Development of an independent, Monte Carlo, dose calculation, quality assurance tool for clinical trials

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Introduction

The Radiological Physics Center (RPC) is one of three National Cancer Institute (NCI) funded, quality assurance (QA) offices that provides radiotherapy QA auditing services to institutions participating in NCI funded cooperative clinical trials. The RPC has developed several programs as a means to efficiently provide dosimetric and QA services to the clinical trial community and to ensure NCI that the institutions participating in clinical trials deliver comparable and consistent radiation doses.

Currently, the RPC is not able to fully verify the accuracy of IMRT and heterogeneity corrected dose calculations. In order to evaluate and judge the accuracy of the TPS predicted dose distributions, a trusted independent dose calculation tool is needed. This tool would serve three primary uses:

1) Evaluate TPS dose calculations against an independent standard

2) Supplement the anthropomorphic phantom program as an additional means of comparison

3) Act as a standard of comparison in any potential retrospective, outcome based analysis of clinical trials

For these reasons the RPC began the development of a multiple source model that is executed using the Monte Carlo technique using the Dose Planning Method (DPM) code. While a generic model for Varian 6 and 10MV beams has been completed[1,2], to be a fully functional tool the dose calculation tool must also include models capable of performing dose calculations for Elekta machines.

Currently, the multiple source model is composed of three analytical components describing the output of a therapeutic megavoltage photon beam. The components correspond to the primary source in the treatment head, an extra-focal scattering source, and a source to model electron contamination in the beam. The analytical model is coupled to the DPM code where simulation of the particle transport occurs resulting in the independent dose calculation tool.

Methods

A three source, Monte Carlo model of Elekta 6 and 10MV therapeutic x-ray beams was developed in a two-step process. Energy spectra of each of three sources, a primary source corresponding to photons created in the target, an extra-focal source corresponding to photons originating from scattered events in the linac head, and an electron contamination source, were determined. The two photon sources were determined by an optimization process that fit the relative fluence of 0.25 MeV energy bins to the product of Fatigue-Life and Fermi functions to match calculated percent depth dose (PDD) data with that measured in a water tank for a 10x10cm^2 field.

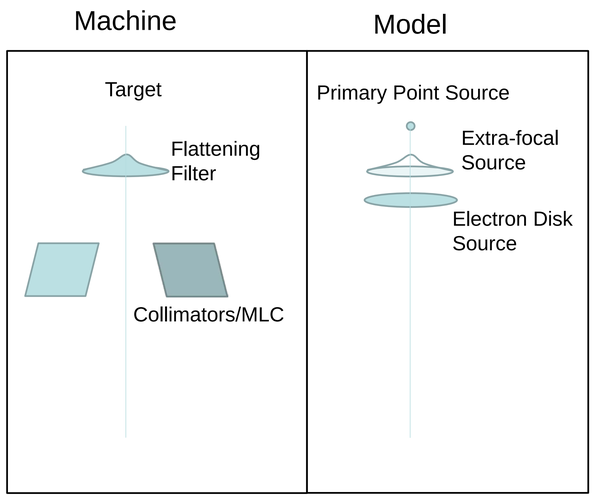

Figure 1: Illustration of location and design of each of the three sources (right) in the multiple source model with respect to the machine design (left). A primary source exists at the location corresponding to the target, an extra-focal source consistent with the location of the flattening filter, and an electron disk source located at the same position as the extra-focal source but shown below for clarity in this diagram.

Off-axis effects were modeled by fitting the off-axis fluence to a piecewise linear function through optimization of relative fluence to match calculated dose profiles with measured dose profiles for a 40 x 40 cm^2 field. A 3rd degree polynomial was used to describe the off-axis half-value layer as a function of off-axis angle. The model was then commissioned by comparing calculated PDDs and dose profiles for field sizes ranging from 3 x 3 cm^2 to 30 x 30 cm^2 to those obtained from measurements.

Results

Agreement between calculated and measured data was evaluated using 2%/2mm global gamma criterion for field sizes of 3x3, 5x5, 10x10, 15x15, 20x20, and 30x30 cm^2. Along the central axis of the beam 99.9% of all data passed the criterion for 6 and 10MV models, respectively. Dose profiles at depths of d_{max}, 5.0, 10.0, 20.0, and 25.0cm agreed with measured data for 99.6% and 99.9% of data tested for 6 and 10MV models, respectively.

