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Original Article

Prostate Bed Radiation Therapy: The Utility of Ultrasound Volumetric Imaging of the Bladder

A. Haworth *†, A. Paneghel *, M. Bressel *, A. Herschtal *, D. Pham *, K.H. Tai *†, R. Oates *, J. Gawthrop *, A. Cray *, F. Foroudi *†

* The Peter MacCallum Cancer Centre, Melbourne, VIC, Australia
† Sir Peter MacCallum Department of Oncology, University of Melbourne, Melbourne, VIC, Australia

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Abstract

Aims: To evaluate the effect of incorporating daily ultrasound scanning to reduce variation in bladder filling before prostate bed radiotherapy. The primary aim was to confirm that coverage of the planning target volume (PTV) with the 95% isodose was within tolerance when the ultrasound-determined bladder volume was within individualised patient limits.

Materials and methods: Cone beam computed tomography (CBCT) images were acquired on 10 occasions during the course of treatment to assess systematic changes in rectal or bladder volume as part of a standard offline image-guided radiotherapy (IGRT) protocol. In addition, through a two-part study an ultrasound scan of the bladder was added to the IGRT protocol. In the Part 1 study, the ultrasound-determined bladder volume at the time of treatment simulation in 26 patients was compared with the simulation computed tomography cranio-caudal bladder length. The relationship between the two was used to establish bladder volume tolerance limits for the interventional component of the Part 2 study. In the Part 2 study, 24 patients underwent ultrasound scanning before treatment. When bladder volumes were outside the specified limits, they were asked to drink more water or void as appropriate until the volume was within tolerance.

Results: Based on the results of the Part 1 study, a 100 ml tolerance was applied in the Part 2 study. Seventy-six per cent of patients found to have bladder volumes outside tolerance were able to satisfactorily adjust their bladder volumes on demand. Comparing the bladder volumes with the CBCT data revealed that the bladder scanner correctly predicted that the target volume would be accurately targeted (using surrogate end points) in 83% of treatment fractions.

Conclusion: A simple hand-held ultrasound bladder scanner provides a practical, inexpensive, online solution to confirming that the bladder volume is within acceptable, patient-specific limits before treatment delivery, with the potential to improve overall treatment accuracy.

Key words: Bladder filling; IGRT; prostatectomy; radiotherapy; ultrasound

Introduction

Radiotherapy after radical prostatectomy is commonly administered in the adjuvant setting in patients at high risk of recurrence or for salvage in patients deemed to have local residual disease [1]. Although postoperative radiotherapy may reduce the risk of biochemical recurrence, accurate treatment delivery to the target volume is challenging due to the highly deformable nature as a result of intrafractional variations in bladder and rectal filling [2,3].

Several studies have proposed a variety of image-guided radiotherapy (IGRT) techniques for prostate bed radiotherapy [2–11]. Although fiducial markers or surgical clips may be useful to guide radiotherapy delivery for a tumour volume that undergoes rigid translation (or rotation), this approach is limited in its effectiveness in a treatment volume that undergoes significant interfraction deformation. By definition, the target volume for the prostate bed follows the contour of the anterior rectal wall and encompasses part of the posterior portion of bladder volume [12,13], with both organs subject to considerable interfractional changes in shape and movement relative to one another, and the

Author for correspondence: A. Haworth, Department of Physical Sciences, Peter MacCallum Cancer Centre, Locked Bag 1 A'Beckett Street, VIC 8006, Australia. Tel: +61-3-9656-3780; Fax: +61-3-9650-4870.
E-mail address: annette.haworth@petermac.org (A. Haworth).

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posterior pubic symphysis that defines the anterior volume [14]. In our previous studies [3,11] we reported the development of a cone beam computed tomography (CBCT) protocol that was designed to limit target volume deformation through surveillance of bladder volume and rectal filling. Briefly, to aid rapid assessment of the CBCT data set, bladder length, distance to anterior and posterior rectal wall were found to be effective surrogates for bladder and rectal volume. Furthermore, a change in bladder length of more than 2 cm, or a change in rectal diameter of more than 1 cm relative to these parameters measured at simulation, were found to adversely affect coverage of the planning target volume (PTV) by the 95% isodose (PTV95) and/or the dose delivered to 50% of the rectal volume. Our clinical protocol therefore incorporated a combination of orthogonal images and bony anatomy matching, with CBCT for verification of bladder and rectal filling. Limitations of this protocol include: (i) a limit of 10 CBCTs to be acquired during the course of radiotherapy to limit excess radiation dose; (ii) the offline nature of the protocol, i.e. patients were counselled regarding their bladder and rectal filling after, rather than before, treatment; (iii) the finite length of the CBCT field (13.5–15 cm, depending on treatment machine). For this reason, we investigated the use of a simple hand-held ultrasound bladder scanner to compliment the current CBCT protocol and to provide a source of non-ionising radiation for pretreatment verification of bladder volume.

