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Evaluation of overall setup accuracy and adequate setup margins in pelvic image-guided radiotherapy: Comparison of the male and female patients

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ABSTRACT

We evaluated adequate setup margins for the radiotherapy (RT) of pelvic tumors based on overall position errors of bony landmarks. We also estimated the difference in setup accuracy between the male and female patients. Finally, we compared the patient rotation for 2 immobilization devices. The study cohort included consecutive 64 male and 64 female patients. Altogether, 1794 orthogonal setup images were analyzed. Observer-related deviation in image matching and the effect of patient rotation were explicitly determined. Overall systematic and random errors were calculated in 3 orthogonal directions. Anisotropic setup margins were evaluated based on residual errors after weekly image guidance. The van Herk formula was used to calculate the margins. Overall, 100 patients were immobilized with a house-made device. The patient rotation was compared against 28 patients immobilized with CIVCO's Kneefix and Feetfix. We found that the usually applied isotropic setup margin of 8 mm covered all the uncertainties related to patient setup for most RT treatments of the pelvis. However, margins of even 10.3 mm were needed for the female patients with very large pelvic target volumes centered either in the symphysis or in the sacrum containing both of these structures. This was because the effect of rotation ($p \leq 0.02$) and the observer variation in image matching ($p \leq 0.04$) were significantly larger for the female patients than for the male patients. Even with daily image guidance, the required margins remained larger for the women. Patient rotations were largest about the lateral axes. The difference between the required margins was only 1 mm for the 2 immobilization devices. The largest component of overall systematic position error came from patient rotation. This emphasizes the need for rotation correction. Overall, larger position errors and setup margins were observed for the female patients with pelvic cancer than for the male patients.

Introduction

The anatomy of the male and female pelvis is different. In the male pelvis, the bones and muscular volume are larger than those of the female pelvis. The female pelvic area tends to accumulate more fat. The shape of the pelvis is also different. In addition, the male skin is thicker. The different anatomic properties between the genders may require different considerations for patient setup in radiotherapy (RT).

Haslam *et al.*[1] have reported that setup accuracy is independent of patient weight, height, and age and it is not possible to estimate setup accuracy based on these factors. However, they have not investigated the difference between the setup accuracy for the men and the women. To the best of our knowledge, no comprehensive studies exist on that topic.

In clinical practice, we have noticed that more image guidance has been needed to confirm the patient setup in pelvic RT for women than that needed for men. However, it is common to assume that equal setup margins can be applied because of the same image-guidance procedure and immobilization. Errors from different sources, such as observer-related errors, have not been investigated comprehensively in recent studies using kV imaging. It might be useful to know to what extent the uncertainty in patient setup is related to translation, rotation, and observer-related factors.

The purpose of this study was to estimate adequate setup margins for image-guided RT (IGRT) based on bony landmarks in

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the pelvis. We evaluated whether an isotropic setup margin of 8 mm is adequate when considering weekly IGRT protocol, combination of patient rotation and deformation, and observer-related errors. We evaluated setup accuracy for both the male and female patients. We analyzed orthogonal x-ray images as they are widely used for frequent (routine) setup verification. As onboard 3-dimensional (3D) verification imaging (such as cone beam computed tomography, CBCT) may be performed less frequently, setup margins should be confirmed suitable for the 2D imaging. Based on bony landmarks, 2D kV and CBCT alignments have been reported to correlate highly, but slightly different margins may be needed.[2]

Methods and Materials

Patient groups

The group males (M) consists of consecutive patients with rectal ($n = 25$) and prostate cancer ($n = 25$) and the group females (F) of consecutive patients with gynecologic ($n = 27$) and rectal ($n = 23$) cancer. All the patients have a large planned target volume (PTV) because of the lymph node involvement as shown in Fig. 1. The average age for the group F and M was 68 and 71 years, respectively. Both groups were immobilized with a knee support that has been made in our department several years ago (device 1). The feet are tied with a stasis. We compared our fixation device to a commercial one used in our satellite unit in Lahti. This device is the combination of CIVCO's Kneefix and Feetfix (device 2), where both knees and feet are fixed into a supporting cushion. Both the devices are presented in Fig. 2. The Lahti group consists of 14 male and 14 female patients (18 patients with rectal cancer, 8 patients with gynecologic cancer, and 2 patients with urinary bladder cancer). Computed tomography (CT) imaging for treatment planning was done at 120 kVp with either Philips Brilliance Big Bore (Philips Medical Systems, Eindhoven, the Netherlands) or Toshiba Aquilion LB (Toshiba Medical System, Tokyo, Japan) using a slice thickness of 3 mm. The patients were treated with the intensity-modulated radiation therapy technique using 6- and 18-MV photon beams of Clinac 2300 iX (Varian Medical Systems, Palo Alto, CA). Image guidance was carried out using orthogonal kV images acquired with an onboard imaging system at 75 kV with 10 to 16 mAs for the anterior images and at 105 to 120 kV with 80 to 126 mAs for the lateral images.

Investigated image-guidance protocols

Our image-guidance protocol used an online correction with a fixed 5-mm action level for translational couch (patient setup) corrections in all 3 orthogonal directions. Imaging was performed in the first 3 treatment fractions and weekly thereafter. If the action level was exceeded, the imaging was repeated in the next fraction. An action level of zero was applied for couch vertical based on the average of the 3 first treatment fractions and 5 mm in weekly imaging. We analyzed the acquired onboard images retrospectively in offline review according to the presented IGRT protocol. We estimated setup errors also without IGRT and with image guidance performed only in the first 3 treatment fractions to demonstrate transfer errors between the treatment-planning CT and a treatment unit.

