THE DEVELOPMENT OF A MONTE CARLO SYSTEM TO VERIFY RADIOTHERAPY TREATMENT DOSE CALCULATIONS

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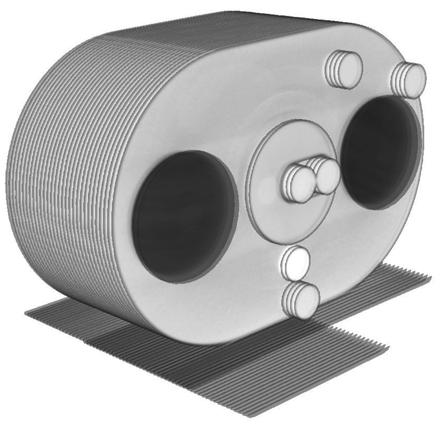
Introduction

Recent advances in the planning and delivery of radiotherapy treatments have resulted in improvements in the accuracy and precision with which therapeutic radiation can be administered. As the complexity of the treatments increases it becomes more difficult to predict the dose distribution in the patient accurately. Monte Carlo methods have the potential to improve the accuracy of the dose calculations and are increasingly being recognised as the "gold standard" for predicting dose deposition in the patient [1].

In this study, software has been developed that enables the transfer of treatment plan information from the treatment planning system to a Monte Carlo dose calculation engine. A database of commissioned linear accelerator models (Elekta Precise and Varian 2100CD at various energies) has been developed using the EGSnrc/BEAMnrc Monte Carlo suite [2]. Planned beam descriptions and CT images can be exported from the treatment planning system using the DICOM framework. The information in these files is combined with an appropriate linear accelerator model to allow the accurate calculation of the radiation field incident on a modelled patient geometry. The Monte Carlo dose calculation results are combined according to the monitor units specified in the exported plan. The result is a 3D dose distribution that could be used to verify treatment planning system calculations.

The software, *MCDTK (Monte Carlo Dicom ToolKit)*, has been developed in the Java programming language and produces BEAMnrc and DOSXYZnrc input files, ready for submission on a high-performance computing cluster. The code has been tested with the Eclipse (Varian Medical Systems), Oncentra MasterPlan (Nucletron B.V.) and Pinnacle3 (Philips Medical Systems) planning systems. In this study the software was validated against measurements in homogenous and heterogeneous phantoms. Monte Carlo models are commissioned through comparison with quality assurance measurements made using a large square field incident on a homogenous volume of water. This study aims to provide a valuable confirmation that Monte Carlo calculations match experimental measurements for complex fields and heterogeneous media.

Quasar Phantom



The Quasar™ multi-purpose body phantom designed to model a patient thorax: it is a 30 cm wide, 20 cm high and 12 cm long acrylic body oval, with openings for cylindrical inserts of 2 and 8 cm diameter.

3 beams were delivered to the phantom using an Elekta Precise linac operating at a nominal energy of 6 MV. These beams were designed on a Varian Eclipse treatment planning system (using a pencil beam dose calculation algorithm), using CT data acquired from a Toshiba Aquilon/LB scanner. The beams were designed to allow the measurements recommended by AAPM [3] for external beam calculation verification: in the inner beam, 0.5 cm inside and outside the penumbral region, outside the beam, in the build-up region and along the central axis.

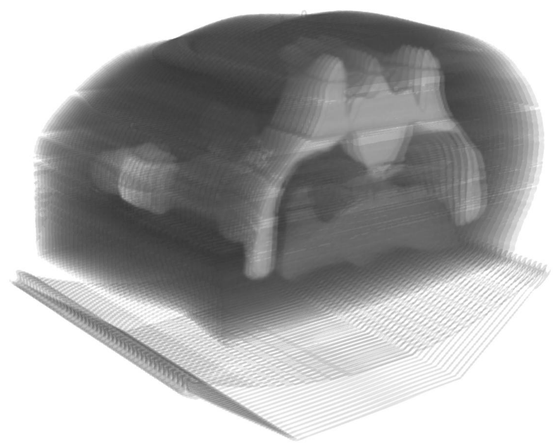
12 measurements were taken: 8 without the lung inserts (a completely homogenous phantom) and 4 with the lung inserts and a 2 cm diameter bone insert. Measurements were normalised to the central dose reference point.

Elvis Phantom

The Trans-Tasman Radiation Oncology Group performed an Australasia-wide dosimetry audit [4], examining the accuracy of planning and delivering dose to a pelvis phantom, referred to as "Elvis". A treatment plan and the corresponding dose measurements were made available for this study.

The "treatment" involved 4 conformal beams delivered to the prostate, using an Elekta Precise linac operating at a nominal energy of 10 MV. These beams were planned on a Varian Eclipse treatment planning system (using a pencil beam dose calculation algorithm), using CT data acquired from a GE HiSpeed scanner.

