

A Beam-Level Delivery Accuracy Study of the Robotic Image Guided Radiosurgery System Using a Scintillator/CCD Phantom

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Traditional Targeting Accuracy Test on CyberKnife



End to End test with an anthropomorphic head phantom:

- Good for overall targeting accuracy.
- Provides quantitative delivery accuracy.

- Limitation • No beam-by-beam level assessment.
- Limitation • Film-based-> cost and time consuming.

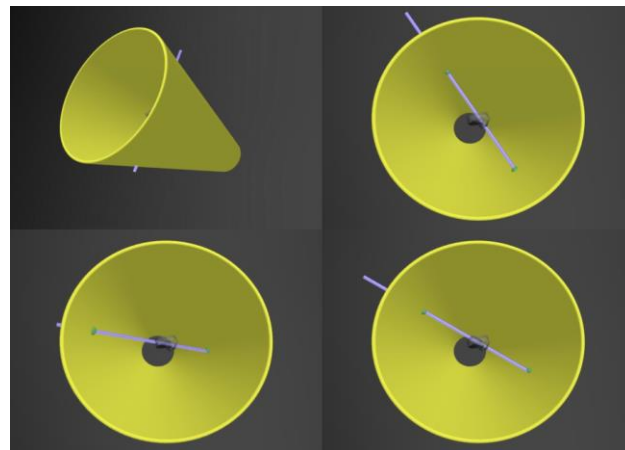
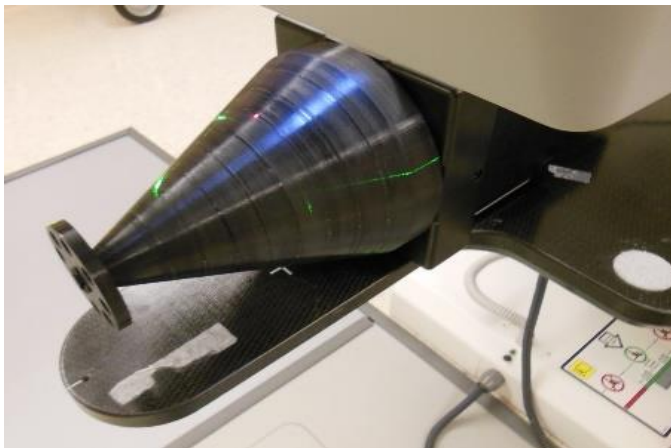
Beam level BB test (TG135):

- A visual test observing the beam laser shine on a small target, simple to perform

- Limitation • Laser is required to be well aligned
- Limitation • Accuracy ~1.5mm

XRV-124 System

Logos Systems Int'l, Scotts Valley, CA



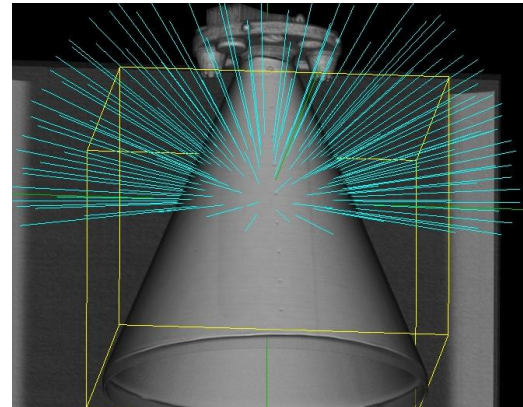
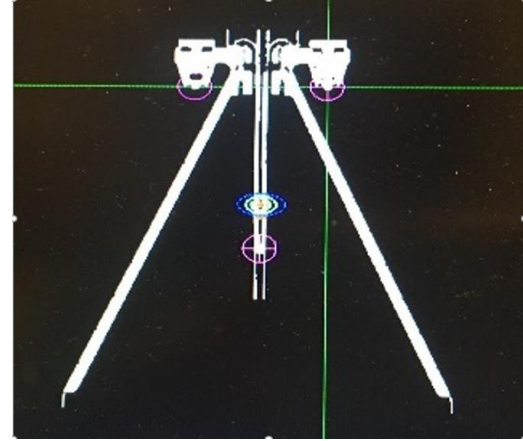
- The XRV-124 phantom is composed of an imaging cone laminated with an x-ray scintillator phosphor, coupled with a sensitive CCD digital camera.
- Radiation beams passing through the XRV-124 scintillator cone create two spots of visible light->used to calculate the beam position and direction.
- Measurement accuracy : 0.2mm

