Development of Magnetic Resonance Imaging Based Prostate Treatment Planning

Jidi Sun

BSc, MSc

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

A thesis submitted for the degree of
Doctor of Philosophy (Physics) from the
Faculty of Science and Information Technology,
University of Newcastle,
Australia

May 2015

STATEMENT OF ORIGINALITY

The thesis 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 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.

**Unless an Embargo has been approved for a determined period.

(Signed) ____________________

STATEMENT OF AUTHORSHIP

I hereby certify that this thesis is in the form of a series of published papers of which I am a joint author. I have included in each relevant section of the thesis a written statement attesting to my contribution to each publication. This is endorsed below by my supervisor and the Faculty Assistant Dean (Research Training).

(Signature of Candidate) (Full Name of Candidate)

________________________ ________________________

Date:

(Signature of Supervisor) (Full Name of Supervisor)

________________________ ________________________

Date:

(Signature of Assistant Dean Research Training (ADRT))

____

(Full Name of ADRT)

____

Date:

LIST OF PUBLICATIONS INCLUDED AS PART OF THE THESIS

1. Sun J, Pichler P, Dowling J, Menk F, Stanwell P, Arm J, Greer PB. MR simulation for prostate radiation therapy: effect of coil mounting position on image quality, Br. J. Radiol, 2014; 87(1042): 20140325.
2. Sun J, Dowling JA, Pichler P, Parker J, Martin J, Stanwell P, Arm J, Menk F, Greer PB. Investigation on the performance of dedicated radiotherapy positioning devices for MR scanning for prostate planning, J Appl Clin Med Phys, 2015; 16(2).
3. Sun J, Barnes M, Dowling J, Menk F, Stanwell P, Greer PB. An open source automatic quality assurance (OSAQA) tool for the ACR MRI phantom, Australas Phys Eng Sci Med, 2014 Nov 21. [Epub ahead of print]
4. Sun J, Dowling J, Pichler P, Menk F, Rivest-Henault D, Lambert J, Parker J, Arm J, Best L, Martin J, Denham JW, Greer PB. MRI Simulation: End-to-end testing for prostate radiation therapy using geometric pelvic MRI phantoms, Phys Med Biol, 2015; 60(8):3097-109.
5. Dowling JA, Sun J, Pichler P, Rivest-Hénault D, Ghose S, Richardson H, Wratten C, Martin J, Arm J, Best L, Chandra S, Fripp J, Menk FW, Greer PB. Automatic substitute CT generation and contouring for MRI-alone external beam radiation therapy from standard MRI sequences, Int J Radiat Oncol Biol Phys. (submitted)

All publications have been included in Chapter 5-9.

I warrant that I have obtained, where necessary, permission from the copyright owners to use any third party copyright material reproduced in the thesis (e.g. questionnaires, artwork, unpublished letters), or to use any of my own published work (e.g. journal articles) in which the copyright is held by another party (e.g. publisher, co-author).

LIST OF ADDITIONAL PUBLICATIONS

Peer reviewed papers:

1. Greer P, Dowling J, Pichler P, Sun J, Richardson H, Rivest-Henault D, Ghose S, Martin J, Wratten C, Arm J, Best L, Denham J, Lau P. Development of MR-only planning for prostate radiation therapy using synthetic CT. MAGNETOM Flash MReadings: MR in RT. 2015.
2. Dowling JA, Burdett N, Greer PB, Sun J, Parker J, Pichler P, Stanwell P, Chandra S, Rivest-Henault D, Ghose S, Salvado O, Fripp J. Automatic atlas based electron density and structure contouring for MRI-based prostate radiation therapy on the cloud. In Journal of Physics: Conference Series (Vol. 489, No. 1, p. 012048). IOP Publishing.

