PhD Thesis Title: "Sensitivity Analysis of the Integral Quality Monitoring System® for Radiotherapy Verification using Monte Carlo Simulation"

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ABSTRACT:

Advanced radiotherapy (RT) techniques have improved the quality of radiation treatment. Notwithstanding, advanced RT techniques have generated complexities in their quality assurance (QA). Therefore, there is huge interest to verify treatment plan data in real-time treatment. The Integral Quality Monitoring (IQM) system® (iRT Systems GmbH, Koblenz, Germany) is an independent real-time treatment verifying system which checks the integrity and validates the accuracy of the treatment plan data. The IQM also functions as a pre-treatment quality assurance tool for radiotherapy. The prototype system (IQM) is currently undergoing its beta testing, and contributions from researchers across the globe are pivotal to its integration into the clinical workflow. The IQM is a large wedge-shaped ionization chamber that is attached to the treatment head of the linear accelerator (linac) for signal measurement in real-time treatment. The aim of this innovative study was to determine how sensitive the IQM is for small alterations in the multileaf collimator (MLC) leaf positions using Monte Carlo (MC) simulations. The sensitivity of the IQM system is essential for its integration into clinical workflow. The MC simulation technique is an accurate dose calculation engine that could score dose in regions that seem complicated for physical measurement.

A new component module (CM) called IQM was successfully developed using TCL/TK, and More FORTRAN (MORTRAN) codes. The newly created CM was added-on to the BEAMnrc MC User code.

Also, a linac source model of an Elekta Synergy linac equipped with an Agility 160-leaf MLC head was developed using the EGSnrc/BEAMnrc. Accurate MC calculations for percentage depth doses, lateral beam profiles, and relative output factors were benchmarked with physical measurements using the Gamma analysis criterion of 2%/2 mm. Characterised photon beams of 10 MV for 1 × 1 up to 30 × 30 cm^2 fields using the BEAMnrc MC Code were simulated. Photon beam data stored in the phase space files after the source model simulations were calculated in a homogeneous water phantom using the DOSXYZnrc MC Code.

For the square field sizes considered, MC dosimetry features (percentage depth doses and lateral beam profiles) passed the gamma (γ) index criterion of 2%/2 mm. MC calculations and physical measurements agreed to approximate local difference of 1.44% for relative output factors. This accurate source model is suitable for the sensitivity study. It also has the potential to be used for dose calculation in advanced radiotherapy treatment planning.

The accurate source model with the IQM CM positioned with its central electrode plate fixed perpendicularly to the photon beam in subsequent simulations was used. The spatial integral dose in the air region of the IQM CM was calculated. The IQM MC dose was calculated for 1 × 1 up to 30 × 30 cm^2 fields at 10 MV photon beams and then correlated with physical measurement of the prototype IQM system. Secondly, systematic positional errors of 1, 2 and 3 mm were subtracted and added to the whole MLC bank of 1 × 1, 3 × 3, 5 × 5 and 10 × 10 cm^2 fields. Thirdly, the IQM signal response for 1, 2, 3, 4 and five leaves shifted out of a 5 × 5 cm^2 field for positional error of 1, 2, 3, 5, and 10 mm was calculated. Fourthly, the signal response was calculated for segments along the gradient of the IQM CM for 3 × 3, 5 × 5 and 7 × 7 cm^2 fields at 10 MV photon beams. Lastly, eleven segments (regular and irregular) were altered randomly within ±1, ±2 and ±3 mm regarding its individual leaf positions as defined at the isocentre. Sensitivity analyses of leaf positioning errors were studied by using techniques such as scatter plots, brute force, variance-based and standard regression coefficient.

The normalised IQM signal increases with an increase in square field sizes for the MC calculation and the physical measurement. The IQM model is highly sensitive to alterations of 1 × 1 cm^2 more than other fields considered. For the segments considered, the magnitude of the signal response decreased and increased when systematic positional errors were subtracted from and added to individual MLC leaves. An increase in numbers of leaves shifted out causes an increase in IQM signal response and an increase in the position of moving leaves causes a further increase in the IQM signal. The sensitivity of the IQM model increases along the gradient of the IQM up to a noticeable plateau. The sensitivity analysis techniques utilised in this study deduced that the IQM model is highly sensitive to leaf positions of small segments compared to large apertures.

The newly developed IQM MC model can now serve as a basis for researchers that have an interest in dose monitoring and MLC calibration using the wedge-shaped ionization chamber. The IQM model shows a potential platform for further study on advanced radiotherapy quality control.

Application of MC techniques to dose monitoring is authentic. It demonstrates that the MC radiation transport method is virtually unlimited when it comes to solving radiation transport and dose calculation challenges.

References to author publications that relate specifically to the dissertation:

1. **Oluwaseyi M. Oderinde** and Freek du Plessis (2017); Technical note: A new wedge-shaped ionization chamber component module for BEAMnrc to model the integral quality monitoring system®. *Radiation Physics and Chemistry; Vol 141, pp 346-351.* http://www.sciencedirect.com/science/article/pii/S0969806X17301949

2. **Oluwaseyi M. Oderinde** and Freek du Plessis (2017); Sensitivity analysis of the integral quality monitoring system using Monte Carlo simulation. *Computational and Mathematical methods in Medicine; Vol 2017, Article ID: 7025281, pp 1-12*. https://doi.org/10.1155/2017/7025281

Published conference abstracts:

1. **Oluwaseyi M. Oderinde** and Freek du Plessis (2016); Monte Carlo modeling of a prototype beam delivery check system for Intensity Modulated Radiation therapy plan. *Physica Medica European Journal of Medical Physics; Vol 32, Suppl 32, p32.* http://www.sciencedirect.com/science/article/pii/S1120179716301454

2. **Oluwaseyi M. Oderinde** and Freek du Plessis (2016a); Accurate Monte Carlo modeling of an Elekta Synergy linac equipped with an Agility 160-leaf MLC. *Physica Medica European Journal of Medical Physics; Vol 32, Suppl 32, pp 31-31.* http://www.sciencedirect.com/science/article/pii/S1120179716301442

3. **Oluwaseyi M. Oderinde** and Freek du Plessis (2015); Monte Carlo study of an integral quality monitoring system. *Physica Medica European Journal of Medical Physics; Vol 31;Suppl 1; p s18.* http://www.physicamedica.com/article/S1120-1797(15)00225-2/abstract