Purpose

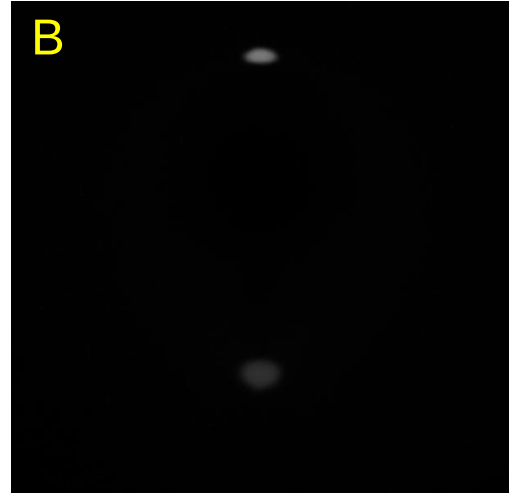
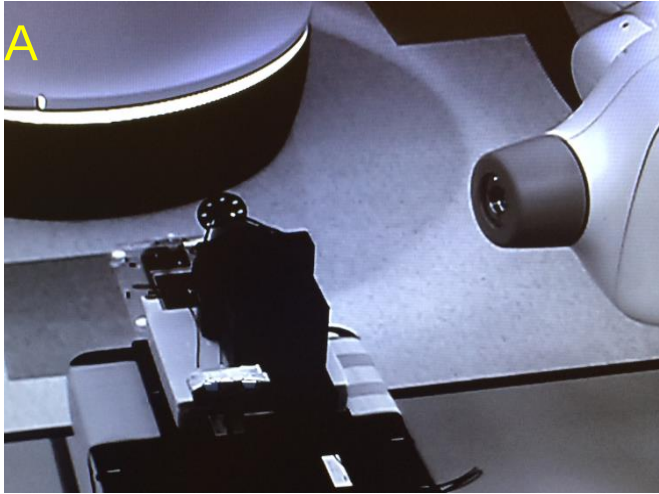
To assess the beam-level targeting accuracy of the robotic system using a scintillator/CCD phantom (XRV-124, Logos Systems Int'l, Scotts Valley, CA).

Material and Method: Treatment Planning

1. XRV124 phantom was scanned at 0.6 mm slice thickness.
2. Isocentric plans were created(Multiplan v5.3) targeting to the center of the cone.
3. Small field sizes were used: 7.5 mm diameter for Fixed Cone and Iris, 7.6mm x 7.7mm for MLC.
4. An extra fiducial was inserted on central rod to ensure tracking centroid is close to target.
5. Full path beams (up to 116 beams), 20 MU per beam.

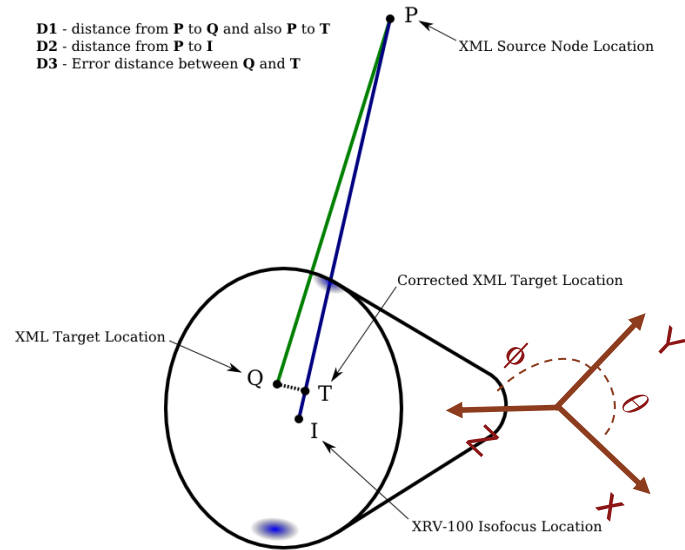


Material and Method: Treatment Delivery



- A. The treatment was delivered on CyberKnife M6 system.
- B. The XRV-124 CCD camera recorded the integrated image.

