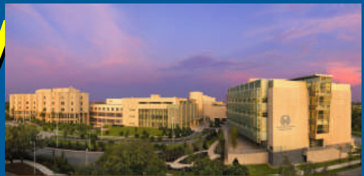
Evaluation of a Biplanar Diode Array Detector for MLC- and Compensator-based IMRT QA

MOFFITT CANCER CENTER

Abstract SU-GG-T-139



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INTRODUCTION

•Delta4 is a biplanar diode array specifically designed for measurements at varying gantry angles

•Suitable for verification of either static or rotational IMRT treatments

•The goal of this work is to characterize this 3D dosimeter and to apply it to verification measurements of Step-And-Shoot MLC- and compensator-based IMRT

•In addition to reporting the experimental results of the evaluation tests, we provide recommendations on optimizing the clinical use of the device

DEVICE DESIGN

•Cylindrical PMMA phantom 22 cm in diameter

•Two orthogonal diode arrays with a total of 1069 p-type cylindrical silicone diodes

•Bisector of detector planes is offset from vertical: can change phantom orientation to minimize beam incidence along the board

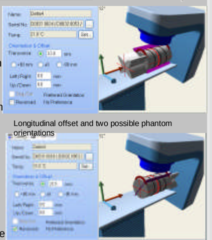
•The system automatically suggests the best phantom orientation

•Optional offset in phantom position accounted for in calculations

•20 x 20 cm² active area on each detector board

•Diodes spaced on a 5 mm rectangular grid in the central 6 x 6 cm² area, 10 mm elsewhere

•Orthogonal arrays ensure that beam modulation information is preserved regardless of beam incidence angle



Longitudinal offset and two possible phantom orientations

CALIBRATION

•PMMA Calibration phantom

•Holds either one full ("main") board or two half-boards ("wings") at a time

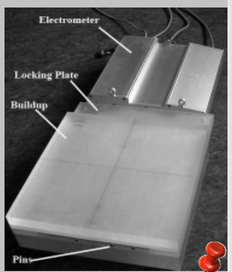
•Detectors at 95 CM SSD, 4.3 cm depth in PMMA (4.9 cm effective depth)

•Relative calibration in the 26 x 26 cm² field at a number of couch positions

•Recommended absolute calibration procedure is with a Farmer chamber replacing the reference diode

•We modified this procedure to avoid interpreting a reading from a water-calibrated chamber irradiated in PMMA

•We calculated the reference dose and scaled by the measured accelerator output.



EFFECTIVE POINT OF MEASUREMENT

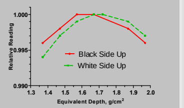
•Used calibration jig to position the main board once in a normal position (black side up) and then up side down

•Keeping the SDD constant at 99.5 cm, incrementally added Solid Water and manually recorded the reading in calibration mode

•The raw readings of nine central diodes were corrected for relative sensitivity and averaged

•No difference in the depth of maximum signal could be ascertained from the TPR graphs

•For practical purposes, the effective point of measurement can be assumed to reside at the mid-plane of the detector board



ROTATIONAL DEPENDENCE

•Used calibration jig to position the main board once in a normal position (black side up) and then up side down. The raw directional dependence ratio 0.975

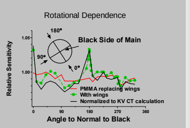
•Replaced the wings with PMMA and rotated the single beam around the phantom, using the 1°increment around the boards

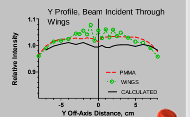
•Repeated with the wings in place

•Recorded longitudinal profile with the beam incident along the wings – worst case scenario

•Excellent isotropic response shown, with an approximately ±3% variation in ±1° intervals around the boards. Reduced to ±2% in ±5° intervals

•Periodic profile variation with beam incident through wings is not clinically significant, as it occurs in a very small angular interval





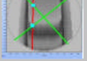
POINT DOSE VERIFICATION

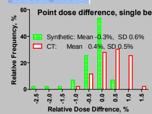
•A number of correction factors are applied to the raw diode reading to arrive at the point dose for each detector

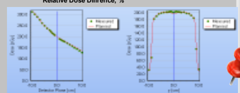
•Semi-empirical 3D point dose representation is possible when reference dose data are present at the individual beam level

