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Original Research Article

The normal tissue sparing potential of an adaptive plan selection strategy for re-irradiation of recurrent rectal cancer ☆

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ABSTRACT

Background and purpose: Radiotherapy (RT) of rectal cancer is challenged by potentially large inter-fractional anatomy changes. The risk of radiation-induced morbidity is a particular concern in patients receiving re-irradiation for recurrent disease. We propose an adaptive RT plan selection strategy for these patients and report on its clinical feasibility and normal tissue sparing potential.

Material and methods: Eight patients with pelvic recurrence were re-irradiated according to a hyper-fractionation protocol (ReRAD-I; 40.8 Gy) using margins around the clinical target volume (CTV) of 15 mm trimmed to anatomical barriers (Plan L). Two new library plans (S and M) were created for each patient, with the target volumes covering the CTV with isotropic margins of 5 and 10 mm. Pre-treatment cone beam CTs were assessed to determine which plan would cover the CTV following soft-tissue match. The selected plans were compared to the clinically delivered plan in terms of normal tissue volume receiving 95% of the dose (V95%) and the volume of bone receiving 30 Gy (V30 Gy).

Results: Plan selections could be performed on all CBCTs for all patients. Plan S was chosen in 213 fractions (79%), plan M in 53 (20%) and plan L in 2 fractions. Normal tissue V95% was reduced by 67% (median; range 30–79%) while bone V30 Gy was reduced by 66% (median; range 40–100%).

Conclusion: The CTV and/or surrogate structures were visible on all CBCTs. Margins smaller than those used clinically would have accounted for 99% of the observed target deformations, translating into a considerable normal tissue sparing potential.

1. Introduction

Radiotherapy (RT) of pelvic tumors is challenged by large inter- and intra-fractional changes during the entire treatment course [1–5]. Highly conformal treatment techniques such as intensity-modulated RT (IMRT) and volumetric modulated arc therapy (VMAT) have been introduced to increase the dose to the tumor while minimizing dose to the normal tissues. However, the use of large population-based margins to ensure target coverage still limits the treatment conformity. The implementation of technologies for image-guidance opens possibilities to also explore adaptive RT (ART) strategies, in order to treat patients with minimal normal tissue irradiation. Several ART strategies have already been developed for different pelvic tumor sites, including the bladder [1] and the cervix [6]. For these two sites bladder filling protocols and multiple plan libraries are used to control and account for target shape changes. In the case of prostate tumors, fiducial markers are routinely implemented [7,8]. For rectal tumors, shape variations are difficult to control and combined with the image contrast of cone-beam CT (CBCT) scans in the pelvic region, safe implementation of ART strategies remains a great challenge [9–13].

Recurrent rectal cancer differs from primary tumors in that the site of recurrence may be local or regional, and a proportion of patients have previously received preoperative RT or chemoRT. The CTV includes the rectal recurrence with a margin, but not the regional lymph nodes. However, the margins often involve the pelvic bones. In many of these patients, population-based (wide) margins may be sub-optimal; resulting in unreasonably high total doses to previously irradiated normal tissue. Of particu-

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lar concern is the radiation to small bowel and pelvic bones, which may lead to severe late morbidities such as diarrhea, pain and fractures [14–17]. In these cases, an adaptive and more individualized RT plan could be even more attractive.

The aim of this study was therefore to evaluate the feasibility and normal tissue sparing potential of an adaptive plan selection strategy for rectal cancer patients with pelvic recurrence.

2. Material and methods

2.1. Patient and image material

Eight patients (five males, three females) re-irradiated for recurrent rectal cancer from July 2015 to August 2017 were included in this study. All patients had previously been treated with preoperative chemo-RT followed by surgery for rectal adenocarcinoma. All patients received pelvic re-irradiation according to a protocol comprising 40.8 Gy delivered in 34 fractions with two fractions of 1.2 Gy per day and concomitant capecitabine (ReRAD-I). The CTV included the recurrent tumor with margins (Fig. 1). One patient completed only 30 of the treatment fractions. Daily set-up was performed with pre-treatment CBCTs matched to the planning CT (pCT) based on pelvic bony anatomy. The delivered treatment consisted of a VMAT plan with two 358° arcs (Eclipse, version 11, Varian Medical Systems, Palo Alto, CA). The planning target volumes (PTVs) were generated by first expanding the CTV isotropically with 10 mm, trimming the resulting volume against relevant anatomical barriers, *e.g.* muscle and bone, and subsequently adding another 5 mm margin isotropically (the PTV may thus extend into muscle and bone). All RT fractions were delivered on Truebeam accelerators (Varian Medical Systems). In the following, this is referred to as the standard treatment and the target volume is denoted PTV_L (L for large).

