Development of MR-only Planning for Prostate Radiation Therapy Using Synthetic CT

Peter Greer, Ph.D.[1]; Jason Dowling, Ph.D.[2]; Peter Pichler, M.P.H.[3]; Jidi Sun, M.Sc.[3]; Haylea Richardson, B.Med.Rad.Sc.[3]; David Rivest-Henault, Ph.D.[2]; Soumya Ghose, Ph.D.[2]; Jarad Martin, M.D.[1]; Chris Wratten, FRANZCR[1]; Jameen Arm, MSc[4]; Leah Best, MSc[4]; Jim Denham, M.D.[1]; Peter Lau, FRANZCR[4]

[1] Calvary Mater Newcastle, Newcastle, New South Wales, Australia and University of Newcastle, Newcastle, New South Wales, Australia
[2] CSIRO, Australian e-Health Research Centre, Brisbane, Queensland, Australia
[3] Calvary Mater Newcastle, Newcastle, New South Wales, Australia

Introduction

The department of Radiation Oncology at Calvary Mater Newcastle, treats approximately 1,800 new patients per year. When it comes to prostate treatments, MR scans are used in addition to CT for treatment planning. Having to undergo two scans however is a burden both to patients as well as the health system. We have looked into addressing this by replacing the CT by an MR-only[1] workflow when treating patients with prostate cancer.

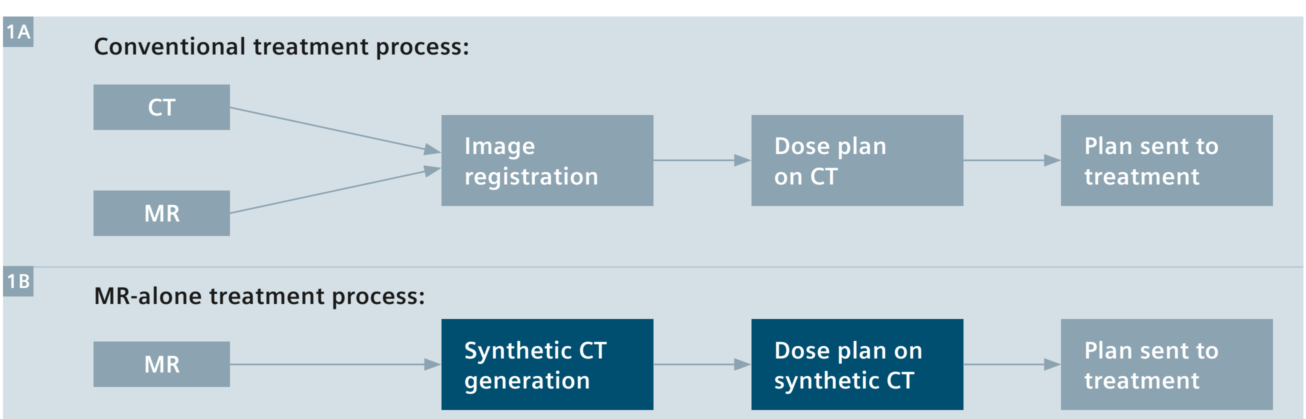
Description of the current treatment process

In the conventional CT based workflow the patient undergoes two imaging sessions, an MR imaging session and a CT imaging session. The MR dataset with its high soft tissue contrast enables precise visualization of the prostate target and adjacent rectum and bladder organs at risk, while the CT dataset provides electron density information for dose calculations. The two image sets are registered in the Varian Eclipse™ treatment planning system (TPS) and the anatomical target and normal tissue contours delineated on the MR scan are transferred to the CT scan. Dose calculation and beam definition are then performed on the CT scan. Virtual or digitally reconstructed radiographs (DRRs) are also generated from the CT scan which shows the location of implanted fiducial gold markers in the prostate relative to the beam isocenter. These are used as reference images to align the patient using orthogonal X-rays before treatment in one of our five Varian (Trilogy™ and TrueBeam™) linear accelerators.

