A custom-developed method for accurate dose recalculation of patient plans entered into clinical trials

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Introduction:

This study demonstrates the use of a independent method ideally suited to recalculate patient plans from clinical trials whose dose distributions traditionally have been calculated from a multitude of participating institutions. We believe the method will be invaluable to the clinical trial community in outcome analysis studies.

A generic measurement-driven multiple-source model was developed, validated, and benchmarked for the Varian 6 MV and 10 MV photon beams. The parameters of analytical functions describing the model were modified depending on the energy and photon distribution of the linear accelerator. The source model, coupled to the Dose Planning Method (DPM) Monte Carlo (MC) code, maintains an accurate dose calculation. Described previously,[1] the multi-source model consists of a primary photon point source, an extra-focal exponential disk source, and an electron contamination uniform disk source. The model accounts for fluence and off-axis energy effects. This work presents some of the validation and benchmark results with an emphasis on the recalculation of patient plans to demonstrate the versatility of the tool for the potential use in clinical trial outcome analysis.

Material and Methods:

Validation testing was performed by comparing percent depth dose (PDD) and dose profiles between the calculation and measurement for typical square fields. Benchmark testing for each energy was performed by comparing calculation and measurement for IMRT and SBRT treatments delivered to anthropomorphic phantoms. Previously planned IMRT and SBRT patient plans were recalculated using DPM. Comparisons between the DPM calculation and the Pinnacle calculation were made. The comparisons included the dose in regions of interest, dose volume histograms (DVHs), and 2D dose distributions.

Validation Results:

Table 1 includes the validation results of the comparisons between calculation and measurement of the field sizes tested for the Varian 6 and 10 MV photon beams. For the 6 MV beam, for field sizes ≤ 15 cm x 15 cm^2 100% of the data met the 2%/2 mm criteria. The mean of the local percent differences was within 1.0%. For the larger field sizes, the minimum percentage of the data meeting the criteria was 95%. The mean local percent difference for the PDD and profiles was less than or equal to 2.0%. The disagreement tended to occur in the build-up region of the larger field sizes. Table 1, also shows the results of the comparisons between calculation and measurement of the field sizes tested for the Varian 10 MV photon beam. The field sizes from 4 cm x 4 cm^2 to 40 cm x 40 cm^2 met the 2%/ 2 mm criteria for 100% of the data points. The mean of the local percent differences for the Varian 10 MV were similar to the results for the Varian 6 MV photon beam.

Energy (MV)	Field size (cm x cm)	percent meeting 2%/2mm criteria	PDD mean local difference > d_{max}	Profile mean local difference
6	4 to 15	100%	≤ 1.0%	≤ 0.8%
	20 to 40	≥95%	≤ 2.0%	≤ 1.3%
10	4 to 15	100%	≤ 1.5%	≤ 1.1%
	20 to 40	100%	≤ 1.4%	≤ 1.2%

Table 1. Validation of Varian 6 MV and 10 MV PDD and dose profiles.

Benchmark Results:

Table 2 provides the summary of the benchmark treatment plans for the percentage of data that met 3%/ 2mm criteria for the 6 MV and 10 MV models. The results show that on average ≥85% of the data tested met the criteria and both beam models were similar to each other in terms of agreement.

	Energy (MV)	IMRT H&N (%)	SBRT lung (%)	IMRT lung (%)
Average	6	93	94	87
Range		90-98	90-97	81-92
Average	10	94	96	85
Range		90-97	91-98	79-90

Table 2. Percentage of data meeting 3%/ 2mm criteria for the Varian 6 MV and 10 MV photon beam models.

The results from a 6 MV IMRT head and neck phantom plan are presented below. The calculation underestimated the dose to the TLDs located in the center of the primary and secondary targets by less than 2%. Figure 1 shows the lateral profile through the center of the secondary and primary target (left to right). The profile indicated the calculation was within 3% or 2 mm.

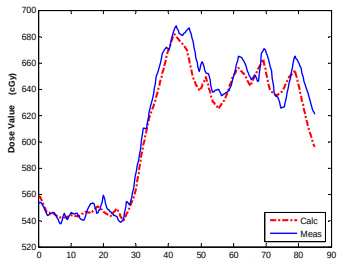


Figure 1. Lateral profile for IMRT H&N, 6 MV photons.

The gamma maps (3%/2 mm) for the 6 MV IMRT H&N phantom plan are shown in figure 2. The gamma maps showed that in general the calculation predicted the dose within the criteria in the high dose, high gradient, and low dose regions. The results indicated that the modeling to describe the penumbra which applied an MLC offset, interleaf leakage, rounded leaf and leaf transmission factors in the highly modulated fields of the head and neck plan was correct. The percentage of the data that met the 3%/2mm criteria was 93%.

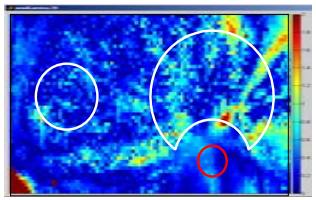


Figure 2. Gamma map (3%/2mm) in axial plane for IMRT H&N plan, 6 MV photons. White contours: Primary target (right); secondary target (left). Red contour: critical structure

Patient Plan Results:

Table 3 shows the ratio of the Pinnacle TPS calculation to the DPM recalculation for the mean dose from selected regions of interest in each of the patient treatment plans studied. In all cases the difference in the mean dose to the gross target volume (GTV) and to planning target volume (PTV) between the calculations was less than 2%. Differences between the calculations for the mean dose to the critical structures ranged from a 2.1% underestimation to a 3.4% overestimation in the TPS calculation.

