A novel anthropomorphic pelvic phantom designed for multicentre level III dosimetry intercomparison

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Statement of Originality

This work contains no material which has been accepted 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 in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1988

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Acknowledgement of Authorship

I hereby certify that the work embodied in this Thesis is the result of original research, the greater part of which was completed subsequent to admission to candidature for the degree.

Signed _____

Project Acknowledgements

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Abstract

INTRODUCTION: Level III dosimetric intercomparison studies test the entire radiotherapy patient treatment chain from diagnostic imaging to treatment delivery and verification imaging at multiple radiotherapy centres. The anthropomorphic phantom employed in an intercomparison needs to meet specific criteria including portability, tissue equivalence and accommodation of radiation detectors to ensure clinical relevance and dosimetric accuracy. The proposition that a purpose-built phantom can encompass all the attributes necessary for precise Level III dosimetric intercomparisons for prostate cancer is the premise of this body of work.

METHODS: Organ outlines were generated from a human computed tomography image set and incorporated into the phantom design to replicate human anatomy as closely as possible. Twenty-five points of interest were located throughout the dataset to identify where point-dose values could be measured with thermoluminescence dosimeters. The centre of the prostate was identified as the location for measurement with a small-volume ionization chamber. The materials used in this phantom were tested against water to determine relative attenuation, density and Hounsfield Units. Three materials were chosen to mimic bone, organs, and a backfill material and the phantom was manufactured using modern prototyping techniques into five separate coronal slices. Time lines and resource requirements for the phantom design and manufacture were recorded. The ability of the phantom to mimic the entire treatment chain was tested at the Calvary Mater Newcastle Hospital.

RESULTS: The phantom CT images indicated the densities and organ geometries were comparable to the original patient. The phantom proved simple to load for dosimetry and rapid to assemble. Measurements indicated the reproducibility to be in the order of 1% for the ionization chamber measurement and within 3% for thermoluminescence dosimeters. Due to heat release during manufacture, small airgaps were present throughout the phantom producing artifacts on lateral images. The overall cost for production of the prototype

phantom was comparable to other commercial anthropomorphic phantoms ($AU45,000).

The phantom was shown to be suitable for use as a “patient” to mimic the entire treatment chain for typical external beam radiotherapy for prostate and rectal cancer. Outlining of relevant structures by a radiation oncologist was uncomplicated and the computerised treatment plan compared well with the dose measured using ionisation chambers and thermoluminescence dosimeters.

DISCUSSION & CONCLUSIONS: The phantom constructed for the present study incorporates all characteristics necessary for accurate Level III intercomparison studies and will be an effective tool for an intercomparison of pelvic treatments in Australasia. These results may benefit analysis of outcomes for prostate cancer treatments, especially in the clinical trial environment. It will be of significant interest in the future to use the phantom to assess advanced radiotherapy delivery techniques such as Intensity Modulated Radiation Therapy (IMRT).

Publications and Presentations associated with this research

Publications that include results of the thesis in parts:

- Ebert M, Harrison K, Cornes D, Howlett S, Joseph D, Kron T, Hamilton C and Denham J 2009 A comprehensive Australasian multi-centre dosimetric intercomparison - issues, logistics and recommendations *J Med Imag Rad Oncol* **53** 119-31
- Ebert M A, Howlett S J, Harrison K, Cornes D, Hamilton C S and Denham J D 2008 Linear-accelerator X-ray output: a multicentre chamber-based intercomparison study in Australia and New Zealand *Aust Phys Eng Sci Med* **31**

Presentations pertaining to the phantom and that include results of the thesis in parts (presented by person named first):

