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Physics Contribution

Image Guided Radiation Therapy Strategies for Pelvic Lymph Node Irradiation in High-Risk Prostate Cancer: Motion and Margins

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Summary

We determined the optimal image guided radiation therapy strategy for pelvic node irradiation in high-risk prostate cancer patients. Margins were derived from motion measured in repeat computed tomography (CT) of 19 patients, simulating either bony anatomy or prostate based image guided radiation therapy. Using bony anatomy, margins were smaller for lymph nodes than using the prostate, but larger for prostate and seminal vesicles. A 6 degrees-of-freedom (6-DOF) couch allowed lymph node margin reduction in the anterior-posterior

Purpose: To quantify the relative motion of the pelvic lymph nodes (LNs), seminal vesicles (SV) and prostate and define indicative margins for image-guided radiotherapy based on bony anatomy or prostate correction strategies for a 3 or 6 degrees-of-freedom couch.

Methods and Materials: Nineteen patients had a planning computed tomography (CT) scan followed by a mean of 11 repeated CT scans during radiation therapy. The prostate, SV, and external and internal iliac LN regions on the left and right were outlined on each CT scan. Systematic and random uncertainties were determined along with correlations between the motions of these regions. The clinical target volume to planning target volume margins required to take only motion into account were calculated for each guidance method.

Results: For bone guidance, motion of the prostate and LNs was largely uncorrelated. Margins to compensate for motion (left−right, superior−inferior, anterior−posterior, in cm) based on a 3-DOF couch were as follows: prostate (0.2, 0.6, 0.8), SV (0.4, 0.9, 1.0), and LNs (0.3, 0.4, 0.6). For prostate guidance, margins were calculated for correlated motion: prostate (0, 0, 0), SV (0.3, 0.5, 0.4), and LNs (0.3, 0.5, 0.9). For a 6-DOF couch, these margins were as follows: prostate (0.2, 0.6, 0.8), SV (0.3, 0.9, 1.0), and LNs (0.3, 0.4, 0.3) for bone guidance. For prostate guidance, margins were as follows: prostate (0, 0, 0), SV (0.2, 0.5, 0.4), and LNs (0.3, 0.6, 0.6).

Conclusions: Image guided radiation therapy based on bony anatomy requires larger prostate and SV margins, and guidance on prostate requires larger LN margins. Neither guidance strategy is optimal, and a combination of the 2 or treatment adaptation after a

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direction compared to a 3-DOF couch.

number of fractions might be preferable. Calculation of the total margin should also include delineation uncertainties.

Introduction

In the last decade the treatment of high-risk prostate cancer patients with external beam radiation therapy has been improved by the use of intensity modulated radiation therapy (1) and image guidance (2) to reduce dose to surrounding tissues without compromising dose to the target structures (3). The introduction of these techniques has led to a reduction in toxicity (4, 5).

Patients with high-risk prostate cancer are usually treated with a combination of external beam radiation therapy and hormone therapy (6). The clinical target volume (CTV) is considered to be the entire prostate, typically including the seminal vesicles (SV). In the case of very high-risk prostate cancer with clinical suspicion or evidence of local disease spread, lymph node (LN) regions may also be included (7). A margin is added to each structure to take account of uncertainties in planning or treatment delivery, resulting in the planning target volume (PTV). This margin is kept as small as possible using a dose-probability approach based on previously measured systematic and random position errors of the targets (8). The day-to-day position of the prostate and SV varies as a result of differences in bladder and rectum filling (9, 10). Nowadays patient positioning for prostate-only radiation therapy is usually based on cone beam computed tomography (CT) or megavoltage (MV) x-ray images, matching to the position of implanted fiducial markers or the prostate itself (11).

In addition to the prostate and SV, local LN regions can also be treated with external beam radiation therapy, though studies investigating the effect of LN radiation therapy on overall survival are ongoing (6). The likelihood of LN metastasis is usually determined using a nomogram combining, for example, prostate-specific antigen level and Gleason score from diagnostic biopsy in the Roach formula (12, 13) rather than detecting involved nodes directly. Imaging techniques such as diffusion-weighted magnetic resonance imaging or positron emission tomography may improve nodal staging and allow more-targeted treatment (14, 15). If involved LNs are to be irradiated, their motion must be characterized to find the appropriate margins that minimize toxicity and risk of geometric miss.

Previous studies have examined the motion of the prostate and LNs using MV CT images from TomoTherapy treatment (16), repeated CT scans (17), and 2-dimensional MV images (7), based on either daily matching to the prostate, bones, or a combination of the 2. Other authors have investigated whether the nodal motion results in suboptimal coverage when using fiducial markers to align the prostate on cone beam CT (18-20). Margins for the prostate, SV, and LNs should be based not only on the day-to-day motion of these structures but also on the relationship between their motions. If the position of the prostate is matched for each treatment, there must be a sufficient margin for the LNs to ensure that they remain in the irradiated volume, and this can only be taken account of if the correlation between the motion of the prostate and LNs is measured. This issue has not been investigated and quantified previously. The analysis by Thörnquist el al (17) is the most advanced published to date, using deformable contour registration but reporting dosimetric evaluation. Although a dosimetric analysis is valuable, the results will depend on the planning technique and actual target volumes used, and this falls outside the scope of this article. Here we provide a geometric analysis of the motion of the relevant structures that has a more general applicability and has not been published before.

In this study, the aim is to find the appropriate CTV to PTV indicative margins to take account of the motion of the prostate, SV, and LNs when using image guidance based on the position of either bony anatomy or the prostate, using a 3 degrees of freedom (3-DOF) or 6-DOF couch.

Methods and Materials

Patients

Nineteen prostate cancer patients participated in this study (3 T stage 1, 4 stage 2, 12 stage 3), each of whom had repeated CT scans throughout their radiation therapy course of 7 to 8 weeks. Treatment was limited to prostate and SV only because these patients did not have nodal disease, but nodal motion could still be assessed in this relevant patient group. Computed tomography was used rather than cone beam CT owing to availability, the required image quality, and the field of view needed to visualize the most superior nodal regions. Details of these patients have been reported previously (9). Briefly, patients had a planning CT scan followed by repeated CT scans on treatment days 1, 2, 3, 6, and 10, then midway through each subsequent week of treatment, aiming at 11 or 12 scans. Because of missed appointments and 1 repeated planning CT, between 8 and 13 repeated scans were available (mean 11). Patients were asked to empty their bladder and rectum and then drink 250 mL of fluid 1 hour before the planning CT scan and before each treatment. They were asked not to empty their bladder between the treatment and the repeat CT scan, which was made within 30 minutes of treatment.

The patients were scanned in the treatment position, with superior−inferior (SI) coverage from the cranial boundary of the sacroiliac joints to 4 cm caudal to the pubis. The slice thickness was 3 mm over the prostate and SV and 5 mm elsewhere. The matrix size was 512 × 512 pixels, with a pixel size of 0.8 mm × 0.8 mm.