Estimation of setup errors

Reference treatment level was defined in the middle of PTV (MID-PTV). The MID-PTV point was located usually within ± 1 cm from the midpoint of the pubic symphysis and the sacrum (Fig. 1). Setup errors were determined separately for the group M ($n = 33$) and the group F ($n = 44$) and for both the groups together. The number of the analyzed kV images was 816 and 480 for the men and women, respectively. Directions are expressed as anterior-posterior (AP or vertical), superior-inferior (SI or longitudinal), and LAT (lateral).

Patient rotation errors

The effect of pelvis rotation was investigated with 50 male and 50 female patients with total number of images being 652 and 600, respectively. This was done by determining systematic and random variations in the distance between the pubic symphysis and the sacrum as seen in Fig. 1, as they are the clearest landmarks and usually placed at the extreme edges of the pelvic targets. Also, deformation of bony structures may contribute to these results. However, the pelvis is a quite rigid object and the rotations play the most important role for these results. The extent of rotation was double checked by rematching the images with a time gap of 2 months.

Estimation of observer errors and comparison of the 2 fixation devices

A group of 20 experienced radiation therapists evaluated the images and their image matches were compared with the reference MID-PTV match. Systematic ($\sum$) and random (σ) errors were determined for the differences. Potential benefit of device 2 in the reduction of the rotation errors was investigated based on data obtained from our satellite clinic, comprehending 28 patients with 378 images. Unfortunately, no larger data were available consistent with our IGRT protocol. Therefore, the devices were compared only for combined groups of the male and female patients.

Estimation of overall errors and treatment margins

The residual setup error of the treatment isocenter after weekly imaging, the rotation of the sacrum and the pubic symphysis, and the observer error were combined to obtain the overall setup errors. All the error components were added in quadrature.[3] Systematic ($\sum$) and random (σ) components were handled separately. The total errors were used to calculate anisotropic setup margins using the van Herk formula $m = 2.5\Sigma + 0.7\sigma$.[3]

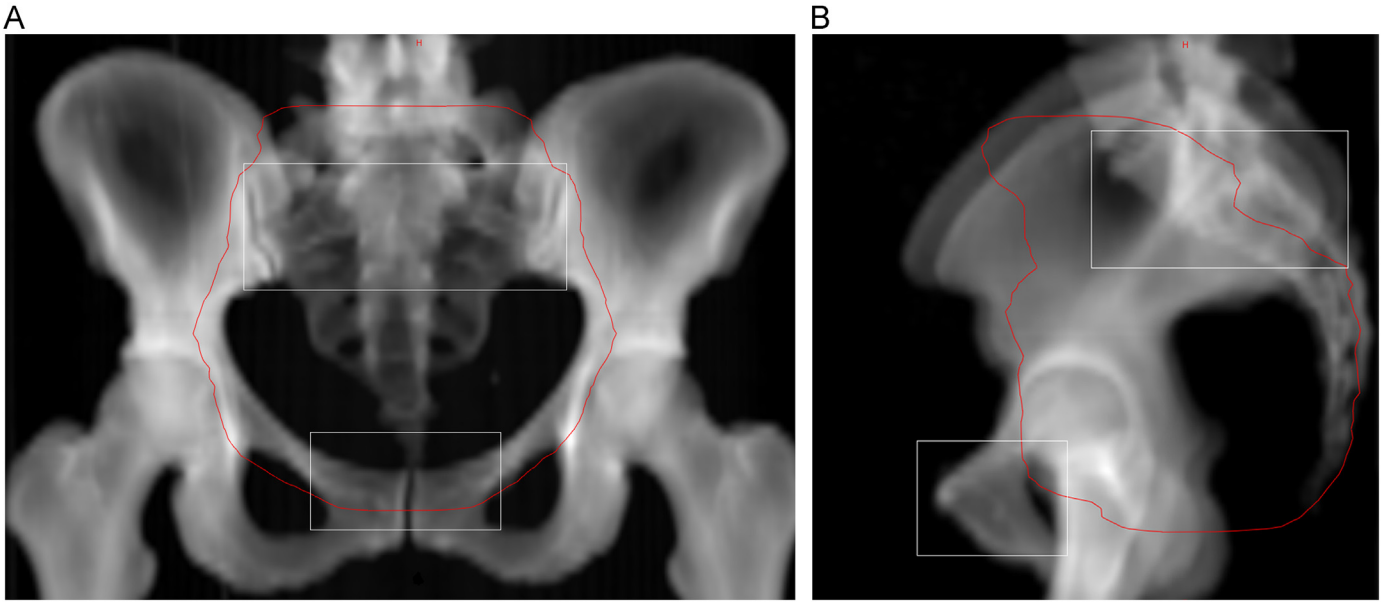

Fig. 1. Regions of interest in the sacrum and the pubic symphysis (white boxes) used to estimate the pelvis rotation. Typical PTV covers both of these structures in (A) anterior and (B) lateral reference images. The translational position errors caused by the rotation about anterior axis (yaw) and lateral axis (pitch) were determined from images (A) and (B), respectively. (Color version of figure is available online.)