Benchmarking a flexible Monte Carlo tool based on the DPM code for use in evaluating IMRT treatment planning systems

S Davidson[1], J Cui[2], D Followill[1], G Ibbott[1], and J Deasy[2]

[1]The University of Texas M. D. Anderson Cancer Center, Houston, TX

[2]Washington University, St. Louis, MO

Introduction

Measurement-based comparisons have traditionally provided an acceptable assurance in determining an institution's performance in terms of correct dose delivery. However, there has been growing concern that today's escalating dose prescriptions, delivered with increased conformality and steep gradients, have pushed the limits of measurement uncertainty.[1] Clinical trial working groups have discussed ways to implement a common tool that can be used to audit all treatment planning system (TPS) dose calculations for quality assurance purposes. One way to address the difficult dosimetry issues is through the use of a trusted independent dose calculation. Monte Carlo dose calculations have been perceived as a complementary method to both measurement and analytical based numerical calculations. Specifically, **a new tool comprised of a unique source model and the Dose Planning Method (DPM) code** adapted for this purpose **is evaluated through verification and benchmark testing** that includes: linac energy spectras, percent depth dose, profiles, a 3D conformal lung plan with the MLC's fully retracted, and an IMRT lung plan.

Key Points

- The source model, described by the product of Fatigue and Fermi functions, simulated the energy spectrum from 9 different linacs. These spectras were compared to those produced using the BEAM code.[2]
- Verification/benchmark tests for a Varian 6MV photon beam using ion-chamber, thermoluminescent detectors (TLDs), and radiochromic film included:
  - Percent depth dose, profiles, and output factors
  - 3-D and IMRT lung plans using the Radiological Physics Center (RPC) thoracic phantom
- Future tests will include: Elekta and Siemens linacs

Benchmark: Energy spectrum

Figure 1 shows the versatility of the source model to agree well with the BEAM code when comparing the energy spectra from 9 different linacs.

Verification: Varian 6MV, Beam data

Figures 2 and 3 show PDD and dose profiles, respectively, of the DPM calculated and measured dose values for a 6MV photon beam, using a 10x10 cm^2 field-size, in a water phantom at 100 cm SSD. Figure 4 compares the calculated and measured output factors at various field sizes. In general, good agreement exists in all basic commissioning beam data. Development of the horn-effect continues in an effort to better match the measured output factors (normalized at the 10 cm x 10 cm results).

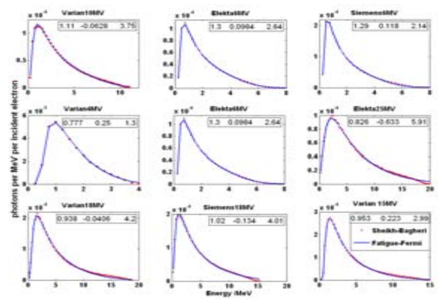

Figure 1. Energy spectrum (ph./MeV/incident e⁻ vs. MeV) comparison between Fatigue-Fermi model (blue) and the BEAM code[2] (red) from 9 different linacs

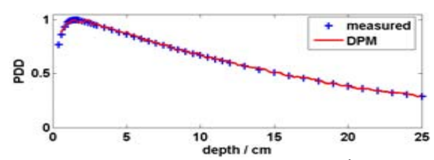

Figure 2. PDD calculation and IC measurement. 6MV, 10x10cm[2] water.

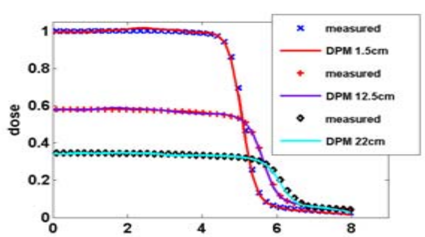

Figure 3. Lateral dose profiles based on the set-up in figure 2 at depths of 1.5cm 12.5cm, and 22cm. The Gaussian kernel for the IC diameter has been convolved onto the calculated dose to account for the smearing of the penumbra by the IC measurement.[3]

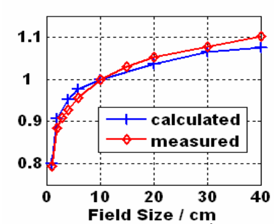

Figure 4. Output factor for field sizes from: 1x1cm[2] to 40x40cm[2]. Development of the horn-effect modeling to improve the agreement of the measured output factors continues.

