Investigation of Uncertainties Associated with the MammoSite™ Breast Brachytherapy Technique: Monte Carlo Simulations and TLD Measurements

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Thesis submitted for the degree of

Doctor of Philosophy

in

The School of Chemistry and Physics,

The University of Adelaide

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November 2010

Contents

List of Tables

Page

List of Figures

Page

Page

Page

Page

Abstract

The MammoSite Radiation Therapy System is a novel brachytherapy technique for treatment of patients with early stage breast cancer. It is used as a sole radiation treatment or in combination with external beam radiotherapy. There are several uncertainties associated with the dose distribution from the MammoSite brachytherapy.

In this research study, the ^{192}Ir brachytherapy source was accurately modelled using the EGSnrc Monte Carlo code. A voxel size of 1.5 mm^3 was found to be suitable for dose calculations as reducing the voxel size any further would increase the simulation time without improving the accuracy of dose simulation.

The impact of uncertainties in balloon deformation and source position on the tumour control probability (TCP) and the normal tissue complication probability (NTCP) were assessed. The effects on the treatment outcome were assessed from (a) organ differential dose volume histograms (dDVHs) obtained from the Plato brachytherapy planning system and (b) EGSnrc Monte Carlo simulations based on actual computed tomography (CT) images of a breast cancer patient who underwent MammoSite brachytherapy treatment.

This study gave low probabilities for developing heart and lung complications.
Monte Carlo calculations showed that a deviation of the source by 1 mm caused approximately 7% dose reduction in the treated target volume at 1 cm from the balloon surface. A 4 mm source deviation produced underdosing of some portions of the PTV by 40% leading to poor treatment outcomes. Furthermore, 4 mm uncertainty in source deviation leads to overdosing of regions of the PTV by about 40%. This results to an excessive dose to the skin and increases the probability of skin complications.

Balloon deformation and incorrect source position had significant effect on the prescribed dose within the treated volume. A 4 mm balloon deformation resulted in reduction of the tumour control probability by 24%. The current study suggested that

the MammoSite treatment protocols should allow for a balloon deformation of less than 2 mm and a maximum source deviation of ≤ 1 mm.

The extent of the dose perturbation for various concentrations of the contrast medium in a MammoSite balloon was investigated using Monte Carlo simulations and thermoluminescent dosimeters (TLDs) measurements. The Monte Carlo simulation was performed using CT images of in-house tissue equivalent breast phantom. The breast phantom was also used for TLD measurements.

The measured and Monte Carlo calculated doses were in agreement within the measurement uncertainty and Monte Carlo statistical errors. The dose reduction resulting from the use of high atomic number contrast (Iodine) caused considerable uncertainty in the MammoSite dose. Our results showed that 100%, 50% and 15% contrast concentrations reduced the dose at the prescription point by 10%, 5% and 2% respectively relative to the dose calculated with the balloon filled with saline (water) only.

The BEAMnrc and DOSXYZnrc Monte Carlo codes were used to model an external beam radiotherapy treatment and simulate a dose distribution using a patient CT data set respectively. The external beam radiotherapy model was validated with measurements and the data analysis was performed using the gamma function algorithm.

The gamma function analysis algorithm was used and the acceptance criteria for comparison were set to distance-to-agreement of 2 mm and 2% dose difference. An excellent agreement (99.4% of detectors passed the criteria) was found between the Monte Caro computed dose maps and the measured ones. This proved that a reliable Monte Carlo model was constructed and used for dose calculations from EBRT treatment. The simulated dose distribution from EBRT was combined with the simulated MammoSite dose distribution.

Finally, it would be beneficial (to the oncologist) to visualize the final (combined) dose distributions from the two modalities to assist with an assessment of treatment plans and the treatment outcome. Currently, combining the dose distributions from the two modalities is difficult to achieve because the two modalities use different planning systems and different dose calculations algorithms and the patient anatomy looks different (balloon is present for brachytherapy). Consequently, the project aimed to build a Monte Carlo linac model to calculate dose delivery to a breast due to external beam radiotherapy.

Having MC models (EBRT & MB) constructed and verified, the dose distributions calculated from each modality were converted using appropriate algorithms to equivalent dose distributions and combined to yield the total dose distribution to a breast from the combined treatment.

Signed Statement

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 consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

SIGNED: ………………….……………… DATE: ……………………………….…….

Acknowledgements

I wish to acknowledge the scholarship support of the Libyan government, which made this project possible.

I am extremely grateful to have had A/Prof. Eva Bezak as my principal supervisor. She was always available to discuss issues related to my project. She taught me the skills of a researcher. Her guidance, intelligence and support were invaluable. I would also like to express my sincere gratitude to my co-supervisor Dr. Martin Borg for his clinical advice.