Treatment	Energy	GTV	PTV	Critical Structure	
IMRT abdomen	6	1.016	1.008	1.033	(kidney)
SBRT lung		1.000	0.984	0.979	(cord)
IMRT prostate	10	1.000	0.996	0.998	(femur)
IMRT lung		N/A	1.008	1.034	(carina)

Table 3 Ratio of mean doses to the ROIs between TPS calculation and DPM recalculation for patient treatments.

The DVHs are shown in Figure 3. The results between the TPS calculation and the DPM calculation are similar. The TPS calculation for the IMRT abdomen 6 MV plan overestimated the dose by 3.3% at 95% of GTV (D_{95}). The differences in the DVHs for the IMRT prostate 10 MV plan were negligible. The SBRT lung 6 MV plan showed the same dose coverage in the GTV, but the TPS calculation under-predicted the PTV D_{95} by 2.2%. The DVHs for the IMRT lung 10 MV plan were similar in the PTV and tended to over-predict the dose to the carina critical structure.

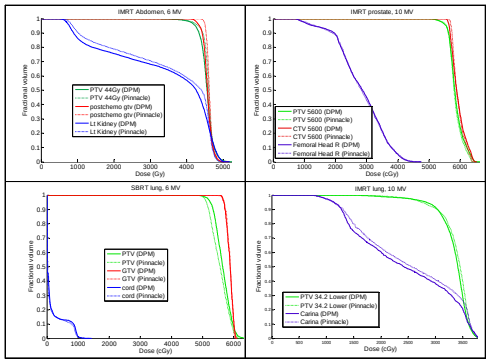
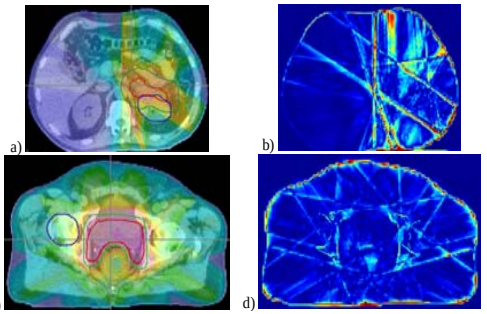


Figure 3. DVH of patient plans: IMRT abdomen, 6 MV (upper left); IMRT prostate, 10 MV (upper right); SBRT lung, 6 MV (lower left); IMRT lung, 10 MV (lower right). DVHs compare TPS calculation and DPM calculation of targets and critical structures.

The differences in the gamma map using a criteria of 5%/ 3mm for all patient treatment plans tested showed a general tendency for the disagreement to occur at the skin build-up, beam penumbra, and heterogeneous interface regions (Figure 4). The difference in the build-up region at the skin surface was not surprising due to electronic disequilibrium. The dose kernels for the convolution superposition algorithm are not as robust in regions of electronic disequilibrium.



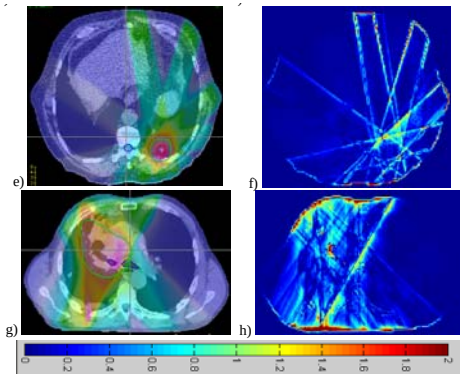


Figure 4 Gamma comparison between Pinnacle and DPM at a criteria of 5% and 3 mm for the patient plans: CT scan of transverse slice at target center with DPM dose distribution is also shown. IMRT abdomen, 6 MV [a) and b)]; IMRT prostate, 10 MV [c) and d)]; SBRT lung, 6 MV [e) and f)]; IMRT lung, 10 MV [g) and h)]. When disagreement occurred, it tended to be at the build-up, beam penumbra, and heterogeneous interface regions.

In addition, the DPM calculation relies on interpreting the voxel location of the contour created for the skin region of interest. The dimension of interest for the voxel size used in the calculation that would affect the true location of the surface of the skin was 2 mm. Therefore, a criterion of 3mm could cause some inaccuracy of the DPM calculation at the skin surface. The differences in beam penumbra have also been difficult to accurately predict the dose. It is known that the Pinnacle TPS dose calculation attempts to address this issue by additional modeling of the MLC leaves. The source model used with the DPM calculation also models the MLC leaves to improve the accuracy of the beam penumbra. The differences observed at heterogeneous interfaces could be a result of the TPS calculation only considering the atomic composition of water and the dose kernels not adequately handling electronic disequilibrium. While the DPM calculation does account for the changes in dose across heterogeneities and the atomic structure of defined anatomy, it is limited by the assignment of the material properties of the anatomy based on a predefined range of the electron density from the CT scan.

Conclusion:

This work demonstrates a source model used with the DPM calculation is robust for the Varian 6 MV and 10 MV photon beams in recalculating patient plans, and therefore could be used to provide a baseline calculation method for patient plans entered into clinical trials for outcome analysis.

Reference:

[1]S. Davidson, J. Cui, G. Ibbott, D. Followill, and J. Deasy, "A flexible Monte Carlo tool for patient or phantom specific calculations: comparison with preliminary validation measurements," Journal of Physics: Conference Series (2008).

Support:

Work supported by PHS CA010953, CA081647, and R01 CA85181 awarded by NCI, DHHS