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Pelvic radiotherapy

Planning organ at risk volume margins for organ motion of the intestine

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Abstract

***Background and purpose*: To account for internal organ motion and set-up uncertainties around organs at risk (OR) in radiotherapy (RT), the ICRU report no 62 introduced the planning organ at risk volume (PRV). In the present study, we have quantified PRV margins for the intestine, which is an important OR in pelvic RT.**

***Materials and methods*: The present study was based on intestine contours outlined in a total of 149 CT scans of 20 male bladder cancer patients (20 planning scans, 129 during treatment). From these data, we created location probability maps of the intestine for each patient. A commercial treatment planning system was used to add 3D isotropic intestine PRV margins (from 5 to 30 mm, in intervals of 5 mm) around the intestine planning outline. We then derived the fraction of patients for which a given PRV encompassed various degrees of intestine motion (85%, 90% and 95% of volumes with different probabilities of intestinal occupancy). As a measure of the specificity of the PRV, we also derived the fraction of the PRV containing volumes with zero probability of intestinal occupancy.**

***Results*: Isotropic margins of up to 30 mm are required to account for all intestine motion in 90% of the patients, while isotropic margins of 5–10 mm will encompass 85–95% of the volumes having a probability of intestinal occupancy of $\geqslant$75% in the same fraction of patients. Intestine PRVs are not very specific and will also include volumes where the intestine will rarely or never be located.**

***Conclusions*: Large intestinal motion was found, but isotropic PRV margins of 5–10 mm will include the major part of volumes with a large probability of intestinal occupancy in most patients.**
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Keywords: Pelvic radiotherapy; Pelvic tumours; RT; Bowel; Intestine; Planning organ at risk volume (PRV)

The small intestine is a radiosensitive organ, which is often the dose-limiting organ at risk (OR) in radiotherapy (RT) of pelvic tumour sites [10]. Decreasing the volumes of small intestine receiving high doses is therefore an important objective in pelvic RT [4,10,11,15]. However, the knowledge about the correlation between dose-volume parameters of the intestine and the risk of intestine adverse effects is less clear, probably due to the mobility of this organ [3,10].

Nuyttens and colleagues have reported considerable variation in the position of the small intestine both in the cranial–caudal and the anterior–posterior direction in patients with rectal cancer treated with preoperative and postoperative RT [21]. Our group has also documented large inter- and intra-patient variation in intestine position and volume when evaluated using weekly repeat CT scans of 20 bladder cancer patients [19]. Recently, Kvinnsland and Muren investigated the impact of pelvic organ motion on dose-volume histograms (DVH) of the intestine in ten of these bladder cancer patients [9]. In six patients, the volume occupied by the intestine in one scan only was larger than the volume occupied by the intestine in all scans. This mobility of the intestine was also reflected in large standard deviations in the DVHs for the individual patients.

To account for internal organ motion and set-up uncertainties around ORs, the ICRU report no 62 introduced the planning organ at risk volume (PRV) [7]. The PRV includes the OR as well as safety margins around the OR, in analogy with the target volume definitions where a planning target volume (PTV) is used around the clinical target volume (CTV) to account for geometrical variation. In 2002, McKenzie and co-workers presented a method for determination of margins around ORs to account for both systematic (treatment preparation) and random (organ motion and set-up errors) geometrical uncertainties [13]. The PRV was defined such that the DVH of the PRV should not underestimate the high-dose components delivered to the OR, in 90% of cases. In our group, an purely empirical approach based

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on repeat CT scans of bladder cancer patients was applied, together with the McKenzie methodology to determine rectum PRV margins, and some limitations with the McKenzie et al., methodology when using it on complex organs such as the rectum were disclosed [16]. Recently, our group also investigated whether use of DVHs of various rectum PRVs (with different margins added) improved the correlation between DVH parameters and acute gastro-intestinal (GI) toxicity in a series of 132 prostate cancer patients [17]. Although a correlation was found for both the rectum only DVH [8,17] and the PRV DVHs [17], 2–3 times (depending on margin size) as many dose levels were significantly related with toxicity for the PRVs compared to the rectum only [8,17].