Data Analyzing



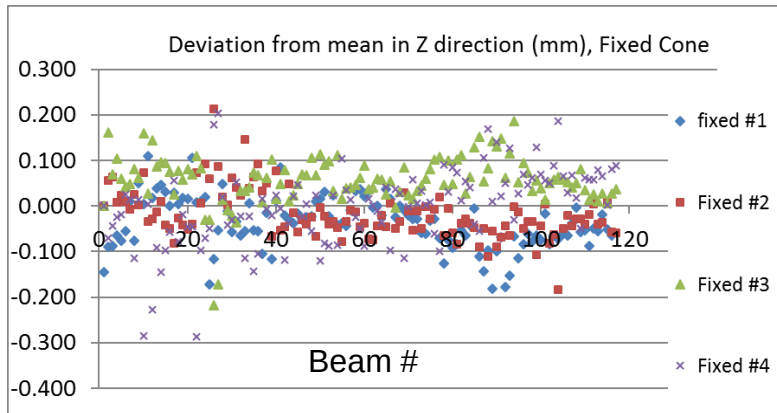
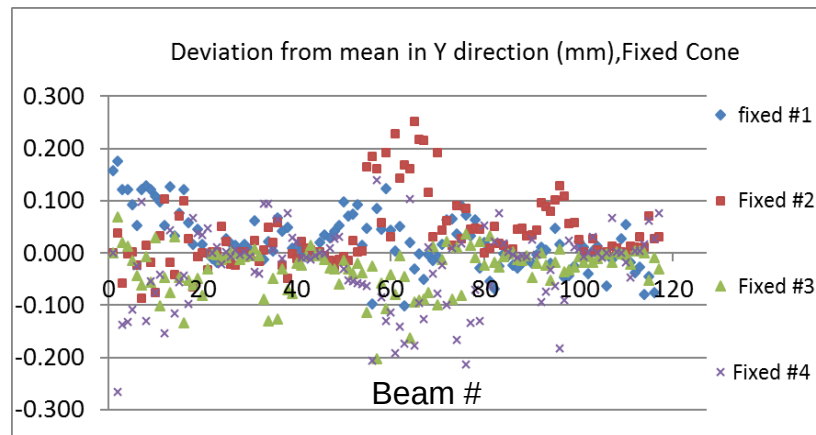
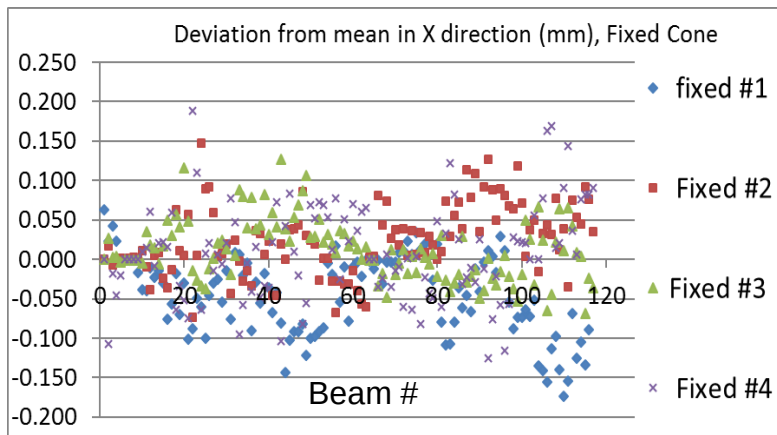
- Measurement coordinate and treatment coordinate is aligned through embedded fiducials in phantom.
- The captured beam positions and directions are compared with the planned parameters from CyberKnife XML file.
- The delivery accuracy is defined as the 3D distance between the planned and the measured actual position.

Targeting Accuracy $(\Delta R \text{ is the total targeting error: } \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2})$

	mean ΔR	$\sigma(\Delta R)$	Max ΔR	mean $\Delta \theta$	$\sigma(\Delta \theta)$	mean $\Delta \phi$	$\sigma(\Delta \phi)$	Phantom Positioning
Fixed Cone #1	0.429	0.219	1.261	-0.205	0.051	0.000	0.192	
Fixed Cone #2	0.402	0.200	1.171	-0.019	0.033	-0.002	0.129	Repositioned
Fixed Cone #3	0.353	0.210	1.19	-0.205	0.049	-0.008	0.191	Repositioned collimator
Fixed Cone #4	0.362	0.209	1.095	-0.132	0.048	-0.047	0.183	Extra shifts and rotations
Average	0.387	0.210	1.261	-0.140	0.045	-0.014	0.174	
Iris #1	0.316	0.145	0.794	-0.113	0.043	-0.004	0.128	
Iris#2	0.299	0.158	0.803	-0.408	-0.053	-0.053	0.126	Repositioned
Iris#3	0.309	0.137	0.726	-0.287	0.057	0.043	0.2	Extra shifts and rotations
Average	0.308	0.147	0.803	-0.269	0.016	-0.005	0.151	
MLC#1	0.411	0.186	0.903	-0.163	0.054	-0.035	0.165	
MLC#2	0.417	0.2	1.041	-0.239	0.068	-0.033	0.208	Repositioned
MLC#3	0.415	0.179	0.817	-0.269	0.079	0.014	0.235	Extra shifts and rotations
Average	0.414	0.188	1.041	-0.224	0.081	-0.018	0.205	

