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Original Article

Planning Target Volume Margin Evaluation and Critical Structure Sparing for Rectal Cancer Patients Treated Prone on a Bellyboard

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Abstract

Aims: To calculate a planning target volume (PTV) margin that would account for inter-fractional systematic and random clinical target volume positional errors for patients treated prone on a recently available couch top bellyboard and to evaluate potential critical structure dose reduction using intensity-modulated radiotherapy (IMRT) techniques.
Materials and methods: Twenty-four patients (12 men and 12 women) were included in this study, all treated on a commercial bellyboard. Cone beam computed tomography (CBCT) data were acquired once every five fractions for a total of five images per patient. A three-dimensional–three-dimensional bony anatomy auto-match was carried out off-line and the residual difference in position used as a surrogate for clinical target volume inter-fractional positional errors. Systematic (Σ) and random (σ) variations were evaluated and used in $PTV_{margin} = 1.96\Sigma + 0.7\sigma$. The influence of intra-fractional positional errors was evaluated in the margin analysis by introducing published values. Critical structure sparing, as a function of PTV_{margin} size, was investigated through the evaluation of three-dimensional conformal radiation therapy (3DCRT) and IMRT treatment plans developed using the margin derived from this work, the American Society for Radiation Oncology Contouring Atlas and the Radiation Therapy Oncology Group 0822 trial specifications.
Results: The PTV_{margin} that accounts for only the inter-fractional positional errors was calculated to be (anterior–posterior (AP), superior–inferior (SI), left–right (LR)) = (5.2 mm, 3.1 mm, 2.8 mm). If we assumed a combined intra-fractional motion up to 3.0 mm then the required PTV_{margin} increased to (AP, SI, LR) = (7.0 mm, 5.0 mm, 5.0 mm). Treatment plan evaluation showed that the bellyboard provides excellent small bowel sparing regardless of planning technique. In most cases, IMRT reduced the average femoral head, bladder and small bowel dose by 20, 15 and 40% with respect to 3DCRT planning.
Conclusion: A PTV_{margin} expansion of (AP, SI, LR) = (7.0 mm, 5.0 mm, 5.0 mm) is required to account for all positional uncertainties. The use of a bellyboard with IMRT provides better critical structure sparing when compared with a bellyboard with 3DCRT.

Key words: Bellyboard; IMRT; PTV margin; rectum

Introduction

Rectal cancer treatment planning and delivery can be difficult due to the large target volume, the proximity to dose-sensitive critical structures and clinical target volume (CTV) overlap with the bladder. The planning target volume (PTV), as defined in Report 62 of the International Commission on Radiation Units and Measurements [1], is a geometrical concept used to define beam apertures that ensure the prescribed dose is delivered to the CTV. As with all other external beam radiation therapy treatments, inter and intra-fractional set-up errors must be accounted for by assigning a margin to the CTV. To date, no study has explored the application of the well-documented Van Herk *et al.* [2] margin recipe $PTV_{margin} = 1.96\Sigma + 0.7\sigma$ for rectal patients treated prone on a couch top bellyboard.

For abdominal/pelvic sites, Xu *et al.* [3] investigated the use of pre- and post-treatment cone beam computed tomography (CBCT) imaging to quantify intra-fractional motion and reported a standard deviation that ranged between ±1.1 and ±1.5 mm. Nijkamp *et al.* [4,5] investigated the day-to-day target volume shape variation in preoperative rectal cancer patients treated to 2500 cGy over

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five fractions. The authors reported substantial systematic and random target volume deformations up to 7.5 and 4.5 mm, respectively, with female patients revealing errors 3.0 mm larger than for male patients. Recent work by Daly *et al.* [6] showed that to encompass most errors associated with rectal motion and/or deformation in size and/or shape the anterior portion of the CTV may require a 1.5 cm extension past the posterior edge of the bladder wall. Although this value is greater than the 1.0 cm recommended in the Radiation Therapy Oncology Group (RTOG) consensus panel contouring atlas [7] it is independent of the PTV_{margin} required to account for daily set-up variations.

