Verification and Benchmark of a Source Model for a Varian 6 MV Photon Beam Using Monte Carlo Calculations

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Introduction

We are developing a flexible measurement-driven machine model for Varian, Elekta, and Siemens linear accelerators for energies of 6 MV and 10 MV.[1] The model is used in the Monte Carlo Dose Planning Method[2] (DPM) dose calculation algorithm. The multi-source model consists of a primary photon point source, an extra-focal exponential disk source,[3] and an electron contamination uniform disk source.[4] The model accounts for fluence and off-axis energy[5] effects due to the flattening filter. This work details the validation and benchmarking of the Varian 6 MV photon beam.

Material & Methods

Dose calculations for field sizes from 4 cm by 4 cm to 40 cm by 40 cm were performed for the Varian 6 MV photon beam. The beam profile measurements were made using an ion chamber. The calculated profiles were convolved with a Gaussian function to account for the artificial broadening of the penumbra due to the ion chamber volume effects.[6] Comparisons between measurement and calculation of beam profiles at several depths and the percent depth dose (PDD) were made. The criteria for acceptance was 2%/2 mm with at least 90% of the data passing.

In addition, a nine beam IMRT homogeneous head and neck (H&N) plan, a nine beam stereotactic lung plan, and a five beam IMRT lung plan were delivered to the Radiological Physics Center's anthropomorphic phantoms that housed TLD and radiochromic film dosimeters for benchmark evaluations (Figure 1). Each delivery was repeated three times. The TLD were positioned next to the film within the phantom. In this way, the film was normalized to the TLD dose value. The films were positioned in the center of the target and extended to low dose regions. The films were oriented in the axial and sagittal planes for the head and neck phantom. Film for the coronal plane was also used for the thorax phantom. The films were read using a CCD camera/light source densitometer. A dose calibration curve was made to convert optical density to dose. Comparisons between measurement and calculation included profiles and gamma maps. The criteria for acceptance was 3%/2 mm with at least 85% of the data passing.

Figure 1: Above, the RPC thorax phantom. Left, the RPC head and neck homogeneous phantom.

Results

Basic beam field sizes from 4 cm by 4 cm to 40 cm by 40 cm for the Varian 6 MV photon beam met the test criteria (2%/2 mm, >90%) (Figures 2 – 7). Benchmark testing of IMRT and SBRT treatment plans for the Varian 6 MV photon beam met the test criteria (3%/2 mm, >85%) (Figures 8 – 24).

Specifically, for basic square beam fields of 4 cm through 40cm (4 cm, 5 cm, 6 cm, 8 cm, 10 cm, 15 cm, 20 cm, 25 cm, and 40 cm) the source model using DPM Monte Carlo calculations agreed with measurement to within 2%/2 mm for at least 90% of the data tested (>96%).

Disagreement at the 2%/2 mm criteria level only occurred for the larger field sizes (20 cm by 20 cm to 40 cm by 40 cm). *[continued]*

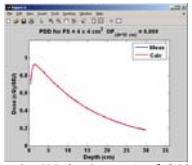

Figure 2: PDD for the 4 x 4 cm² fieldsize. Calculation versus measurement

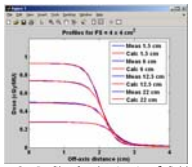

Figure 2: Profiles for the 4 x 4 cm² fieldsize. Calculation versus measurement

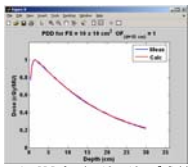

Figure 4: PDD for the 10 x 10 cm² fieldsize. Calculation versus measurement

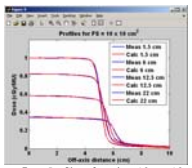

Figure 5: Profiles for the 10 x 10 cm² fieldsize. Calculation versus measurement

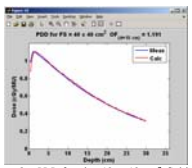

Figure 6: PDD for the 40 x 40 cm² fieldsize. Calculation versus measurement

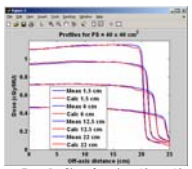

Figure 7: Profiles for the 40 x 40 cm² fieldsize. Calculation versus measurement

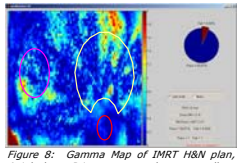

Figure 8: Gamma Map of IMRT H&N plan, Axial plane. Primary target shown as yellow, secondary target shown as pink, critical structure shown as red.