2.2. Plan library generation

For the purpose of this study, two library VMAT plans (small S and medium M) were generated. The plans covered the CTV with an isotropic margin of 5 mm and 10 mm, see Fig. 2. Plans were optimized to cover 99% of the new PTVs with more than 95% of the prescribed dose. During the optimization process, the dose to surrounding normal tissues such as bowel, bladder and femoral heads was minimized while coverage of the target was maintained.

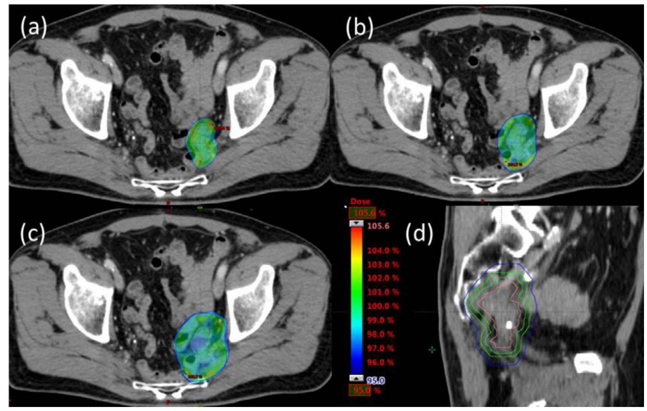

Fig. 2. PTVs and dose distributions for a) plan S (CTV + 5 mm), b) plan M (CTV + 10 mm) and c) the standard plan L (CTV + 15 mm, trimmed) for one patient. Standard CTV (pink), PTV (blue) and library PTVs (green) are depicted in d). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3. Plan selection

Retrospectively, a total of 268 CBCT scans were evaluated to determine which plan would cover the CTV at the specific treatment fraction following *offline* soft-tissue match to the pCT (note: patients were actually treated based on bony anatomy based image-guidance). The soft-tissue match was performed automatically (using the Eclipse Offline Review module) with the CTV with a margin of 1 cm as the structure volume of interest. The automatch procedure did not include rotations. The plan selection was performed by an experienced medical physicist (LN) and confirmed by a second medical physicist. In case of doubt, the plan with the largest volume was selected. Volumes of the CTVs and PTVs were measured and compared to an 'effective' PTV (PTV_{eff}), a weighted mean of the volumes which would have been treated throughout the treatment course using the plan selections.

2.4. DVH analysis

The normal tissue sparing potential was evaluated by introducing a normal tissue structure equal to the delineated body outline subtracted the CTV for all plans and all patients. Summed dose volume histograms were then calculated using the planning CT and

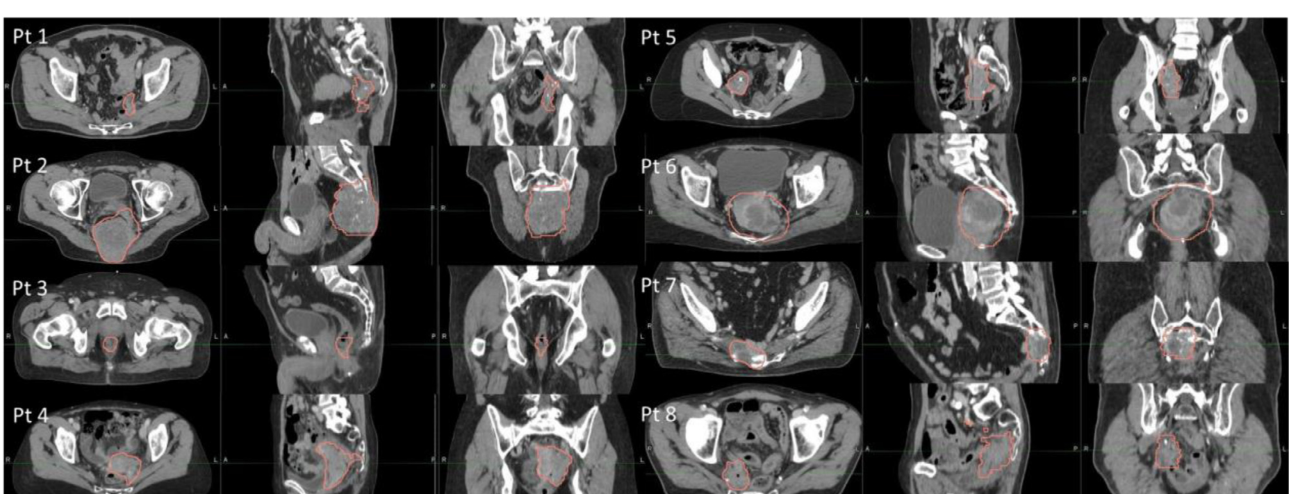

Fig. 1. Planning CT scans with clinical target volumes (CTVs) for all eight patients.