TLD measurements were taken at 10 locations: in the target volume and organs-at-risk; and in tissue and in bone. The simulation doses were expressed relateive to the dose to the near-isocentric prostate TLD.



Results & Discussion

Agreement between measured and simulated dose was found for both phantoms: with the exception of one case, the deviation did not exceed the uncertainty of the dose. The simulated dose values represent the average dose over the measurement volume and the stated uncertainty was calculated using the standard deviation of those voxel values.

This approach, while accurately representing the "noise" inherent in Monte Carlo simulation, can result in large dose measurement uncertainties in high dose gradient regions (such as the penumbra and build up region).

The disagreement between the measured and simulated dose values seen at the "before lung insert" measurement location was larger than the uncertainty. This measurement was made in a 3 cm gap between the top-side of the phantom and a lung insert: within the build-up region, where dose can be incorrectly measured. With the exception of the "outside field" measurement, where the deviation is not significant in an absolute sense, the largest deviations were found in other high dose gradient regions. These regions are more suited to a distance-to-agreement analysis.

The Monte Carlo simulated dose more accurately predicted the measured dose in 9 of the 10 measurement locations in the "Elvis" phantom. The planning system over-estimated the dose to all measurement locations except the out of field pelvis side wall. Four of the planning system dose deviations exceeded 5%: a common standard of acceptable uncertainty and three of these corresponded to significant dose levels.

The least accurate Monte Carlo prediction (3.36% deviation) in the "Elvis" measurements still provides greater accuracy than 80% of the treatment planning system calculations.

Ion Chamber	Measured Dose	Simulated Dose	Deviation
Central axis (2 cm depth)	1.564	1.414 ± 13.5%	10.6%
Central axis (5 cm depth)	1.399	1.383 ± 2.7%	1.2%
Central axis (8 cm depth)	1.159	1.149 ± 2.8%	0.9%
Central measurement	1.000	1.000 ± 2.0%	-
Inside Penumbra	1.352	1.229 ± 23.8%	10.0%
Outside Penumbra	0.089	0.296 ± 88.4%	69.9%
Outside Field	0.014	0.011 ± 15.4%	27.3%

Table 1. Homogeneous Quasar Phantom Measurements

Ion Chamber	Measured Dose	Simulated Dose	Deviation
Central measurement	1.000	1.000 ± 1.5%	-
Before Lung Insert	1.474	1.430 ± 1.8%	3.1%
Beyond Lung Insert	0.961	0.975 ± 3.1%	1.5%
Beyond Bone	0.590	0.611 ± 3.4%	3.4%

Table 2. Heterogeneous Quasar Phantom Measurements

TLD Position	Measured Dose (Gy)	Planning Dose (Gy)	Deviation	Simulated Dose (Gy)	Deviation
Prostate (Approx. Isocentre)	1.929 ± 0.62%	2.021	4.55%	1.929 ± 3.41%	-
Left Femoral Head	1.097 ± 0.98%	1.120	2.05%	1.100 ± 3.46%	0.27%
Right Femoral Head	1.063 ± 1.02%	1.120	5.09%	1.089 ± 2.48%	2.48%
Left Seminal Vesicle	1.974 ± 1.08%	2.087	5.41%	1.982 ± 1.94%	0.39%
Right Seminal Vesicle	1.986 ± 0.94%	2.086	4.79%	1.968 ± 1.89%	0.91%
Base of Seminal Vesicles	1.988 ± 0.87%	2.087	4.74%	1.965 ± 1.16%	1.14%
Posterior Prostate (Rectal Wall)	1.946 ± 1.28%	2.063	5.67%	1.968 ± 2.74%	1.13%
Prostate Apex	1.908 ± 0.80%	2.010	5.07%	1.931 ± 2.98%	1.21%
Anorectal Sphincter (Dentate Line)	1.187 ± 1.08%	1.205	1.49%	1.208 ± 2.24%	1.80%
Right Pelvis Side Wall (Out Of Field)	0.082 ± 0.92%	0.064	28.13%	0.079 ± 6.64%	3.36%

Table 3. Elvis Phantom Measurements

Conclusion

The study demonstrated the accuracy of Monte Carlo simulation in predicting dose in a heterogeneous phantom. This provides increased confidence that a Monte Carle dose prediction for a clinical treatment plan will more accurately reflect the dose delivered to the patient. IMRT radiotherapy is beginning to be adopted in the Australasian region: as more conformal treatments become the standard of care and as image-guided techniques improve treatment delivery, the accuracy of dose calculation will become more important. This study is part of on-going doctoral research, that will involve the simulation and verification of complex clinical treatment plans.

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