In addition to potentially improving the predictive power of dose-volume statistics, PRVs may also be useful as a tool in planning of RT, in particular in inverse planning of intensity-modulated RT (IMRT). Currently, we are using IMRT to treat pelvic lymph nodes in locally advanced prostate cancer. In the present study, we therefore quantified PRV margins for the intestine as an OR in pelvic radiotherapy.

Materials and methods

Patient material

The present study was performed using 20 male patients with muscle invading transitional cell urinary bladder cancer. Out of these, 14 were referred for radical conformal radiotherapy at Haukeland University Hospital (HUH) in the period from January 2000 to October 2001, while the other 6 were treated at Edinburgh Cancer Centre (ECC) during 2003. For the whole group, age ranged between 58 and 87 years (mean age: 74 years).

For the patients treated at HUH, weekly repeat computer tomography (CT) scans were acquired as close to the treatment session as practically possible. Patients were instructed to empty their bladder before all treatment and scanning sessions, and 70 ml of contrast was instilled into the bladder before the planning scan only. For the six patients from ECC, CT scans were acquired twice a week during the four-week treatment course, again as close to treatment session as practically possible. These six patients were scanned with an empty bladder, without instillation of contrast.

Repeat CT data and intestine outlining

Overall, 6–9 CT scans (totally 149 scans) were acquired for each of the patients. For the patients treated at HUH, the CT scans covered both the abdomen and pelvis, while the CT scans of the patients from ECC covered the pelvis up to the sacral promontory. All patients were scanned in supine position: The patients from HUH as well as one of the patients from ECC (i.e., 15 patients) were scanned with 5 mm slice thickness and 5 mm interval (5/5 slices) throughout the pelvis, while the five remaining patients from ECC were scanned with 3/3 slices.

The repeat scans were registered to the planning scan using the Advantage Fusion software (v. 1.15; GE Medical Systems, Milwaukee, WI, USA) — initially by using an automatic procedure that primarily matched on bony anatomy, and further by defining six bony landmarks in the abdomen and pelvis. One of the authors (LPM) outlined all segments of the intestine located below the sacral promontory for the patients treated at HUH. For the patients treated at ECC, one of the authors (HL) outlined the intestine in the repeat scans, while another author (LBH) did the intestine outlining in the planning scans. The same instruction for outlining was followed for all cases, with each individual loop of the intestine (both small and large) being outlined. Only the part of the intestine located below the sacral promontory was included in the analysis. The organ outlines in the repeat scans were automatically transferred to the planning scan using the 3D image registration transform in the Advantage Fusion software and saved as separate DICOM RT Structure sets (DICOM RTSSs). These RTSSs were transferred to a PC, where further analysis was performed using specially designed software written in Interactive Data Language (IDL, Research Systems, Inc., Boulder, USA).

Defining the intestine location probability map

A 3D *location probability (LP) map* for the intestine was created for each patient, using eight intestine outlines for each patient. The maps had the same pixel resolution as the CT matrix, containing voxels with a value from 1/8 to 8/8, corresponding to how many times the voxel had been occupied by the intestine (i.e., as observed in the repeat scans). For patients with fewer than 8 repeat scans, a few randomly selected intestine outlines were used twice to create the location probability matrix.

The probability of intestinal occupancy for each voxel in the location probability map was equal to the voxel value, and a *location probability volume* of $\geqslant$LP% (with LP being 12.5–100% in intervals of 12.5%) was defined as the volume of the voxels with a value greater or equal to the LP.

The planning outline of the intestine was not included in the location probability map.

Calculation of volumes and volume comparison

The volume of the intestine was calculated by multiplying the number of pixels within the contours in each slice of the CT scan with the pixel size and the slice thickness of the CT scan of each individual patient. The same definition was applied for the location probability maps.

Since the patients treated at HUH had a small amount (70 ml) of contrast instilled into the bladder before the planning scan, it was investigated whether the volume of the intestine from the planning CT scan differed from the volumes of the intestine from repeat CT scans. This analysis was performed separately for the patients from HUH and ECC, since the latter had no contrast instilled during the planning CT session. We also compared the ratio between the location probability volumes and the average intestine volume of each patient.

Analysis of intestine PRVs

The PRV concept was used to quantify various degrees of intestine motion relative to the intestine planning outline in each patient. Using the 3D margin tool of the Eclipse treatment planning system (v. 6.5, Varian Medical Systems, Palo