Peer reviewed abstracts:

1. Dowling JA, Pichler P, Sun J, Rivest-Henault D, Ghose S, Martin J, Wratten C, Stanwell P, Fripp J, Greer PB. CT substitute derived from MRI for external beam prostate radiotherapy. ESTRO33, Vienna, Austria, 2014.
2. Sun J, Dowling J, Pichler P, Martin J, Arm J, Parker J, Menk F, Greer PB. MR simulator commissioning for pelvic radiotherapy treatment planning. EPSM2013, Perth, Australia.
3. Sun J, Barnes M, Stanwell P, Dowling J, Menk F, Greer PB. Semi-automatic quality assurance (SAQA) Matlab script for ACR MRI phantom. EPSM2013, Perth, Australia
4. Peter G, Lambert J, Parker J, Pichler P, Menk F, Patterson J, Dowling J, Denham JW, Sun J, Salvado O. End-to-end testing for clinical implementation of prostate MRI-simulation. EPSM2013, Perth, Australia
5. Sun J. Cumulative Dose Assessment Using MRI for Prostate Treatment. MRlinac group meeting, Sydney, Australia
6. Dowling J, Lambert J, Chandra S, Parker J, Sun J, Stanwell P, Fripp J, Salvado O, Greer P. MRI based radiation therapy treatment planning. In Proceedings of The Australian-Canadian Prostate Cancer Research Alliance Symposium, DayDream Island, Queensland, Australia, p. 16-17, 2012.
7. Sun J, Dowling J, Menk F, Stanwell P, Salvado O, Parker J, Greer PB. Investigation on CIVCO coil mount for MR-based prostate treatment planning. EPSM-ABEC 2011 Conference, Gold Coast, Australia.

ACKNOWLEDGEMENTS

I would like to express my most sincere gratitude to my supervisors, Prof. Peter B Greer, Dr. Jason Dowling and Prof. Fred Menk. Their world-class research experience in the medical physics, computer science and space physics fields were an inspiration to me. They have given me their guidance, full support, constructive and valuable comments, and continuous encouragement throughout this project. They also have patiently helped me with the corrections of all the publication manuscripts and this thesis. I learned from them not only the research skills, but also many communication skills which will be very useful to my future career.

I wish to thank the University of Newcastle and the Cancer Council NSW for providing me with the scholarship to have this wonderful learning experience in Australia. I also wish to thank CSIRO for providing both the opportunity and funding to visit their facility in Brisbane to gain valuable research experience. I thank the University of Newcastle and the Calvary Mater Newcastle (CMN) hospital for providing me with all the necessary resources to conduct my clinical experiments.

During my study at CMN, I had the great opportunity to work beside and learn from so many top-class and experienced clinical physicists, Michael Barnes, Dr. Claire Dempsey, Paul Simpson, Dr. Trish Ostwald and Tamara Molloy. I would like to give special thanks to Michael Barnes, who collaborated closely with me to complete the automatic QA program's validation and publication. The technician, Bruce Aldrich, was always helpful and took generous lengths to share many clinical works with me to expand my clinical knowledge. There are three medical physics registrars, Renee Jones, Cameron Stanton and Dr. Marcus Doebrich, who have also allowed me to observe many of their clinical works and trainings.

The MR images used in this study were acquired at the Radiology Department of CMN. The MR radiographer team, Jameen Arm, Leah Best, Melissa Murphy, Nick Marks, Narelle Grabham, Benjamin Ling and Daniel O'Kane, were very friendly and patient with me whenever I need their help. In spite of all their clinical duties, they always found time and sometimes worked overtime in order to help me to acquire the images I needed.

I also want to thank the following people for their extensive expert help on my study. The previous PhD student, Dr. Jonathan Lambert, gave me the background knowledge I needed to help me start this study smoothly. The friendly radiotherapists, Joel Parker and Peter Pichler, have guided me to use the treatment planning system and been extremely helpful on the patient recruitment for my study. This project cannot be completed without them. A/Prof. Peter Stanwell has also been very helpful to provide me with the essential MR background and knowledge. Radiation oncologist, Dr. Jarad Martin, has been very friendly to help me to contour the prostate on the volunteer images for one of my publications. Dr. David Rivest-Henault and Dr. Soumya Ghose from CSIRO have provided me with extensive help and guidance on the image registration knowledge and coding. Dr. Carlos Riveros has helped me to install and setup the GPU computer, on which the phantom image registration was conducted.