MR-only workflow[1]

The MR-only workflow differs in that the only imaging session is the MR and a synthetic CT scan is produced for dose calculations and DRR generation [1]. This workflow reduces the patient and health system burden and reduces systematic errors in treatment planning introduced by image registration uncertainties. This project is a collaboration between the clinical/academic site the Department of Radiation Oncology, Calvary Mater Newcastle and the Biomedical Imaging Research Group of the Commonwealth

[1] Radiotherapy Planning where MR data is the only imaging information is ongoing research. The concepts and information presented in this article are based on research and are not commercially available. Its future availability cannot be ensured.



1 Flowchart contrasting **(1A)** the conventional CT-MR based treatment process and **(1B)** the MR-only treatment process.

Scientific and Industrial Research Organisation (CSIRO).

The major technical steps in the treatment process are setup and imaging of the patient in the 3T MAGNETOM Skyra suite, production of synthetic CT scans; contouring of relevant organs; beam definition and dose calculation in Eclipse; setup, image-guided positioning and treatment at the Linac.

To date 40 men with ages ranging from 58 to 78, undergoing prostate cancer radiation therapy treatment have been scanned under a research protocol. All prostate patients undergoing long fractionation treatment were eligible except that patients with hip prostheses were excluded due to distortions induced by metallic implants. Synthetic CT scans were produced for treatment planning comparisons to conventional CT based dose calculations.

Conventional MR scanning sequences are currently used for the MR-only workflow. Three sequences are used. The planning MR is a 3D, T2-weighted 1.6 mm isotropic voxel SPACE sequence with field-of-view (FOV) to cover the entire pelvis (ranging from 380-450 mm^2). The prostate delineation sequence is a 2D axial T2-weighted sequence with FOV approximately 200 × 200 mm^2. A further T1-weighted gradient echo sequence with flip angle 80 degrees is used to image the implanted prostate fiducial markers (gold seeds 1 × 3 mm). These sequences were acquired in 12-15 minutes total with 340 s for the planning MR, 235 s for the small FOV T2 scan and 186 s for the T1 flip 80 scan. Patients were MR imaged prior to treatment as close as possible to the acquisition of the conventional planning CT scan so that dose comparisons on synthetic CT and conventional CT could be made. Although not necessary for treatment planning a further set of weekly MR scans was obtained for each patient to examine patient anatomical and dose variations. Therefore the data set consists of one MR session of three sequences for RT planning and seven MR scanning sessions of three sequences throughout the duration of treatment.

Seven field intensity modulated treatment delivery is used at our Center for prostate treatments. The treatments are delivered in 39 fractions of 2 Gy per fraction. Typical margins are 7 mm with 5 mm posteriorly.

Simulation at the MR

The patient is positioned at MR in the treatment position. This is achieved with an MR compatible laser bridge for patient rotation alignment, a radiation therapy specific couch top and coil mounts (CIVCO, Rotterdam, The Netherlands) which hold the coils away from the patient surface so they do not disturb the patient position. The 3T images are utilized for both delineation of the target and normal tissues using the MR patient model and for the production of the synthetic CT for dose calculation and DRRs for image-guidance at treatment.

The synthetic CT scans are created using an enhancement of our previous single atlas method [2] that combines multi-atlas deformable registration to the patient MR scan and local weighted voting to assign a CT value to each voxel of the MR planning scan. Firstly an atlas database is created in two steps:

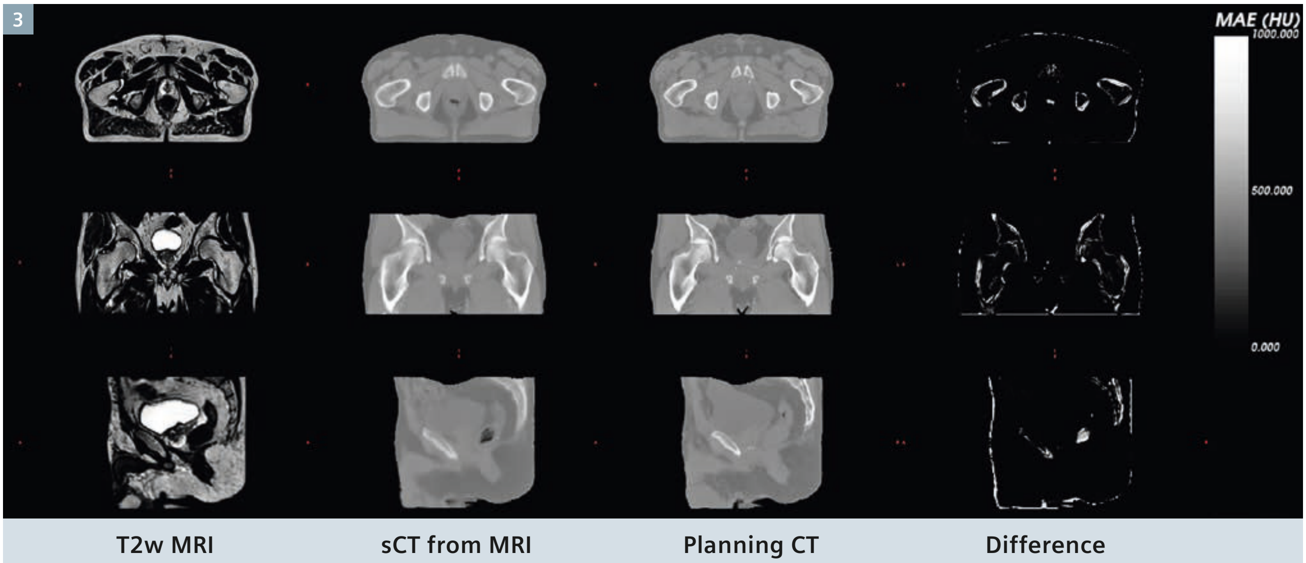
1. A set of matching patient MR and CT planning scans are acquired;
2. The patient CT scan is deformably registered to the corresponding patient MR scan to form conjugate MR-CT pairs with matching geometry.

Then to create synthetic CT scans from a subsequent patient planning MR scan the following steps are used:

1. Each atlas MR scan is deformably registered to the patient planning MR scan;
2. For each small region of the patient planning MR, the intensity is compared to the same region in all the registered atlas MR scans;
3. Each atlas scan is assigned a weighting according to the similarity of the region values with the most similar having the highest weighting (all assigned weights sum to 1);
4. The CT values from the corresponding region of the conjugate CT atlas scans are added together using the previously determined weightings to provide the CT intensity value of that region of the synthetic CT scan. Methods to automatically segment both prostate and normal tissues are also being developed which will further increase treatment planning efficiency [3, 4]. The bone contours on the MR scans can be segmented very accurately with the deformable image registration method.

2

2 Patient positioning for MR scanning showing the coil bridges.



3 Shows axial, coronal and sagittal views from an original MR image of a 67-year-old study participant. The second column shows the automatically generated synthetic CT (sCT) with the original patient CT shown in the third column. The final column shows the difference between the synthetic and actual CT.