Intensity-modulated radiotherapy (IMRT) has been shown to be a reasonable delivery method for increased critical structure sparing without loss of target coverage. This concept has been extrapolated to the treatment of rectal cancer patients treated with or without a bellyboard [8–11]. With comparable target coverage, the choice to treat using IMRT in place of traditional three-dimensional conformal radiation therapy (3DCRT) delivery techniques may be decided by assessing critical structure sparing. As highlighted above, the dose to critical structures in rectal cancer treatment is largely dependent on the target volume definition and therefore intimately linked to PTV expansion.

The goal of this work was two-fold: (i) to use CBCT images taken at the time of treatment to derive the PTV_{margin} that would account for inter and intra-fractional systematic and random CTV positional errors and (ii) to evaluate critical structure dose reduction as a function of IMRT planning with respect to traditional 3DCRT techniques using various CTV to PTV margin sizes.

Materials and Methods

Twenty-four patients (12 men and 12 women) were included in this study. Ten were preoperative and 14 were postoperative, including five abdominal perineal resection (APR) and nine low anterior resection (LAR). All patients were treated on a commercial bellyboard (see Figure 1). The general set-up was to have the patient lay prone on the bellyboard

Fig 1. The couch top bellyboard on a Varian iX exact couch.

with the iliac crest aligned to lie between the bellyboard hump and the inferior edge of the opening. Computed tomography (CT) data were acquired on a GE Lightspeed 16 slice scanner set in the helical scan mode (120 kVp, 60 mA) with a slice thickness of 2 mm. The radiation oncologist contoured the treatment planning volumes according to the published RTOG guidelines [7] for rectal cancer. At treatment, a set of kV–kV images were taken daily, a bony anatomy match carried out online, and moves made along each axis. Anterior and lateral digitally reconstructed radiographs were used as reference images. CBCT data were acquired once every five fractions for a total of five images per patient.

Probabilistic Margin Analysis

The RTOG contouring guideline for anorectal cancer defines CTV_A, CTV_B and CTV_C as follows: (A) the regions that would always be treated for rectal cancer (internal iliac, presacral, and peri-rectal), (B) the external iliac nodal region and (C) the inguinal nodal region. More specifically, the mid-pelvis posterior and lateral margins of CTV_A are to extend to lateral pelvic sidewall muscle structure or bone. In general, a bony anatomy match does not equate to soft tissue CTV match. CTV for rectum being defined using the pelvic bony anatomy and the rigid nodal regions, the lymphovascular scaffolding being covered by parietal peritoneum and fixed on to the pelvic wall, is clearly a special case. As such, one can reasonably assume equivalence between CTV and pelvic bony structure position (see Figure 2). Assuming equivalence between CTV position and that of the pelvic bony anatomy, a three-dimensional – three-dimensional (3D-3D) bony anatomy match between the planning CT and each of the five CBCT images was used as a surrogate for the evaluation of inter-fractional CTV positional errors.

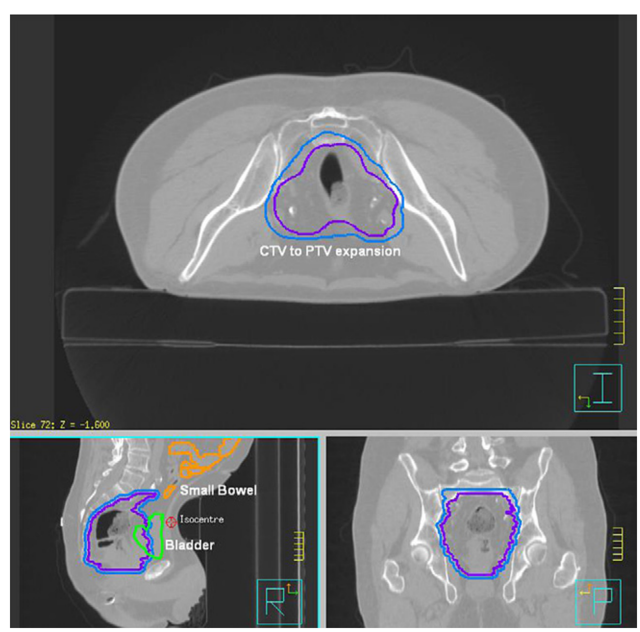

Fig 2. A typical planning CT dataset that includes the clinical target volume (purple), the planning target volume (blue), bladder (green) and small bowel (orange).