Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

A comparison of treatment plan quality between Tri-Co-60 intensity modulated radiation therapy and volumetric modulated arc therapy for cervical cancer

Jong Min Park [a,b,c,d], So-Yeon Park [a,b,c], Jung-in Kim [a,b,c], Hyun-Cheol Kang [a,b,c], Chang Heon Choi [a,b,c,*]

[a] Department of Radiation Oncology, Seoul National University Hospital, Seoul, Republic of Korea
[b] Institute of Radiation Medicine, Seoul National University Medical Research Center, Seoul, Republic of Korea
[c] Biomedical Research Institute, Seoul National University Hospital, Seoul, Republic of Korea
[d] Center for Convergence Research on Robotics, Advanced Institutes of Convergence Technology, Suwon, Republic of Korea

ARTICLE INFO

Article history:
Received 17 May 2017
Received in Revised form 12 June 2017
Accepted 15 June 2017
Available online xxxx

Keywords:
Volumetric modulated arc therapy
Intensity-modulated radiation therapy
Cervical cancer
MRI
Image guided radiotherapy

ABSTRACT

Purpose: To investigate the plan quality of tri-Co-60 intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) for cervical cancer.
Methods: A total of 20 patients who received postoperative radiotherapy for cervical cancer were selected. For each patient, a tri-Co-60 IMRT plan for which the target volume was the planning target volume (PTV) generated by adding 1 mm isotropic margins from the clinical target volume (CTV) and a VMAT plan for which the target volume was the PTV generated by adding 7 mm and 10 mm margins from the CTV were generated. The tri-Co-60 IMRT plans were generated with the ViewRay™ system while the VMAT plans were generated with 15-MV photon beams from a linear accelerator (prescription dose = 50.4 Gy in 28 fractions).
Results: The average volumes of the PTVs and CTVs were 704.9 cc ± 87.8 cc and 271.6 cc ± 51.6 cc, respectively. No noticeable differences in the dose-volumetric parameters for the target volumes were observed between the tri-Co-60 IMRT and VMAT plans. The values of V_{40Gy} for the small bowel and rectal wall, V_{45Gy} of the bladder, and V_{35Gy} of the femoral heads for the VMAT plans were 14.6% ± 7.8%, 54.4% ± 4.2%, 30.0% ± 4.7%, and 8.9% ± 3.3%, respectively. Those of the tri-Co-60 IMRT plans were 2.8% ± 2.1%, 23.0% ± 8.9%, 17.1% ± 6.1%, and 0.3% ± 0.4%, respectively.
Conclusions: Owing to the target margin reduction capability, the tri-Co-60 IMRT plans were more favorable than the VMAT plans for cervical cancer.

1. Introduction

Magnetic-resonance image-guided radiation therapy (MR-IGRT) has recently become available in the clinic with the release of the ViewRay™ system (ViewRay Inc., Cleveland, OH, USA) [1,2]. The ViewRay system can acquire magnetic resonance images (MRI) with 0.345 T superconducting magnets. To be compatible with the MR imaging system, the ViewRay system uses Co-60 sources for the generation of treatment beams. To overcome the relatively low dose-rate of the Co-60 source in comparison with linear accelerator (linac) sources, the ViewRay system uses a total of three Co-60 sources located at intervals of 120° in a ring-type gantry. Each source has double-focused multi-leaf collimators (MLC). The leaf width is 1.05 cm at the isoplane located 105 cm from the source. With these MLC systems, the ViewRay system can perform static intensity-modulated radiation therapy (IMRT), *i.e.* tri-Co-60 IMRT.

The treatment beam delivery system of the ViewRay system is relatively inferior to those of conventional linacs since the penumbra of the Co-60 source is larger than that of linac, the penetrating power of gamma ray of the Co-60 is lower than that of linac photon beam, and the leaf width of the ViewRay system is larger than that of linac (1 cm at 100 cm from the source for the ViewRay system vs. MLCs with a leaf width of 0.25 cm or 0.5 cm at 100 cm from the source for the conventional linac) [2–5]. However, the most attractive feature of the ViewRay system is the capability of MR imaging. Since there is no extra imaging dose with the ViewRay system, as many patient MR images that are needed can be acquired. Daily-based adaptive radiation therapy (ART) is possible with the ViewRay system through the combination of the volumetric MR images and its fast optimization and dose calculation algorithm [2].

* Corresponding author at: Department of Radiation Oncology, Seoul National University Hospital, Seoul, Republic of Korea.
E-mail address: dm140@naver.com (C.H. Choi).

http://dx.doi.org/10.1016/j.ejmp.2017.06.018
1120-1797/© 2017 Published by Elsevier Ltd on behalf of Associazione Italiana di Fisica Medica.

In some cases, such as prostate or cervical cancer, MR images can provide more useful information to define accurate target volumes or organs at risk (OAR) than computed tomography (CT) images [6–11]. In addition, the ViewRay system can perform respiratory gating based on the patient's internal anatomy with near-real-time cine sagittal MR images acquired continuously during treatment. This enables margin reduction for the planning target volumes (PTVs), which could improve the plan quality by irradiation of a smaller volume of normal tissue [12].

In conclusion, the ViewRay system has a relatively inferior beam delivery system but also has a unique and superior imaging system. Therefore, it is unclear whether the plan quality of the ViewRay system is better than that of the linac because the radiation delivery system potentially degrades the plan quality owing to the inferior beam delivery system, while the MR imaging system potentially improves the plan quality by margin reduction. The combined effect of these two factors on the plan quality might vary depending on the treatment sites, target volume sizes, or the proximity of the target volume to the OARs.