- Ebert M, Harrison K, Cornes D, Howlett S, Hamilton C and Denham J 2005 Design and Construction of a Realistic Pelvic Phantom for a Level III Dosimetry Study *Oral presentation at the 2005 AAPM Conference*
- Harrison K, Ebert M, Cornes D, Howlett S, Hamilton C and Denham J 2005 Level I and III National Dosimetry Project *Poster presentation at the 2005 TROG Annual Meeting, Darwin*
- Ebert M, Harrison K, Cornes D, Howlett S, Hamilton C and Denham J 2004 Design of an Inter-centre Dosimetry Study Using an Anthropomorphic Pelvic Phantom (Elvis the Pelvis) *Oral presentation at the 2004 RANZCR Annual Meeting, Perth*
- Harrison KM, Rolton S, Cornes D, Denham J, Ebert M, Howlett S, Hamilton C 2004 Elvis the Pelvis: A purpose built anthropomorphic phantom for an Australiasian Level III dosimetry intercomparison *Oral presentation at the 2004 MedPhys Symposium, ACPSEM (NSW Branch)*
- Harrison KM, Rolton S, Cornes D, Denham J, Ebert M, Howlett S, Hamilton C 2004 Elvis the Pelvis: A purpose built anthropomorphic phantom for an Australiasian Level III dosimetry intercomparison *Oral presentation at the 2004 EPSM Conference, Geelong.* (Awarded prize for best oral presentation at conference – Varian Prize)
- Harrison K, Ebert M, Cornes D, Howlett S, Hamilton C and Denham J 2004 Australiasian Level III dosimetric intercomparision using a purpose-built anthropomorphic phantom *Oral presentation at the 2004 EPSM Conference, Geelong.*
- Rolton S, Harrison K, Ebert M, Cornes D, Howlett S, Hamilton C and Denham J 2004 Australian Success Story: Design and Construction of an Anatomically correct Male Pelvis Radiation Phantom *Oral presentation at the 2004 Geomagic Conference, Bali*

Presentations of the broader Level I and III multicentre study (presented by person named first):

- Ebert M, Harrison K, Cornes D, Howlett S, Hamilton C and Denham J Level I and III dosimetric intercomparison for a prostate 3D-CRT trial *Oral presentation at the 2007 ESTRO Biennial Physics and RT Meeting, Barcelona Spain*
- Ebert M, Howlett S, Harrison K, Cornes D, Denham J, Hamilton C Accelerator output in Australasia - Comparison with other international Level I studies, *Oral presentation at the 2007 EPSM, Fremantle*
- Ebert MA, Harrison K, Denham JW, Cornes D, Howlett S and Hamilton C QA of conformal radiotherapy for multi-centre radiotherapy trials in Australasia. *Oral presentation at the 2006 International Conference on Quality Assurance and New Technologies in Radiation* Medicine IAEA, *Vienna*
- Ebert M, Harrison K, Cornes D, Howlett S, Hamilton C and Denham J 2006 Ambition vs Reality Level III Dosimetry & the Travelling Elvis Show *Oral presentation at the 2006 TROG Annual Meeting, Linderman Island*
- Ebert M, Harrison K, Cornes D, Howlett S and Denham J 2005 On the road with Elvis – Progress on the national Level III dosimetry study *Oral presentation at the 2005 EPSM Conference, Adelaide*
- Howlett SJ, Ebert MA, Harrison KM, Cornes D, Hamilton C S and Denham JD Dose Measurement in the Level I section of the national dosimetry pilot project *Oral presentation at the 2004 EPSM Conference, Geelong.*
- Hamilton C, Harrison K, Ebert, M, Cornes D, Hamilton C and Denham J 2004 National Dosimetry Lead-In Project *Oral presentation at the 2004 TROG Annual Meeting, Queenstown*

Thesis Outline

This thesis is concerned with the development, material testing, manufacture and evaluation of an anthropomorphic phantom purpose-built for application to level III dosimetry intercomparison studies. Consequently the thesis is divided into the following chapters:

Chapter 1 covers theory relating to radiation therapy, dosimetry, phantoms and previous research into the area of multicentre intercomparison dosimetry. The chapter ends with the aims of this body of work including the key criteria the phantom was designed to fulfil.

Chapter 2 outlines the design of the phantom and material testing including methodology and results. This is followed by a description of the manufacture of the phantom.

Chapter 3 detail the methodology and results of the collation of physical properties of the completed phantom such as weight, dimensions, CT imaging in comparison to material tests and the timeline and costs.

Chapter 4 describes the assessment of the dosimetric properties of the phantom which incorporates the adjunct Level I study used for calibration. The chapter also covers equipment used, methodology and results of application of the phantom to Level III dosimetry.

Chapter 5 evaluates the phantom in the context of a multicentre study. The methodology used is as described in chapter 4, but applied to an additional 4 radiation therapy centres. The results for anatomical regions are compared across the 5 centres for 2 treatment sites. A broader multicentre intercomparison project (37 site visits) adjunct to this study is not discussed in this body of work, but results will be published in the near future.

Chapter 6 is the discussion of the results presented in chapters 2 through to 5 with emphasis on addressing the key criteria, preliminary results of the multicentre intercomparison and further applications of the phantom.

Chapter 7 concludes the thesis with a brief summary of the outcomes of the thesis.

The references and an explanation of the acronyms referred to in the thesis follow Chapter 7.