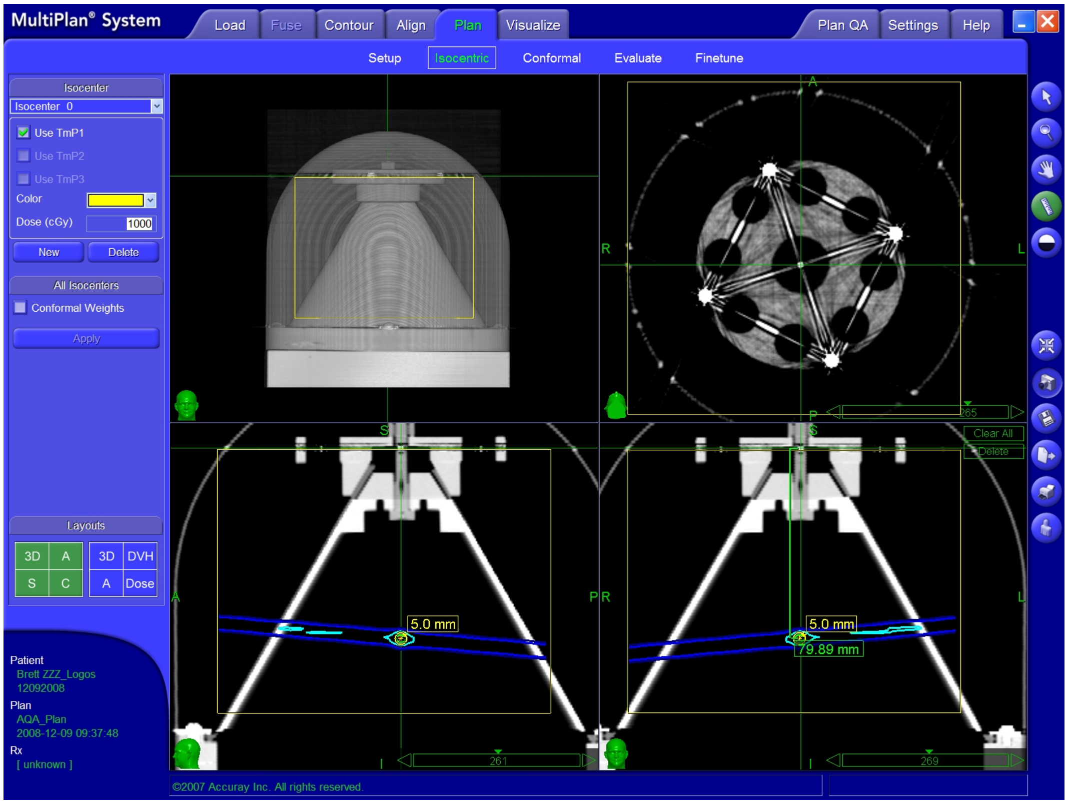

***Figure 6*—Accuray software positions the treatment volume using CAT scan data from the shroud portion of the XRV.**

Isocenter Test Results

The vector results shown in Figures 7a-7c show that the distance from the planned 0,0,79.89 isocenter to the captured isocenter of -0.2, -0.7, 79.9 is 0.73 mm, confirming this CyberKnife's submillimeter accuracy.

