EPID-based Dosimetry for Remote Auditing of Radiotherapy Clinical Trials

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Abstract

The objective of this research is to implement a novel approach for remote dosimetric auditing of clinical trials. The audit should ensure an accurate dose delivery at different radiotherapy centres with minimum cost.

High variation and complexity of planning and delivery systems may result in discrepancy of dose delivery for the trials. The deliveries are assessed to reduce variability and improve reliability of the trials. The assessment is conducted through rigorous quality assurance (QA) and/or external dosimetric audits. Conventionally, an independent centre performs external audits by site visits or mailing phantoms and dosimeters.

This research presents an innovative approach to remotely audit dose deliveries for clinical trials performed at centres in Australia and New Zealand. Participants are provided with CT data sets of two trial patients and two virtual phantoms. They plan the trials for intensity modulated radiotherapy (IMRT) and/or volumetric modulated arc therapy (VMAT) deliveries using local treatment planning systems (TPSs). Then, they send in-air acquired images from their electronic portal imaging devices (EPIDs) to the auditing site. The EPIDs provide relatively consistent data acquisition system for analysis significantly reducing the audit cost.

A model was developed using images from aS1200 EPIDs for verification of IMRT dose distribution from deliveries of TrueBeam linacs. The model was based on published methods and a clinically established IMRT QA procedure for Varian C-series linacs. Similarly, an Elekta specific model was developed for deliveries of Elekta systems and the results were compared to those from Varian specific model. Minor improvement was observed for the vendor specific models. The QA method was extended for remote auditing of IMRT/VMAT deliveries. The audit instruction provided benchmark planning exercise of two head and neck (HN) and post-prostatectomy (PP) patients and two flat and cylindrical phantoms for participants. The feasibility of the approach including implementation details was demonstrated over six facilities in a pilot study. Then, the audit results from 30 facilities were used to develop a linear model on explanatory variables. It demonstrated significant influence of TPS-linac, calculation grid resolution and IMRT/VMAT type on the audit outcome. The audit outcome demonstrated high gamma pass rates for the trials and provided results comparable to the established more resource-intensive audit methods.

Statement of originality / Declaration by author

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

The author acknowledges that copyright of published works contained within this thesis resides with the copyright holder(s) of those works.

All the enclosed publications in this thesis are the author's original work. The model for EPID to dose conversion for the Varian aS1000 system was developed by P.Greer based on work by B.King and the software used for the VESPA audit results was developed by P.Greer and B.Zwan. The VESPA audit instructions to the centres was developed by P.Greer.

Narges Miri 20/08/2018

Thesis by publication

I hereby certify that this thesis is in the form of a series of papers. I have included as part of the thesis a written declaration from each co-author, endorsed in writing by the Faculty Assistant Dean (Research Training), attesting to my contribution to any jointly authored papers.

By signing below I confirm that Narges Miri contributed analysis and writing to the papers/publications of J2, J3 and J5 in the publication list.

Joerg Lehmann 21/08/2018

By signing below I confirm that Narges Miri contributed measurement, modelling, analysis and writing to the papers/publications of J2, J3, J4 and J5 in the publication list.

Philip Vial, 20/08/2018,

By signing below I confirm that Narges Miri contributed modelling, analysis and writing to the papers/publications of J1 and J3 in the publication list.

Benjamin Zwan, 21/08/2018

By signing below I confirm that Narges Miri contributed analysis and writing to the paper/publication of J5 in the publication list.

Kim Colyvas

By signing below I confirm that Narges Miri contributed writing and analysis to the papers/publications of J2, J3 and J5 in the publication list.

Kimberley Legge, 21/08/2018,

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Alisha Moore 21/8/18

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Monica Harris 21/8/18

By signing below I confirm that Narges Miri contributed modelling, measurement, writing and analysis to the papers/publications of J1, J2, J3, J4 and J5 in the publication list.

