Brachytherapy ■ (2017) ■

BRACHYTHERAPY

Benefit of adaptive CT-based treatment planning in high-dose-rate endorectal brachytherapy for rectal cancer

Roy P.J. van den Ende*, Eva C. Rijkmans, Ellen M. Kerkhof, Remi A. Nout, Martijn Ketelaars, Mirjam S. Laman, Corrie A.M. Marijnen, Uulke A. van der Heide

Department of Radiation Oncology, Leiden University Medical Center, Leiden, The Netherlands

ABSTRACT

PURPOSE: In this planning study, we investigated the dosimetric benefit of repeat CT-based treatment planning at each fraction vs. the use of a single CT-based treatment plan for all fractions for high-dose-rate endorectal brachytherapy (HDREBT) for rectal cancer.

METHODS AND MATERIALS: We included 11 patients that received a CT scan with applicator in situ for all three fractions. The treatment plan of the first fraction was projected on the repeat CT scans to simulate the use of a single treatment plan. In addition, replanning was performed on the repeat CT scans, and these were compared to the corresponding projected treatment plans.

RESULTS: Repeat CT-based treatment planning resulted on average in a 21% higher ($p = 0.01$) conformity index compared to single CT-based treatment planning. Projecting the initial treatment plan to the repeat CT scans of fraction two and three, 12/22 fractions reached a CTV D98 of 85% of the prescribed dose of 7 Gy, which increased to 14/22 using replanning. For the remaining fractions, median CTV D98 was 4.2 Gy, and an intervention would be necessary to correct applicator balloon setup or to remove remaining air and/or feces between the CTV and the applicator.

CONCLUSIONS: Using a single CT-based treatment plan for all fractions may result in a suboptimal treatment at later fractions. Therefore, repeat CT imaging should be the minimal standard practice in HDREBT for rectal cancer to determine whether an intervention would be necessary. Replanning based on repeat CT imaging resulted in more conformal treatment plans and is therefore recommended.

Keywords: Rectal cancer; Brachytherapy; Image guided; Repeat CT

Introduction

Total mesorectal excision is the mainstay in the treatment of rectal cancer. For more advanced cases, the addition of neoadjuvant (chemo)radiotherapy has resulted in lower local recurrence rates, but none of the recent trials has demonstrated a benefit in overall survival (1–4). Unfortunately, (chemo)radiotherapy is associated with an increased risk of side effects such as bowel and sexual dysfunction (5). Vuong *et al.* introduced high-dose-rate endorectal brachytherapy (HDREBT) as a replacement of neoadjuvant external beam radiation therapy (EBRT) with promising results in local control (6, 7). For patients unfit or unwilling to undergo surgery, definitive or palliative radiotherapy are alternatives. Rijkmans *et al.* demonstrated the feasibility of an HDREBT boost after EBRT in inoperable patients (8). Compared with EBRT, HDREBT can deliver high doses to the tumor while sparing surrounding organs due to a steeper dose gradient (7). As a consequence, HDREBT has the potential to decrease morbidity and reduce the risk of side effects (9). However, the steeper dose gradient means that an anatomical interfraction variation of millimeters can have a high impact on the delivered dose to the target volume or surrounding organs. Therefore, high precision is required in imaging, contouring, and treatment planning.

For HDREBT treatment planning, the conventional approach is to use the treatment plan generated at the first

Received 11 May 2017; received in revised form 27 June 2017; accepted 20 August 2017.

Conflict of interest: The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

Financial disclosure: This work was supported by the Dutch Cancer Society/Alpe d'HuZes Fund (grant number UL2013-6311). The funding source had no involvement in the study design, in the collection, analysis and interpretation of data, in the writing of the manuscript, and in the decision to submit the manuscript for publication.

* Corresponding author. Department of Radiation Oncology, Leiden University Medical Center, P.O. Box 9600, 2300 RC Leiden, The Netherlands. Tel.: +31 715297077.

E-mail address: r.p.j.van_den_ende@lumc.nl (R.P.J. van den Ende).