Benchmark: 3D and IMRT lung plans

General method: The 3-D and IMRT lung plans were designed using the Pinnacle TPS. In each case, three repeated irradiations were made using TLD and radiochromic film housed within the Radiological Physics Center thoracic phantom (Figure 5). These measurements were compared to the DPM and Pinnacle superposition-convolution calculations. Analysis included point-dose comparisons within the tumor, heart, and cord (Table 1 and 2) and dose-profile comparisons through the center of the tumor in all three anatomical planes (Figure 6 and 7 show the lateral profiles).

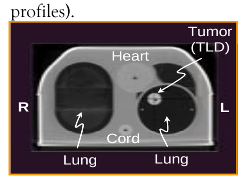

Figure 5. CT scan of the RPC anthropomorphic thoracic phantom. Shown here, is the axial slice through the center of the tumor.

3-D plan: The plan consisted of five beams positioned 72° apart. The MLCs of this plan were fully retracted such that this aspect of the model was not represented.

IMRT plan: The plan consisted of five beams (four coplanar beams and one non-coplanar beam) having 63 MLC static segments.

General result: The noise from the DPM dose calculation is evident (Figure 6 and 7). This is due, in part, to the down-sampling used for this calculation. Also, some of the differences in the calculated dose are due to the presently limited material definitions that affect the correct stopping power assignment.

Table 1. 3-D conformal plan point dose comparisons of calculation (DPM and TPS) to TLD measurements.

	Ratio of calculation to measurement		
Calculation	Tumor	Heart	Cord
DPM	1.008	0.736	0.948
Pinnacle	1.025	0.774	1.083

Table 1. In the tumor, the ratio of calculated doses, DPM and TPS, compared well to measurement (1% and 2.5%, respectively). In the cord, where the dose is low, discrepancies of over 5% are noted. In the heart where the dose gradient is high, DPM and the TPS agree within 5% of each other, while both are lower than TLD by about 25%. The setup uncertainty of the phantom contributed to the large discrepancy within a known high gradient region.

Table 2. IMRT plan point dose comparisons of calculation (DPM and TPS) to TLD measurements.

	Ratio of calculation to measurement		
Calculation	Tumor	Heart	Cord
DPM	1.018	1.075	0.993
Pinnacle	1.019	1.053	0.983

Table 2. The ratio of calculated point doses, DPM and TPS, compared to measurement are within 2%. The dose in the heart did not have a high dose gradient like the conformal plan further confirming the discrepancy noted in the 3-D plan. Although the DPM and the TPS did overestimate the dose in the heart by at least 5% in a low dose region.

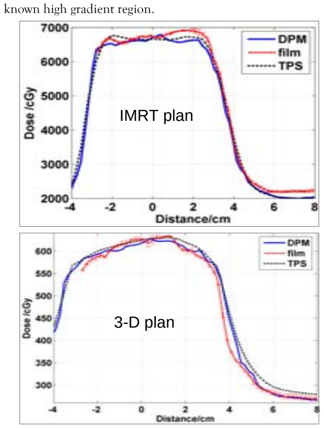

Figure 6 and 7. Lateral profile comparison through the center of the tumor, extending into the penumbra and low dose lung region. Good agreement exists between the calculation and measurement.

Conclusions

The Fatigue-Fermi function for the source model fits the photon spectra from various linear accelerator manufacturers making it flexible for use within a generic calculation tool. While more development of the source model is necessary, verification testing of the basic beam data and initial benchmark testing of the 3-D and IMRT lung plans demonstrates the viability of this source model approach with the DPM Monte Carlo code in order to make dose calculations for use in quality assurance audit checks.

References

[1]Ezzell, G.A. et al, "Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee," Med Phys 30 (8), 2089-2115 (2003).

[2]Sheikh-Bagheri, D. and Rogers, D.W.O., "Monte Carlo calculation of nine megavoltage photon beam spectra using the BEAM code," Medical Physics 29 (3), 391-402 (2002).

[3]Arnfield, M.R. et al, "The use of film dosimetry of the penumbra region to improve the accuracy of intensity modulated radiotherapy," Med Phys **32** (1), 12-18 (2005).