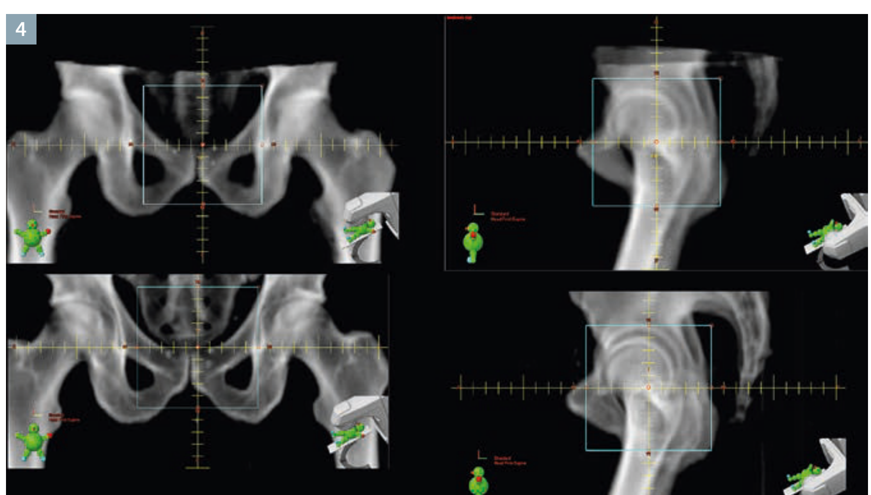
Treatment planning

The synthetic CT and MR images are imported to the Eclipse TPS with the AAA algorithm. The synthetic CT is first written to DICOM format with the header details written so that Eclipse interprets this as a CT scan for the patient. As the synthetic CT is created from the MR image data the scans are inherently registered. Target and normal tissue anatomy are delineated by the radiation oncologist on the MR scans. A treatment plan and dose calculation is then developed by the radiation therapist using the synthetic CT scan. The dose is then displayed for the radiation oncologist on the MR scan. The image guidance is performed using the Varian On-Board-Imager® and the treatment plan is delivered using the Varian Trilogy Linac.

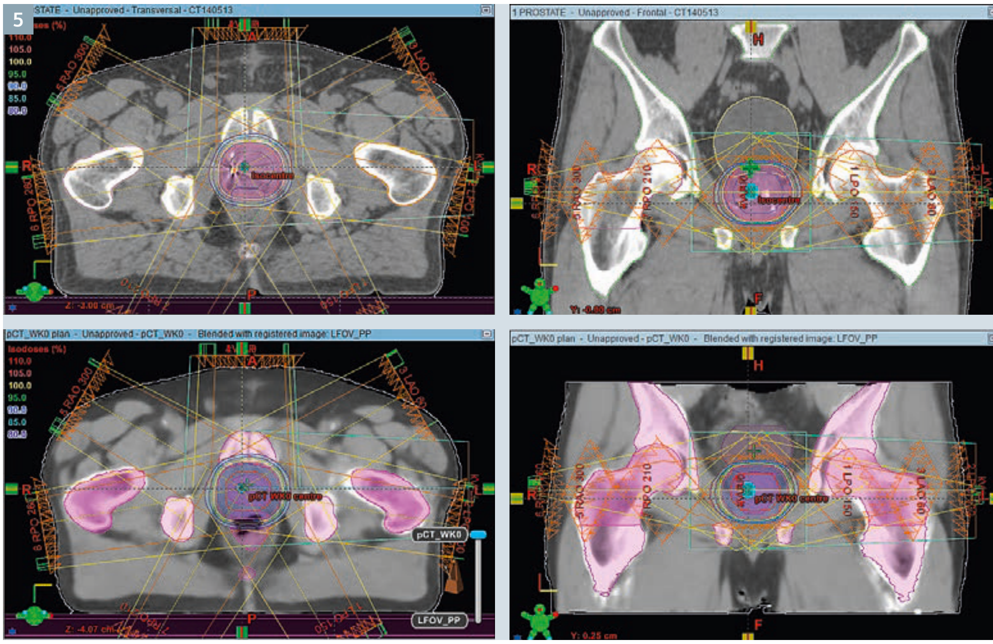
Doses calculated on the synthetic CT scans were compared to gold standard doses calculated on the conventional CT scan with an average difference of 0.3% on average. A major advantage of the technique is that it does not require specialized sequences such as ultra-short echo time sequences. Only the single 3D SPACE sequence is required for synthetic CT generation which reduces the potential for patient motion compared with multi-sequence methods of generating synthetic CT that have been proposed [5, 6].