1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2017.08.011

fraction, for all later fractions (10, 11). Alternatively, an adaptive approach could be used by creating a new treatment plan based on new imaging acquired at each fraction, taking into account interfraction anatomical variation (12, 13). For cervical cancer, several studies on image-guided brachytherapy compared the use of one treatment plan for all fractions to an adaptive approach using a newly generated treatment plan at each fraction (14, 15). The treatment plan for the first fraction was simulated on the imaging of the later fractions. The results showed that the treatment plan based on imaging of the first fraction did not lead to comparable target volume coverage and dose to organs at risk at later fractions (14, 15). Nowadays, repeat MR imaging is therefore recommended in brachytherapy for cervical cancer (16).

Most studies on the use of HDREBT for rectal cancer focus on oncological outcome and treatment-related toxicity in the preoperative setting, with limited detail on treatment planning. They do not address the question of using a nonadaptive or adaptive approach (9, 17–19). Vuong *et al*. initially reported a nonadaptive approach using one planning CT scan with applicator in situ on which a treatment plan is generated and used for all later fractions (10, 11). Recent publications by the same group describe an adaptive approach generating a new treatment plan based on a new CT scan for each fraction (12, 13). A recent abstract concludes that an adaptive approach resulted in a more conformal dose distribution (20).

In our study, we further investigated the comparison between a nonadaptive and an adaptive approach and added a quantification of conformity. In addition, we analyzed the repeat CT scans and reported causes of insufficient target volume coverage. The aim of this study was to determine the differences regarding treatment plan conformity, target volume coverage, and dose to organs at risk between using a single treatment plan for all fractions vs. a new treatment plan at each fraction in HDREBT for rectal cancer.

Methods and materials

Patient selection

For the present study, we selected 11 patients from the HERBERT trial in whom repeat CT scans with applicator in situ were available at each fraction (the HERBERT trial, registered with the Dutch Central Committee on Research Involving Human Subjects; registration no. NL17037.031.07) (8, 21).

Treatment

All patients were treated with 13 × 3 Gy EBRT at four fractions per week, followed by three weekly fractions of HDREBT using a prescription dose of 5–8 Gy starting 6 weeks after conclusion of EBRT. We adapted the brachytherapy equipment, application and positioning procedures from Devic *et al*. as described in Rijkmans *et al*. (8, 11). Patients received an enema before the CT scan with applicator in situ at each fraction.

We acquired a planning CT scan with applicator in situ before the first fraction. An inflatable balloon around the applicator on the opposite side of the clinical target volume (CTV) was used to fixate the applicator and to decrease the dose to the normal rectal wall. Treatment planning was performed using Oncentra Brachy (Elekta, Veenendaal, The Netherlands). The aim for treatment planning was to cover the CTV with the 100% isodose while containing the 400% isodose within the applicator. Repeat CT scans with applicator in situ were acquired for research purposes. In case of obvious differences compared to the CT scan of the first fraction, the treatment plan was adapted accordingly. These adapted treatment plans were not used in this study.

Delineation

The CTV was defined as residual macroscopic tumor and scarring after EBRT. CTV, anus, mesorectum, and healthy rectal wall were delineated by 2 observers with the help of diagnostic MRI, rectoscopy images, and inserted endoluminal clips at the proximal and distal border of the tumor. The rectoscopy images were acquired before EBRT and before the first brachytherapy fraction. Comparing CTV delineations between fractions of the same patient was allowed to check for consistency. In case of discrepancy between delineations, consensus was sought.

Projection and replanning

To determine the differences in conformity, CTV coverage, and dose to organs at risk between the use of a single treatment plan for all fractions and a new treatment plan at each fraction, the treatment plan of the first fraction and the new treatment plan were compared for each repeat CT scan. To obtain the dose distribution of the initial treatment plan on the repeat CT scans, the treatment plan of the first fraction was projected on the repeat CT scans. For this purpose, the most cranial activated dwell position was identified on the repeat CT scans in the same location with respect to the most cranial slice of the CTV delineation as on the CT scan of the first fraction. Subsequently, the dwell position pattern and dwell times were copied.

An experienced radiation treatment technologist created new treatment plans based on the repeat CT scans. As a result, for each repeat CT scan, we thus obtained both a projected treatment plan of the first fraction and a new treatment plan.

Analysis

To quantify dose conformity, the COnformal INdex (COIN) parameter was used, as defined by Baltas *et al*. in the following equation (22)

$$COIN = \frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}} \times \prod_{i=1}^{N_{CO}} \left[1 - \frac{V_{COref,i}}{V_{CO,i}} \right]$$