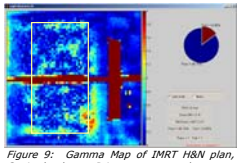

Figure 9: Gamma Map of IMRT H&N plan, Sagittal plane. Primary target shown as yellow.

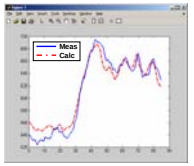

Figure 10: Lateral profile of IMRT H&N plan.

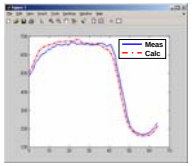

Figure 11: Anterior to posterior profile of IMRT H&N plan.

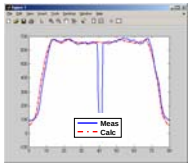

Figure 12: Superior to inferior profile of IMRT lung plan.

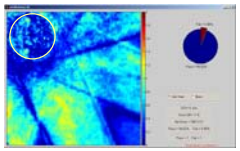

Figure 13: Gamma Map of SBRT lung plan, Axial plane. Target shown as yellow.

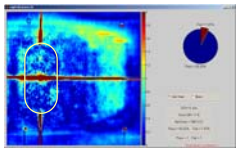

Figure 14: Gamma Map of SBRT lung plan, Sagittal plane. Target shown as yellow.

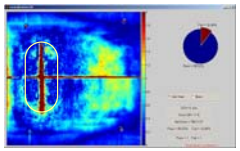

Figure 15: Gamma Map of SBRT lung plan, Coronal plane. Target shown as yellow.

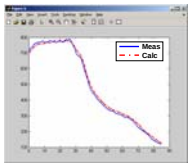

Figure 16: Lateral profile of SBRT lung plan.

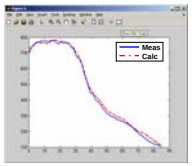

Figure 17: Anterior to posterior profile of SBRT lung plan.

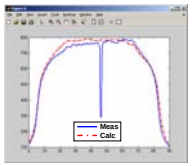

Figure 18: Superior to inferior profile of SBRT lung plan.

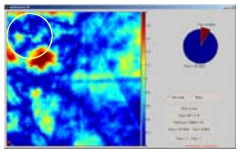

Figure 19: Gamma Map of IMRT lung plan, Axial plane. Target shown as yellow.

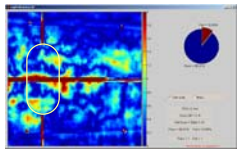

Figure 20: Gamma Map of IMRT lung plan, Sagittal plane. Target shown as yellow.

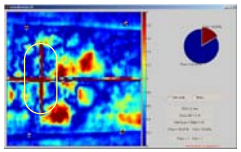

Figure 21: Gamma Map of IMRT lung plan, Coronal plane. Target shown as yellow.

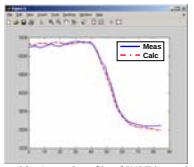

Figure 22: Lateral profile of IMRT lung plan.

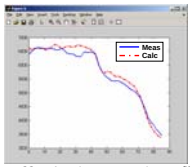

Figure 23: Anterior to posterior profile of IMRT lung plan.

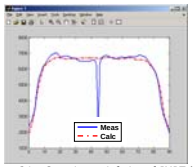

Figure 24: Superior to inferior of IMRT lung plan.

Results

[continued] The horn-effect model tends to overestimate the dose as the off-axis angle increases. While along the central axis, some overestimation in dose occurred between the depths of about 2 cm to 5 cm. In all cases, this disagreement was either within 3% or 3 mm.

For the benchmark results, the agreement at the tested criteria level of 3%/2 mm between calculation and measurement for the IMRT H&N plan was 91%, for the SBRT lung plan was 92%, and for the IMRT lung plan was 87%.

Disagreement at 3%/2 mm criteria level tended to occur in the penumbra regions. In the low-density lung regions of the thoracic phantom the calculation overpredicted the measured dose, while for the homogeneous H&N phantom the calculation underpredicted in the sharp transition from the primary target the adjacent critical structure of this highly modulated plan.

Conclusion

A measurement driven source model applying the DPM Monte Carlo dose calculation has been developed, validated, and benchmarked for use in verifying dose distributions in phantom or patient treatment plans in a non-clinical environment for the Varian 6MV photon beam.

Extending the model to include the Varian 10 MV photon beam is underway. Model development is planned for the Elekta and Siemens 6 MV and 10 MV photon beams.

References

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