•The TPS-calculated depth dose along incident rays is renormalized at the measurement points intercepted by the ray

•Mean dose error for a number of points in a single 18x18 cm² bisecting the planes less than 0.5%. No statistically significant difference in error between the points directly at the detectors, interpolated on the array, or in 3D between arrays







Dose profiles, single beam

CHOICE OF PHANTOM DATASET

•Generic synthetic CT dataset is provided for representation of the phantom in the TPS

•User must verify that the resulting electron density is correct

•We investigated the use of a real CT dataset

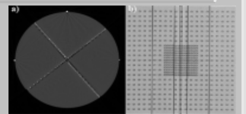
•Minimum artifacts

•Maximum CT number 288

•Slightly different results of dose calculations because of different average electron density

•Straightforward use of the clinical CT to ED conversion table

•Still fails to predict dose variations when irradiated along the board



We chose an actual CT dataset to represent the phantom for IMRT analysis

OPEN BEAMS ON A CT DATASET

Beam Arrangement	% Pass*		
	Dose (3%)	DTA (2 mm)	γ(3%,2 mm)
5°, 18x18 cm²	99.3	76.1	99.7
Four-field box, 18x18 cm²	78.2	97.1	88.4
Seven equally spaced fields, 18x18 cm²	79.1	99.1	91.5
Seven fields, 4x4 cm²	70.3	89.7	93.5

*Depends on choice of reference level

POTENTIAL FOR DOSE SAMPLING BIAS WITH MLC

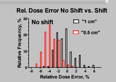
•TPS algorithm produces a regularly spaced set of segment match lines in 1 cm increments

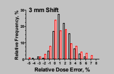
•This can produce systematic patterns of dose error when superimposed on a regular detector grid

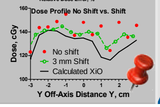
•Detectors on the 0.5 cm sub-grid in the center are systematically under different conditions than the detectors on the main 1 cm grid

•The mean dose error is statistically different between the two subgroups of detectors

•This difference is reduced, but not always eliminated, if the phantom is shifted away from isocenter by 3 mm along the leaf movement direction







STEP-AND-SHOOT IMRT

•Ten plans that previously passed ion chamber/film QA

•XiO TPS, Varian linac with Millenium 120-leaf MLC, 6MV

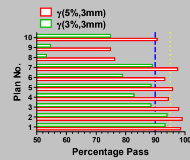
•Three plans required carriage shifts (8-10)

•Two out of those (8,9) did not pass γ(5%,3mm) test at 90% level

•The cause has been traced to the combination of the segmentation algorithm, simplistic representation of the penumbra by a single Gaussian, and a suboptimal initial choice of the radiation field offset (RFO) value

•While the error can be mitigated by a better choice of the RFO, it cannot be completely eliminated

•The effect is more pronounced for the split-field plans.



COMPENSATOR IMRT

•Seven plans that previously passed ion chamber/film QA

•XiO TPS, Siemens Oncor linac, 6MV, *.decimal* brass compensators

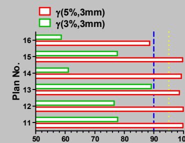
•One plan (16) did not pass γ(5%,3mm) test at 90% level

•Measured dose systematically lower than planned

•Confirmed by analysis ion chamber measurements for the whole patient database

•The cause is under investigation

•High likelihood that the culprit is the beam energy spectrum



Ion Chamber Rel. Error	D4 Mean Rel. Error
-2.0	-2.9
-1.6	-2.7
0.4	-1.3
-2.6	-3.3
-2.9	-3.0
-2.5	-4.0

CONCLUSIONS

•The effective point of measurement coincides with the middle of the detector board

•The unit has an excellent isotropic response

•The phantom can be represented by either a synthetic or a real CT dataset

•Good understanding of the delivery mechanics would help to avoid dose sample bias. For instance, a small phantom shift can mitigate the effect of excessive detector exposure to the segment match line

•The measurements of realistic IMRT plans revealed systematic dose-error patterns which have different underlying mechanisms for MLC- and compensator-based IMRT

•The device is capable of quickly providing a large amount of absolute, three-dimensional dose data, which makes it a robust tool for IMRT commissioning and verification

Disclosure:

Gorgen Nilsson is President and CEO of ScandiDos AB, who loaned the unit for evaluation at no charge