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List of publications included in the thesis

Peer reviewed journal publications:

J1- N. Miri, P. Keller, B. J. Zwan, and P. Greer, "EPID-based dosimetry to verify IMRT planar dose distribution for the aS1200 EPID and FFF beams," Journal of Applied Clinical Medical Physics, vol. 17, no. 6, 2016.

J2- N. Miri, J. Lehmann, K. Legge, P. Vial, and P. B. Greer, "Virtual EPID standard phantom audit (VESPA) for remote IMRT and VMAT credentialing," Physics in Medicine and Biology, vol. 62, no. 11, p. 4293-4299, 01/2017.

J3- N. Miri, J. Lehmann, K. Legge, B. J. Zwan, P. Vial, and P. B. Greer, "Remote dosimetric auditing for intensity modulated radiotherapy: A pilot study," Physics and Imaging in Radiation Oncology, vol. 4, pp. 26-31, 10/ 2017.

J4- N. Miri, P. Vial, and P. B. Greer., " Remote dosimetric auditing of clinical trials: the need for vendor specific models to convert images to dose" Journal of Applied Clinical Medical Physics, vol. 20, no. 1, 11/2018.

J5- N. Miri, K. Colyvas, K. Legge, J. Lehmann, P. Vial, A. Moore, M. Harris, and P. B Greer, " A remote EPID-based dosimetric TPS-planned audit of centers for clinical trials: outcomes and analysis of contributing factors" Radiation Oncology, vol. 13, p. 178, 2018.

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Thesis Structure

This thesis opens by introducing radiotherapy and auditing methods for radiotherapy clinical trials. Then, the body of the thesis will be presented in nine chapters:

Chapter 1) Introduction:

- Chapter 1 introduces an overview of radiotherapy process and quality assurance (QA). It provides a background on the QA of radiotherapy clinical trials and conventional methods for dosimetry auditing. Challenges for current audits open the new approach for the audit.

Chapter 2) Literature review and research design:

- Chapter 2 presents a literature review on conventional dosimetric auditing methods for intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) deliveries. It then reviews current methods on 2D and 3D dosimetry methods for images from electronic portal imaging devices (EPIDs). Required corrections and calibrations are explained for the images. Then, the chapter outlines the concept of the new approach, virtual EPID standard phantom audit (VESPA), for dosimetric auditing.

Chapter 3) Modelling for Truebeam systems:

- Chapter 3 performs a dosimetry commissioning on aS1200 EPIDs from Truebeam linear accelerators (linacs) compared with aS1000 EPIDs from Varian C-series. Then, a model is developed to convert aS1200 EPID signals to dose inside a virtual flat phantom. The delivered dose is then compared with calculated TPS dose to assess accuracy of the deliveries. This chapter was presented in a journal paper [J1].

Chapter 4) Modelling for Elekta systems:

- Chapter 4 follows on Chapter 3 by presenting a model development for Elekta system deliveries. It evaluates relevant dosimetric differences between Varian and Elekta systems and whether the audit requires a vendor specific model for auditing purpose. This chapter was presented in a journal paper [J4].

Chapter 5) Remote Auditing:

- Chapter 5 introduces a novel approach to remotely audit radiotherapy clinical trials. The approach has a potential to significantly reduce the audit cost. This chapter explains

implementation of the method for auditing IMRT/VMAT deliveries. The material in Chapter 5 was presented in a journal paper [J2].

Chapter 6) A pilot auditing:

- Chapter 6 follows on from chapter 5 by applying the method for six pilot centres. The centres provide pre-treatment IMRT images from their EPIDs while the auditing site converts the images to dose inside virtual phantoms and assesses accuracy of each delivery. The material in Chapter 6 was presented in a journal paper [J3].

Chapter 7) Overall auditing:

- Chapter 7 studies the audit outcome for several remote IMRT/VMAT deliveries. It compares the results with conventional audits and introduces the significance of explanatory variables on the audit outcome. The material in Chapter 7 was presented in a journal paper [J5].

The thesis is concluded in Chapter 8, with a discussion followed by suggestions for future research opportunities in dosimetry auditing of radiotherapy clinical trials in Chapter 9.