Gregory Bolard, a clinical physicist visiting from France, has extensive clinical experiences and programming knowledge. His time and conversation was very helpful, providing me with many clinical ideas.

The CMN research coordinator, Dr. Mary-Claire Hanlon, has helped me to proofread this thesis and provided me with very useful comments. My old classmate from the University of Canterbury, James Talbot, is a clinical physicist and he has also helped me to proofread several of my publication manuscripts. Dr. Aitang Xing, a clinical physicist from Liverpool Hospital, also graduated from the same university as mine. He not only helped me to acquire several QA phantom images, but also gave me many valuable suggestions on the research and thesis strategies.

Jameen and his wife, Raina Lew, and their kids, Elias and Sophie, are like a family to me in Australia and they have shown me the cultures of Australia and Singapore. I have enjoyed their delicious Indian and Singaporean food during these years. Marcus has been a good friend outside work, he and his partner, Janice Bartley, have shared many great German and Australian cultures with me. I have never felt lonely in Australia by having these friends with me.

I want to thank my Master supervisors, A/Prof. Juergen Meyer and Dr. TheamYong Chew. Juergen's interesting lectures and supervision gave me my initial introduction to the field of medical physics and for that I have a lot to be thankful for. His encouragement let me start to learn and use Matlab and I have been able to use this skill in nearly all aspects of my research ever since. TheamYong has introduced me many valuable programming concepts, which is still useful to me nowadays.

Lastly, I would like to thank all my family members, from both my father's and mother's sides, for their belief in me for all these years. They have continuously provided me with not only financial support but also emotional support. My grandfather, Prof. Fuxing Sun, has been my encouragement and my inspiration in the constant pursuit of knowledge. My loving parents, Ye Sun and Yan Lin, have been my everything in the world. They have given me the opportunity to come to this world and have shown me the most wonderful love in this universe.

Table of Contents

ABSTRACT

Radiotherapy is one of the main methods used to treat prostate cancer. Radiotherapy treatment relies on accurate planning and simulation before any radiation is administered. Currently this is mainly based on CT (computed tomography) imaging, although MR (magnetic resonance) imaging provides superior soft-tissue contrast and is therefore often used to assist with accurate organ delineation. The overall treatment planning workflow and performance can be improved if the entire workflow is solely performed using MR images. In order to achieve such MR-only treatment planning, three main challenges need to be overcome: 1) the geometric accuracy of MR images needs to be assured, 2) the MR simulator needs to be commissioned and evaluated, 3) electron density information required for dose calculation needs to be generated from MR images. This thesis examines each of these challenges.

First, a pelvic shape phantom was used to quantify the geometric distortion arising in prostate treatment. The CT image was acquired as the gold reference and the distortion of the MR image was corrected with the vendor's built-in algorithm. Using the image registration method, the maximum geometric distortion was reduced from nearly 8 mm to within the radiotherapy tolerance level.

Second, commercial radiotherapy-dedicated equipment was implemented on the Siemens Skyra 3 Tesla MR scanner. This involved a hard flat tabletop which mimicked the flat radiotherapy treatment table, and coil mounts to lift the MR coil above the patient's body and minimise coil-induced disagreement between the MR planning and treatment geometry. A reduction in image quality was observed on the MR simulator, but no clinically significant difference was found in the accuracy of organ delineation. Furthermore, use of the MR simulator eliminated patient positioning error associated with conventional MR scanner design and thus reduced the systematic dosimetric error. The entire workflow of MR-based planning was tested using an anthropomorphic phantom and no significant difference was found between MR- and CT-based plans.

Finally, substitute (also known as synthetic or pseudo) sCT images were generated from MR images using a multi-atlas local weighted voting method. Validation was conducted on 39 patients and the sCT images were in high level agreement with the CT images.

In summary, MR-based radiotherapy planning for treating prostate cancer has been thoroughly tested and evaluated in this study. This may provide an important stepping stone for the future clinical implementation.