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Prostate radiotherapy

Conventional margins not sufficient for post-prostatectomy prostate bed coverage: An analysis of 477 cone-beam computed tomography scans

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ABSTRACT

Purpose: To study prostate bed deformation, and compare coverage by 5 mm and 10 mm posterior expansion PTV margins.
Method: Fifty patients who completed post-prostatectomy radiotherapy had two expansion margins applied to the planning CT CTV: PTV10 (10 mm isometrically) and PTV5 (5 mm posteriorly, 10 mm all other directions). The CTV was then contoured on 477 pre-treatment CBCTs, and PTV5 and PTV10 coverage of each CBCT-CTVs was assessed. The maximum distance from the planning CT CTV to the combined CTV of all CBCTs including the planning CT CTV was measured for the superior part of the prostate bed, and the inferior part of the prostate bed, for every patient.
Results: The mean difference between largest and smallest CBCT-CTVs per patient was 18.7 cm^3 (range 6.3–34.2 cm^3). Out of 477 CBCTs, there were 43 anterior geometric geographical misses for either PTV with a mean volume of 2.25 cm^3 (range 0.01–18.88 cm^3). For PTV10, there were 26 posterior geometric geographical misses with a mean volume of 1.37 cm^3 (0.01–11.02 cm^3). For PTV5, there were 46 posterior geometric geographical misses with a mean volume of 3.22 cm^3 (0.01–19.82 cm^3). The maximum edge-to-edge distance for the superior prostate bed was anterior 19 mm, posterior 16 mm, left and right 7 mm. The maximum edge-to-edge distance for the inferior prostate bed was anterior 4 mm, posterior 12 mm, left and right 7 mm.
Conclusion: This study supports differential margins for the superior and inferior portions of the prostate bed. Because of the large deformation of CTV volume seen, adaptive radiotherapy solutions should be investigated further.
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Clinical target volume (CTV) to planning target volume (PTV) expansion margins in post-prostatectomy radiotherapy is a grey area, and early studies suggest that the prostate bed may be more mobile and deformable than the intact prostate [1,2]. Since 2007, the EORTC, Canadian, Australian and RTOG consensus guidelines have been published on defining the prostate bed CTV [3–6]. The guidelines however have broad recommendations for CTV to PTV margins. The EORTC guidelines recommended a minimum margin of 5 mm with image guidance [3]. The Australian guidelines recommend a 1 cm isometric margin, however if dose-volume histogram criteria were not met at planning a 5 mm posterior margin could be used, either as a single phase or two phase technique [5]. The Canadian guidelines evaluated the proposed CTV with differential margins for the superior CTV and inferior CTV of 15 mm superior–inferior (SI) and anterior posterior (AP) and 12 mm left–right (LR); 11 mm SI and AP and 8 mm LR [4]. The RTOG guideline did not propose a set CTV to PTV margin size [6]; however the RTOG 0534 protocol specifies a minimum of 6–8 mm, to a maximum of 1.5 cm [7].

Several authors have studied prostate bed motion, especially since many centres now use image-guided radiotherapy (IGRT) during treatment. Showalter et al. contoured the cone beam CTs (CBCT) of ten patients, and suggested a posterior PTV margin of 8.6–10.2 mm, and an anterior PTV margin of 5.9–7.1 mm [8]. This study however was conducted before the availability of any prostate bed contouring guidelines. Additionally, only bladder and rectum were contoured on each CBCT, with the suggested PTV margins derived from posterior bladder wall and anterior rectal wall motion, using mid-sagittal point displacement and the Van Herk margin formula – neither of which account for organ deformation. Other studies have looked at surgical clip displacement in the prostate bed. For example, when looking at only four patients, Kupelian et al. reported that surgical clip movement above 5 mm was infrequent (0% AP, 1% SI) after correcting bony

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misalignment [9]. Schiffner et al. found displacements >5 mm occurred in 3.7% AP and 2.5% SI in ten patients [10] and Sandhu et al. found displacements >5 mm occurred in 10% AP and 8% SI directions in twenty-six patients [11]. None of these methods incorporate the margin for deformation of the prostate bed tissue; or address the adequacy of PTV margins suggested by international guidelines.

We conducted a retrospective study to assess if margins employed at our institution for post-prostatectomy radiotherapy were adequate. The purpose of the present study was to analyse the adequacy of coverage of the CTV with two PTV expansion margins, i.e. 10 mm in all directions; or 5 mm posterior and 10 mm in all other directions. These two margins were assessed because the Australian and New Zealand Faculty of Radiation Oncology Genito-Urinary Group (FROGG) consensus guidelines recommend either of these margins, depending on whether or not planning constraints are met with the larger margin [5]. In addition, we also studied the deformation of the prostate bed at the superior portion and inferior portion of the CTV, to see if differential margins for the prostate bed may be more suitable.

Method

This study was conducted on fifty consecutive post-prostatectomy patients treated at one academic cancer centre between August 2009 and May 2011. All patients enrolled had completed treatment.

For simulation, and also prior to each fraction, the patients were instructed to empty their bladder and bowels one hour before and then to drink approximately 750 ml of water. Immobilisation was conducted in the supine position with knee stocks and a footrest (Combifix-Sinmed, Civco, Kalona, IA). All planning CT scans were acquired at 3 mm slice thickness and 3 mm spacing. Planning was conducted on the Eclipse™ v8.9 treatment planning system (Varian Medical Systems, Palo Alto, CA). Patients were treated to 64–70 Gy in 2 Gy fractions over approximately 6–7 weeks. Pre-treatment cone beam CT scans were taken daily for the first week of radiotherapy (days 1–5), then weekly on weeks 2–6 (total ten CBCT per patient). All cone beam CT scans were taken on Varian linear accelerators.