Conclusion

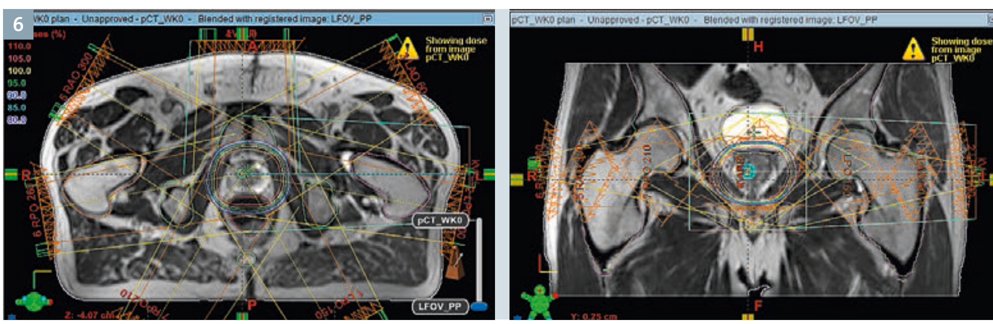
This study has shown that synthetic CT scans can be generated from MR scans using conventional T2-weighted sequences and that dose calculations are comparable to conventional CT scan dose calculations. Investigations of MR image distortion were also performed using test phantoms. Distortions in the region of the prostate were found to be sub-mm and distortions at the periphery were a maximum of 1.7 mm with the MAGNETOM Skyra 3D distortion correction applied. The MR-only workflow is efficient and only requires one imaging session for the patient. The next stage of our work is a prospective study where treatment will be performed using the MR-based treatment plan for a group of patients. MR-only prostate treatment planning is feasible and represents an improved process in radiation therapy planning.



4 Anterior-posterior (AP) (left) and lateral (right) Digitally Reconstructed Radiographs (DRRs) generated from the MRI derived synthetic CT volume (top row) and actual planning CT (bottom row) for the same patient as in figure 3.



5 Screenshots from Eclipse TPS for the same patient as in figures 3, 4 showing comparison of dose calculation on conventional CT (top) and on synthetic CT (bottom). Contours displayed on the synthetic CT are the MR defined contours.



6 Screenshot from Eclipse TPS showing dose calculated on the synthetic CT scan displayed on the MRI scan.

Acknowledgments

This work was supported by Cancer Council New South Wales research grant RG11-05, the Prostate Cancer Foundation of Australia (Movember Young Investigator Grant YI2011) and Cure Cancer Australia.

References

1 Greer P, Dowling J, Lambert J, Fripp J, Parker J, Denham J, et al. A magnetic resonance imaging-based workflow for planning radiation therapy for prostate cancer. Med. J. Aust. 2011;194:S24.

2 Dowling JA, Lambert J, Parker J, Salvado O, Fripp J, Capp A, et al. An atlas-based electron density mapping method for magnetic resonance imaging (MRI)-alone treatment planning and adaptive MRI-based prostate radiation therapy. Int. J. Radiat. Oncol. Biol. Phys. 2012;83:e5–11.

3 Dowling JA, Fripp J, Chandra S, Pluim JPW, Lambert J, Parker J, et al. Fast automatic multi-atlas segmentation of the prostate from 3D MR images. Prostate Cancer Imaging. Image Analysis and Image-Guided Interventions. Springer; 2011. p. 10–21.

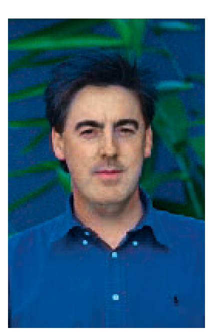
4 Chandra S, Dowling J, Shen K, Raniga P, Pluim J, Greer P, et al. Patient Specific Prostate Segmentation in 3D Magnetic Resonance Images. IEEE Transactions on Medical Imaging. 2012 Aug 2;31.

5 Johansson A, Karlsson M and Nyholm T, CT substitute derived from MRI sequences with ultrashort echo time, Med. Phys. 2011;2708-2714

6 Hsu, S-H, Cao Y, Huang K, Feng M, Balter JM, Investigation of a method for generating synthetic CTmodels from MRI scans of the head and neck for radiation therapy, Phys. Med. Biol. 2013;8419-8435.

Contact

Peter Greer
Principal Physicist
Calvary Mater Newcastle
Corner of Edith & Platt Streets
Waratah, NSW, 2298 Australia
Phone: +61 2 4014 3689
peter.greer@newcastle.edu.au



Contact

Jason Dowling
Research Scientist
CSIRO, Australian e-Health Research Centre
Level 5 – UQ Health Sciences Building
Royal Brisbane and Women's Hospital
Herston, QLD, 4029 Australia
Phone: +61 7 3253 3634
Jason.Dowling@csiro.au