

Filmless Treatment Localization QA for the CyberKnife System

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Purpose: Accuray recommends daily evaluation of the treatment localization and delivery systems (TLS/TDS) of the CyberKnife. The vendor-provided solution is a Winston-Lutz-type test that evaluates film shadows from an orthogonal beam pair (known as AQA). Since film-based techniques are inherently inefficient and potentially inconsistent and uncertain, this study explores a method which provides a comparable test with greater efficiency, consistency, and certainty. This test uses the QAStereoChecker (QASC, Standard Imaging, Inc., Middleton, WI), a high-resolution flat-panel detector with coupled fiducial markers for automated alignment. Fiducial tracking is used to achieve high translational and rotational position accuracy.

Methods: A plan is generated delivering five circular beams, with varying orientation and angular incidence. Several numeric quantities are calculated for each beam: eccentricity, centroid location, area, major-axis length, minor-axis length, and orientation angle. Baseline values were acquired and repeatability of baselines analyzed. Next, errors were induced in the path calibration of the CK, and the test repeated. A correlative study was performed between the induced errors and quantities measured using the QASC. Based on vendor recommendations, this test should be able to detect a TLS/TDS offset of 0.5mm.

Results: Centroid shifts correlated well with induced plane-perpendicular offsets ($p < 0.01$). Induced vertical shifts correlated best with the absolute average deviation of eccentricities ($p < 0.05$). The values of these metrics which correlated with the threshold of 0.5mm induced deviation were used as individual pass/fail criteria. These were then used to evaluate induced offsets which shifted the CK in all axes (a clinically-realistic offset), with a total offset of 0.5mm. This test provided high and specificity and sensitivity.

Conclusion: From setup to analysis, this filmless TLS/TDS test requires 4 minutes, as opposed to 15-20 minutes for film-based methods. The techniques introduced can potentially isolate errors in individual joints of the CK robot.

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Figure 1: *Left.* The QAStereoChecker (Standard Imaging, Inc., Middleton, WI), a flat-panel-based detector developed specifically for the CyberKnife System. Once aligned using the treatment localization system, 5 narrow beams are delivered from varying angles, creating elliptical regions which are subsequently analyzed.

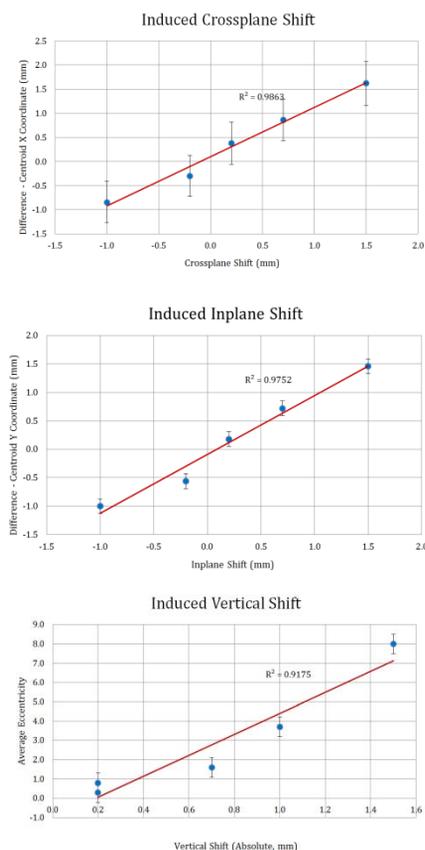
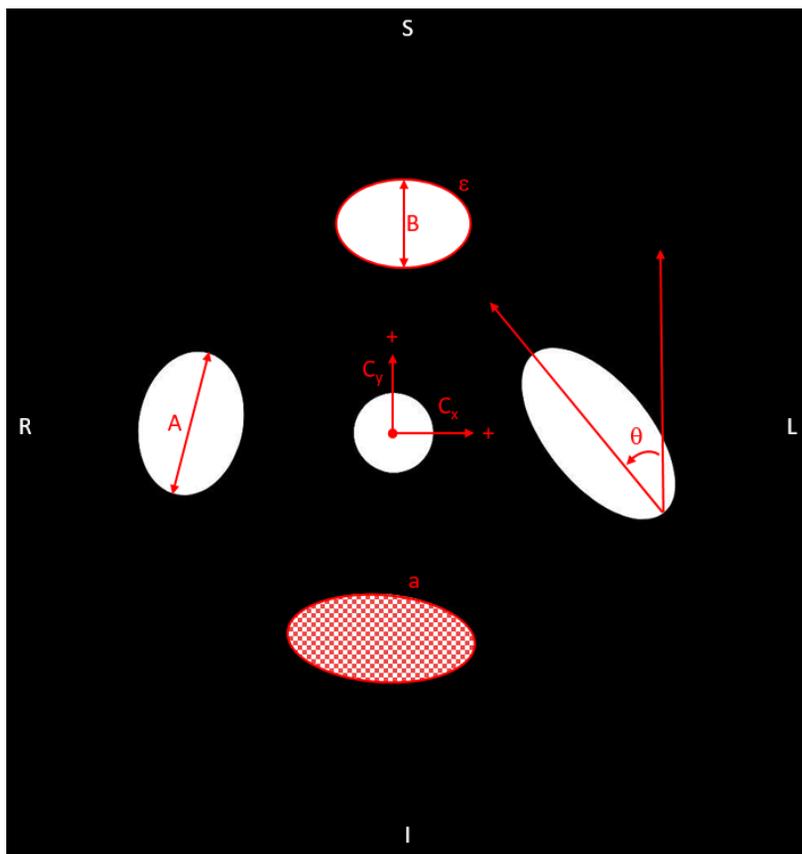


Figure 2: *Left.* A binary image of the TLS/TDS image, overlaid with diagrams representing the metrics used in the current study. These include area (a), major axis (A), minor axis (B), eccentricity (ϵ), centroid deviation (C_x and C_y), angular orientation (θ). Each of these metrics are used in the analysis of the five beams analyzed during the TLS evaluation. *Right.* A correlative study was performed between the induced errors and quantities measured using the QASC correlation between induced shifts and resultant metric deviations. Error bars represent standard deviation in repeat measurements, where no error is induced, rather the system is removed, repositioned, and re-irradiated.

Metric	Mean	RSD(%)	Threshold	Sensitivity	Specificity	PV+	PV-
Mean Absolute Eccentricity Deviation	1.423×10^{-4}	10.8	1.000	0.966	1.000	1.000	0.833
Absolute Center Centroid Deviation (mm)	0.536	15.7	0.400				

Table: Total offsets of 0.5mm were induced in the CyberKnife's TLS/TDS (based on the 0.5 mm vendor-recommended threshold). Values of the correlated metrics are determined ($n=23$, mean and relative standard deviation shown) and used for determining threshold values. When used with these threshold values, the sensitivity, specificity, positive predictive values, and negative predicative values are shown. A positive value refers to a "positive failure," meaning the CK's TLS/TDS is out-of-tolerance.