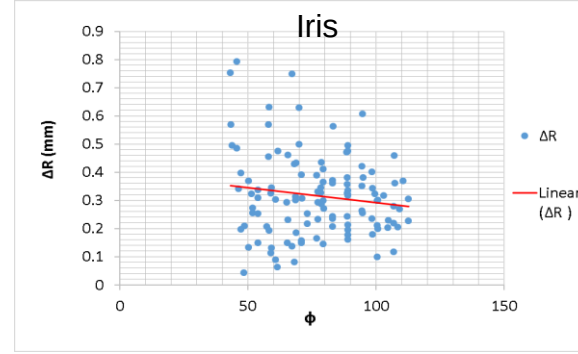
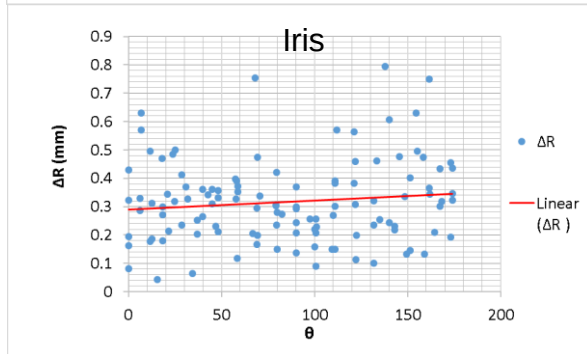
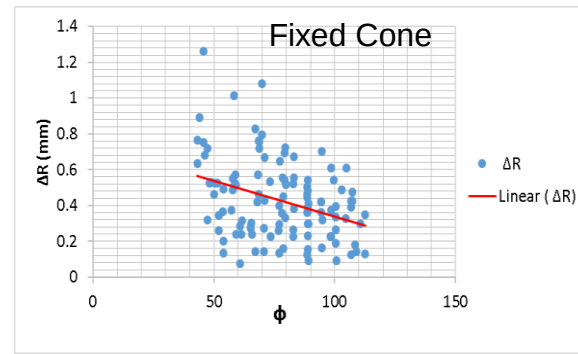
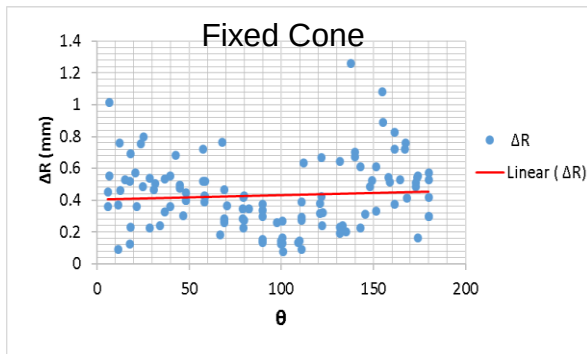
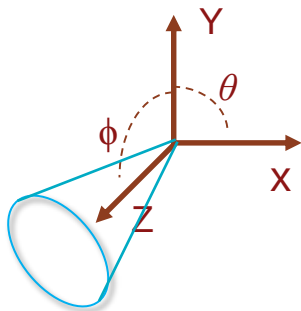
- Average total targeting error < 0.5 mm
- Max total targeting error < 1.3 mm. Worst case in fixed cone: 3 out of 116 beams are > 1mm.
- Average angular error < 0.3 degree
- No significant differences were found with reposition and extra residue shifts and rotations in deliveries.

Delivery/Measurement Precision: Targeting Deviation from Mean for Fixed Cone



With 99% confidence, beam delivery and measurement precision in X, Y and Z directions is within $\pm 0.2\text{mm}$.

Targeting Accuracy vs. Beam Angle (Fixed Cone data displayed)



Slight angular dependency in targeting accuracy was observed in ϕ direction. We are not certain if this is due to the measurement uncertainty or machine delivery uncertainty. Further investigation will be conducted.

Conclusion

- This study verified sub-millimeter delivery accuracy of CyberKnife system at beam-level for the entire body path nodes with three available collimators.
- The XRV-124 phantom was proved to be a valuable systematic delivery QA tool for the robotic targeting accuracy.
- This check is not dependent on central laser alignment. It provides ~0.2mm measurement accuracy with instantaneous results.

Conclusion

Limitation:

- This phantom only provides fiducial tracking, therefore it will not replace the anthropomorphic head phantom.
- It should be able to verify majority of the brain path nodes, but not the nodes from superior angle.

Thank you!