I strongly appreciate the encouragement, moral support and help from the staff of the Medical Physics Department at the Royal Adelaide Hospital: Thomas Rutten, Daniel Ramm, John Lawson, John Schneider, Tim Willams, Kim Quach, Scott Penfold, Raelene Nelligan, Siva Saranandarajah, Mohammad Mohammadi and Christine Robinson. A special thanks to Dr. Justin Shepherd for proof reading the thesis.

I would also like to thank Thuc Pham for sharing his knowledge of the Monte Carlo technique with me. Special thanks to Hologic Corporation who have supplied me with their MammoSite images.

My friendship with my fellow graduate students has been a delightful part of my life.

Finally my greatest thanks go to my family for their love and support.

Publications in refereed journals

The work in this thesis has been published and presented in the following:

1. Saleh benSaleh, Eva Bezak and Martin Borg, "Review of MammoSite brachytherapy: Advantage, disadvantages and clinical outcomes". Acta Oncologica 48: 487-494 (2009).
2. Saleh benSaleh, Eva Bezak and Thuc Pham, "Combined Dose Distribution for External Beam Whole Breast Irradiation and MammoSite Breast Brachytherapy: Monte Carlo Investigation" published in Proceedings of Medical Physics and Biomedical Engineering World Congress 2009.
3. Bensaleh S and Bezak E. Investigation of source position uncertainties & balloon deformation in MammoSite brachytherapy on treatment effectiveness. Australas Phys Eng Sci Med 2010; 33:35-44.

Papers submitted to refereed journals

Bensaleh S, Bezak E, "The effect of uncertainties associated with MammoSite® brachytherapy on the dose distribution in the breast: Monte Carlo simulations and TLD measurements" submitted to Brachytherapy.

Papers in preparation

Bensaleh S, Bezak E, "Combined dose distribution for MammoSite brachytheray and external beam breast irradiation" to be submitted to Medical Physics.

Conference presentations

International

1. Saleh benSaleh and Eva Bezak "MammoSite Brachytherapy Tecnique Review, Monte Carlo Modelling and Measurements of Uncertainties" International Conference on Medical Physics, Radiation Protection and Radiobiology (2009), Feburary11-13, Jaipur, India [Invited Paper].

2. Saleh benSaleh, Eva Bezak and Thuc Pham, "Combined Dose Distribution for External Beam Whole Breast Irradiation and MammoSite Breast Brachytherapy: Monte Carlo Investigation" Medical Physics and Biomedical Engineering World Congress 2009. Munich, Germany.

National

1. Saleh benSaleh, Eva Bezak and Martin Borg, "Dose Investigation of the MammoSite Applicator using Monte Carlo Method". Engineering and Physical Science in Medicine (2007), October 14-18, Fremantle, Western Australia.

2. Saleh benSaleh and Eva Bezak, "Investigation of the Dose Reduction in the Breast due to Various Contrast Concentrations in the MammoSite Balloon: Monte Carlo Simulations and TLD Measurements". Engineering and Physical Science in Medicine (2008), November 16-20, Christchurch, New Zealand.

3. Saleh benSaleh and Eva Bezak, "The Effect of Source Positioning Errors on TCP & NTCP in MammoSite® Breast Brachytherapy". Engineering and Physical Science in Medicine (2008), November 16-20, Christchurch, New Zealand.

4. Saleh benSaleh and Eva Bezak, "Quantitative Analysis of Dose Reduction in MammoSite Brachytherapy Breast Cancer Technique by Monte Carlo Simulations". Australian Institute of Physics 18th National Congress (2008), November 30th – December 5th, Adelaide, South Australia.

5. Saleh benSaleh and Eva Bezak, "Monte Carlo Modelling of Combined Dose Distributions in Breast Radiotherapy" Engineering and Physical Science in Medicine (2009), November 8-12, Canberra, Australia.

6. Bensaleh S, Bezak E. Dose equivalent for the combination of external beam breast irradiation and MammoSite breast brachytherapy: Monte Carlo simulations. 3rd Modelling of Tumour (MOT) Meeting. 2010. Adelaide, Australia.

Other presentations

1. Saleh benSaleh and Eva Bezak, "Dose Uncertainties in MammoSite Breast Brachytherapy" Postgraduate Student Papers Night. Adelaide, Australia. 2006. Sponsored by ACPSM, SAMBE and EACBE (SA branches) [**].

2. Saleh benSaleh, Eva Bezak and Martin Borg, "Dose Investigation of the MammoSite Applicator using Monte Carlo Method" Postgraduate Student Papers Night. Adelaide, Australia. 2007. Sponsored by ACPSM, SAMBE and EACBE (SA branches) [*].

3. Saleh benSaleh and Eva Bezak, "Investigation of the Effects of Contrast Medium on the MammoSite Dose distribution: Monte Carlo Simulations and TLD Measurements". Student Paper Competition 2008, sponsored by the South Austral Branch of the Australian Radiation Protection Society.

* Awarded first prize

**Awarded second prize

TO MY FAMILY