As our goal was to add the ultrasound measurement to our routine CBCT protocol, we first wanted to confirm that the ultrasound and the CBCT bladder length measurements both consistently identified bladder volumes that were out of tolerance. Hence, the first aim of our project was to determine if changes in bladder volume (measured with the ultrasound scanner) correlated with changes in bladder length (measured on CBCT). The second aim of our project was to determine if patients could adjust their bladder volume before treatment on demand. The third aim of our project was to show that a change in volume (when measured with the ultrasound scanner) predicted for a change in the PTV95.

Materials and Methods

To achieve the three aims, we conducted a two-part project (Figure 1). The goal of the Part I project was to establish the relationship of bladder length (measured on the simulation computed tomography) and bladder volume (using the ultrasound scanner). In the Part II interventional study, our goal was to determine the frequency bladder volumes were outside tolerance, the ability of patients to adjust their bladder volumes on demand and to investigate the relationship of change in bladder volume with change in PTV95.

Patient Details

Recruitment followed human ethical board review (Human Research Ethics Committees-HREC) approval. Twenty-six patients were recruited to the Part I study from four of the Peter MacCallum Cancer Centre campuses and 24 patients were recruited from three campuses for the Part II study due to limited availability of the scanner at the treatment machines of the fourth campus. Patients who were incontinent, unable to speak English or felt they would not be able to comply with the protocol were ineligible for this project. All patients were planned to receive 64–70 Gy in 2 Gy fractions to the prostate bed according to consensus guidelines [12]. Details of planning and simulation have been described previously [3]. Briefly, patients were planned using either a five-field three-dimensional conformal technique (3DCRT) using 18 MV photons prescribed to ICRU 50 point [15] or a seven-field sliding window intensity-modulated radiotherapy (IMRT) technique using 6 MV photon fields. 3DCRT techniques were planned for the PTV to receive at least 95% of the prescribed dose. For prescribing an IMRT technique, a suitable isodose value was chosen to achieve 95% of PTV coverage, with D99% receiving a dose greater than or equal to 95% of the prescribed dose. The frequency of the use of an IMRT technique increased over the life of the project. However, in general, IMRT was indicated in patients where the rectal constraints (no more than 50, 30 and 25% of the rectum volume to receive more than 50, 60 and 70 Gy, respectively) could not be easily met with a 3DCRT approach. All patients were treated according to the standard IGRT protocol that required weekly or daily orthogonal kV/kV imaging with matching on bony anatomy for 3DCRT and IMRT techniques, respectively, and daily CBCT for the first four fractions followed by weekly CBCT for all patients. CBCT data were assessed offline and patients counselled if bladder or rectal volumes were outside tolerance. Patient positioning and isocentre adjustments were based on the combination of these image-guided techniques.

Equipment

Three of the four recruiting campuses had access to a BVI 9400 BladderScan (Verathon Medical, Bothell, WA, USA) and the fourth campus (recruiting four patients to the Part II project) used the BVI model 3000. Patients were scanned by placing the ultrasound transducer on the abdomen at midline (avoiding any surgical scar), 2 cm above the pubic symphysis and angled towards the bladder. All CBCT images were acquired using a Varian Trilogy or iX linear accelerator (Varian Medical Systems, Palo Alto, CA, USA).

Part I Project

All 26 patients recruited to the Part I project were imaged using the ultrasound scanner immediately (within 10 min) before simulation using the local diagnostic quality computed tomography simulator (Brilliance; Philips Electronics, Koninklijke, the Netherlands). Patients were simulated according to our standard in-house protocol that requires patients to empty their bladder and then drink up to 750 ml of water 30 min before simulation and empty their bowels before planning computed tomography and