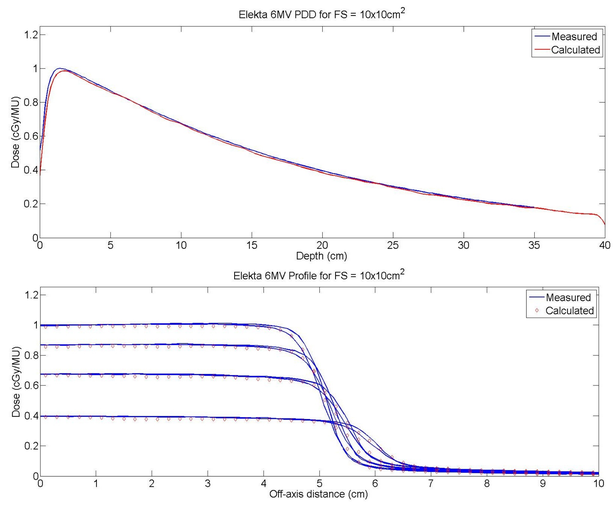

Figure 2: Percent depth dose comparison (top) and dose profile comparison at depths of d_{max}, 5.0, 10.0, and 20.0 cm (bottom) of commissioned, 6MV Elekta model for field size of 10x10 cm^2.

Elekta 6 MV Total	
PDD Average	**99.9%**
Profile Average	**99.6%**

Table 1: Averages of percentage of pixels passing 2%/2mm gamma analysis for commissioned, Elekta 6MV model. Averages were taken for field sizes of 3x3, 5x5, 10x10, 15x15, 20x20, and 30x30 cm^2 for percent depth dose data and does profiles and at depths of 1.5, 5.0, 10.0, and 20.0 cm for dose profiles.

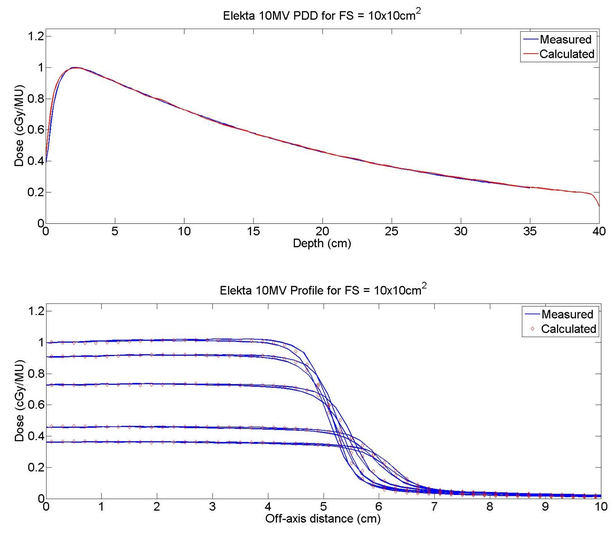

Figure 3: Percent depth dose comparison (top) and dose profile comparison at depths of 2.0, 5.0, 10.0, 20.0, and 25.0 cm (bottom) of commissioned, 10MV Elekta model for field size of 10x10 cm^2.

Results (continued)

Elekta 10 MV Total	
PDD Average	**99.9%**
Profile Average	**99.9%**

Table 2: Averages of percentage of pixels passing 2%/2mm gamma analysis for commissioned, Elekta 10MV model. Averages were taken for field sizes of 3x3, 5x5, 10x10, 15x15, 20x20, and 30x30 cm^2 for percent depth dose data and does profiles and at depths of d_{max}, 5.0, 10.0, 20.0, and 25.0 cm for dose profiles.

Conclusion

A multiple-source, Monte Carlo model of Elekta 6 and 10MV therapeutic x-ray beams has been commissioned for open field calculations. Model agreement compared to measurements has been excellent as 99.9% and 99.6% of all percent depth dose data and dose profile data respectively met a 2%/2mm criterion in gamma analysis for the 6MV model. Agreement for the 10MV percent depth dose data and dose profile data was 99.9% each using the same criterion.

Future Work

Expansion of the tool to perform calculations for patient and phantom treatment plans is ongoing and being done by benchmarking calculated doses to measurements taken using the RPC's anthropomorphic phantoms. Modeling of multi-leaf collimators and multiple beam angles while performing calculations in heterogeneous media will complete the development of this independent, dose calculation, quality assurance tool.

References

1) Davidson, S., J. Cui, et al. (2008). "A flexible Monte Carlo tool for patient or phantom specific calculations: comparison with preliminary validation measurements." Journal of Physics: Conference Series **102**.

2) Davidson, S., S. Kry, et al. (2010). DPM Monte Carlo with multi-source model: validation and benchmark results. Proceedings of the CVIth ICCR, Amsterdam, North Holland, Netherlands.

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