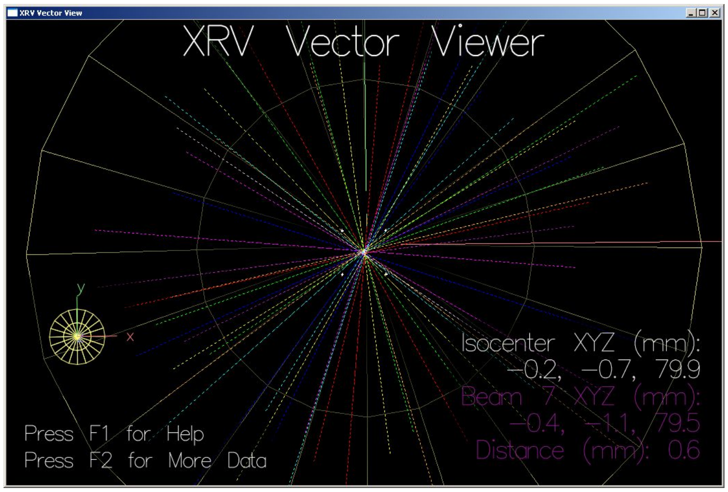

***Figure 7a*—Isocenter test vector results frontal view.**

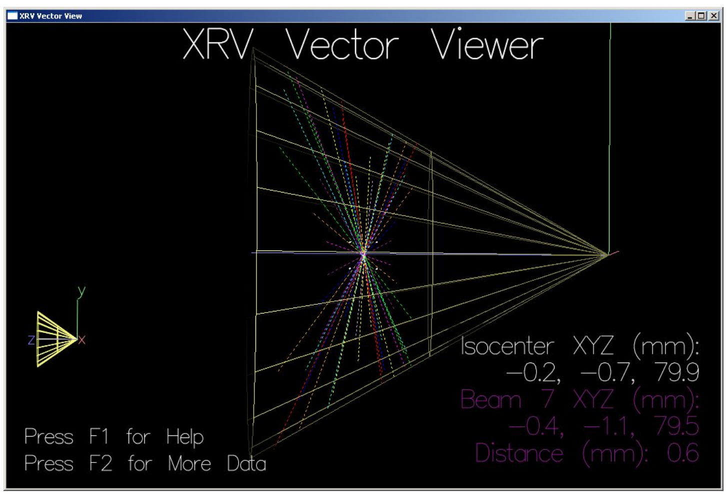

***Figure 7b*—Isocenter test vector results side view.**

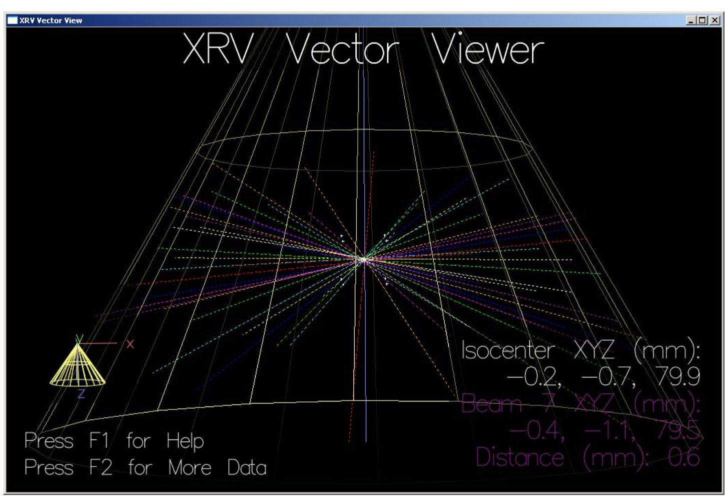

***Figure 7c*—Isocenter test vector results top view.**

AQA 10 mm Beam Profile Test Results

The CyberKnife AQA-style test delivers a vertical beam followed by a horizontal beam. The position where the vertical beam enters the XRV cone is useful for measuring fluence beam widths. The spreadsheet data for several different measurement series are shown in Figure 8.

CK2 - 10mm fixed - 12/9/2008 - 4fps - 600 mmu - SAD 75 cm

Widths	50%	20%	80%	Penumbra
Average (mm)	10.87	13.68	7.81	2.92
StdDev (mm)	0.02	0.02	0.05	0.03

CK1 - 10 mm fixed - 1/30/2009 - 2fps - 400 mmu - SAD 75 cm

Widths	50%	20%	80%	Penumbra
Average (mm)	10.69	13.35	7.89	2.73
StdDev (mm)	0.06	0.02	0.05	0.03

CK2 - 10 mm IRIS - 5/19/2009 - 5 fps - 800 mmu - SAD 75 cm

Widths	50%	20%	80%	Penumbra
Average (mm)	10.56	13.64	7.42	3.11
StdDev (mm)	0.11	0.12	0.15	0.06

***Figure 8*—Beam Profile Data.**

CK2 Beam Commissioning using a 10 mm fixed collimator records a 50 cm depth dose field width of 10.6 mm and a penumbra of 2.8 mm placing the XRV fluence data within 4% of the dose values.

Conclusion

The XRV results demonstrate that 3D beam fluency metrology can be fast, accurate, and a powerful adjunct to existing radiosurgery QA systems.

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