For this study, the cone beam CT scans were transferred into Eclipse™ and fused with the planning CT matched to bony anatomy. The Faculty of Radiation Oncology Genitourinary Group (FROGG) post-prostatectomy contouring guidelines were used for segmentation [5]. In view of difficulty identifying the vesico-ureteric anastomosis precisely on CBCT the superior–inferior (SI) displacement was not reported in this study (only left–right (LR) and anterior–posterior (AP)). The planning CT CTV and CBCT CTV was contoured on all CT scans by one Radiation Oncologist (RI). Two PTV expansion margins were created from the planning CT CTV. PTV10 was created from an isometric expansion of 10 mm, and PTV5 was created with an expansion of 5 mm posterior, and 10 mm in all other directions. The CBCT CTVs were labelled CTV 1–10. The Boolean exclusion function in Eclipse™ was used to create another volume called the Missed Target Volume (MTV) (CTV1 (exclude) PTV10 = MTV1 and so on). The physical volume of MTV 1–10 in cm^3 for each patient was recorded in an Excel spreadsheet (Microsoft Inc., Redmond, WA).

The Boolean addition function in Eclipse™ was used to create a combined CTV of the planning CT CTV and all ten CBCT CTVs for each patient (i.e. planning CT CTV + CTV1 + CTV2 + CTV3 + CTV10 = CTVcombined). The maximum distance, defined as edge-to-edge distance, from the edge of the planning CT CTV to the edge of the CTVcombined was measured for all fifty patients, in the AP, LR and SI directions for the superior half of the planning CT CTV and the inferior half of the planning CT CTV. In addition, the minimum isometric expansion that would cover the entire CTVcombined was estimated by expanding the planning CT CTV by 1 mm steps. See Fig. 1 (supplementary material) which illustrates the difference between the edge-to-edge distance, and the isometric expansion distance. Volumes for all CTVs were measured in cm^3.

Results

On the planning CT, the mean CTV volume for the 50 patients was 81.1 cm^3 (range 38.2–153.1 cm^3). The mean CBCT combined CTV volume was 123.2 cm^3 (range 58.57–212.49 cm^3). The mean difference between largest and smallest CTV for individual patients during treatment was 18.7 cm^3 (range 6.3–34.2 cm^3). The largest individual CTV volume during treatment was on average 16% (range 0–61.1%) larger than the planning CT CTV volume, and smallest individual CTV volume during treatment was on average 8% (range 0–30.7%) smaller than the planning CT CTV. For individual patients, the CTVcombined was on average 56.3% (9.3–193%) larger than the planning CT CTV. Fig. 2 (supplementary material) illustrates the difference in size between the planning CT CTV, the PTV10 and the PTV5. The PTV10 was very much larger than the planning CT CTV with a mean volume of 297.2 cm^3 (range 195.8–425.45 cm^3). Reducing the posterior margin by 5 mm did not appear to change the total volume significantly, as the mean PTV5 volume was 279.9 cm^3 (range 181.7–403.7 cm^3). This suggests unnecessary margin in some parts of the volume due to the isometric expansion, as the mean PTV10 was significantly larger than the CTVcombined.

Out of 477 CBCTs, there were 43 (9%) CBCTs that had a geographical miss anteriorly for both the PTV5 and PTV10, as both had the same 10 mm margin anteriorly. The mean MTV volume was 2.25 cm^3, and the range was 0.01–18.88 cm^3. The mean MTV for PTV5 was 3.77 cm^3 and range 0.01–19.82 cm^3 and geometric geographical miss occurred 46 times out of 477 CBCTs (10%). The mean MTV for PTV10 was 1.73 cm^3 and range 0.01–11.02 cm^3 and geometric geographical miss occurred 26 times out of 477 CBCTs (5%). There were no MTV in the LR direction, i.e. the 1 cm LR margin was adequate. The volume and frequency of MTV for individual patients in the anterior and posterior directions are shown in Fig. 3 (supplementary material) and Fig. 4, respectively.

The isometric expansion which covers 90% of CTVcombined for all fifty patients was 18 mm. The isometric expansion of the planning CT CTV varied between patients as shown in Fig. 5. A 1 cm isometric expansion was adequate for 47% of patients. Twenty four percent required a margin under 1 cm. Deformation patterns for the superior and inferior CTV are illustrated in Fig. 6. The edge-to-edge distances for the superior planning CT CTV to the CTVcombined was anterior 19 mm, posterior 16 mm, left and right 7 mm. The edge-to-edge distance for the inferior planning CTV to the CTVcombined was anterior 4 mm, posterior 12 mm, left and right 7 mm.

Discussion

The margin for prostate bed deformation has been measured using three methods in this study. In the first method, we measured the volume of geographical miss by subtracting each individual CBCT CTV from the planning CT CTV with two posterior margins of 5 mm and 10 mm. This method is probably the most comprehensive method to estimate margins, because information from each individual CBCT was assessed individually. By using this method, we have deduced that the number of posterior geographical misses were 5.4% (26/477) and 9.6% (46/477) for PTV10 and PTV5 respectively and information from each CBCT was taken indi-