Several studies have investigated the plan quality of the tri-Co-60 IMRT in comparison with that of conventional linac-based IMRT or volumetric modulated arc therapy (VMAT) [12–16]. Wooten et al. have demonstrated that the tri-Co-60 IMRT plans of the ViewRay system were comparable to those of the linac-based IMRT plans for various diseases in the abdomen, pelvis, thorax, and head and neck (H&N) regions [16]. In their study, all of the tri-Co-60 IMRT plans were clinically acceptable. Kishan et al. investigated the treatment plan quality of the tri-Co-60 IMRT for liver stereotactic ablative radiotherapy (SABR) in comparison with VMAT plans [14]. They also showed the tri-Co-60 IMRT plans were clinically acceptable and comparable to the VMAT plans. Merna et al. demonstrated that no clinically significant differences were observed between the tri-Co-60 IMRT plans and linac-based IMRT plans for lung SABR when the target volumes were large and located in the central regions of the lung [15]. Park et al. demonstrated the plan quality of the tri-Co-60 IMRT was comparable with that of the VMAT for lung SABR for small target volumes, except for target conformity [12]. In that study, the target conformity became inferior when the target volumes were very small (<10 cc) due to the large MLC leaf width of the ViewRay system. Choi et al. investigated the plan quality of the tri-Co-60 IMRT for spine SABR in comparison with that of VMAT plans [13]. Because of the large penumbra of the ViewRay system due to the Co-60 sources, the tri-Co-60 IMRT plans could not generate a steep dose fall-off between the target volume and spinal cord, hence most of the tri-Co-60 IMRT plans were not clinically acceptable for spine SABR.

Various studies on the tri-Co-60 IMRT plan quality have been performed; however, no study has been performed on cervical cancer, for which the target volume sizes are large [12–16]. The target volume of cervical cancer can be defined more accurately with MR images than with CT images [6,8,9,17–19]. Moreover, the benefits of margin reduction with real-time cine MR images as well as the ART capability of the ViewRay system could be maximized for cervical cancer since the target volume sizes and the internal movement of the target volumes are large [20,21]. For example, a margin of 1 cm for a large target volume irradiates a much larger absolute volume of normal tissue than the same margin of 1 cm for a small target volume [22]. The adverse effect of the large MLC leaf width of the ViewRay system on the plan quality might be less significant for the large target volumes of cervical cancer than for cancers with smaller target volumes. Therefore, in this study, we investigated the tri-Co-60 IMRT plan quality for cervical cancer with PTVs generated with 1 mm margins from the clinical target volumes (CTVs) compared to that of VMAT with PTVs generated with 7 mm and 10 mm margins from the CTVs.

2. Materials and methods

2.1. Patient Selection and simulation

After institutional review board approval, a total of 20 patients who received postoperative radiotherapy for cervical cancer using the VMAT technique were retrospectively selected for this study. Every patient received concurrent chemotherapy. All patients underwent CT scans with the Brilliance CT Big Bore™ (Phillips, Amsterdam, Netherlands) in the supine position with a slice thickness of 2 mm. Contrast was administered to all patients for delineation of the target volume in the CT images.

2.2. VMAT planning for cervical cancer

The CTV was defined as including the pelvic lymph nodes, parametrial tissue, vaginal stump (or cervical mass if present), and upper vagina (if present) for each patient. The PTV as the target volume of the VMAT plan was generated by adding 0.7 cm margins from the CTV in all directions except in the anterior and posterior directions. Margins of 1 cm were added in the anterior and posterior directions from the primary target. The prescription doses were 50.4 Gy in 28 fractions (daily dose of 1.8 Gy). Two full arcs and the 15-MV photon beam of the Trilogy™ with the Millennium 120™ MLC (Varian Medical Systems, Palo Alto, CA, USA) were used. The VMAT plans were optimized with the progressive resolution optimizer 3 algorithm (PRO3, ver. 10, Varian Medical Systems, Palo Alto, CA, USA) in the Eclipse™ system. During optimization, dose constraints of the RTOG 0724 were followed to limit the delivered doses to OAR in order to avoid radiotherapy complications [23]. The V_{40Gy} of small bowel was kept at less than 30%. The V_{40Gy} of the rectal wall, V_{45Gy} of the bladder, and V_{35Gy} of the femoral heads were kept at less than 60%, 35%, and 15%, respectively [23]. After optimization, dose distribution in the patient CT images was calculated with the anisotropic analytic algorithm (AAA, ver. 10, Varian Medical Systems, Palo Alto, CA, USA) with a dose calculation grid of 2.5 mm. All VMAT plans were normalized to cover 95% of the volume of the PTV with 100% of the prescription dose.

2.3. Tri-Co-60 IMRT planning for cervical cancer

The patient CT images as well as the structures used for the VMAT planning were imported to the MRIdian™ system (ViewRay Inc., Cleveland, OH, USA) in DICOM format. The MRIdian system can generate IMRT plans quickly by using a fast Monte Carlo dose calculation algorithm as well as an inverse optimization algorithm, therefore, ART is possible with the MRIdian system. The MRIdian system can calculate dose distributions by the Co-60 sources with the presence of the static 0.35 T magnetic field. Since the dose calculation algorithm of the MRIdian system is Monte Carlo algorithm, it calculates dose distributions within a field of view (FOV) not a particular structure such as the body structure. For the tri-Co-60 IMRT planning, MR images were not used. Only CT images were used to eliminate disturbance factors caused by the deformation image registration of the CT images to MR images. In addition, the CT number to electron density curve same as that used for the VMAT planning was used for the dose calculation with the MRIdian system. In contrast to the VMAT planning, the PTV with an isotropic 1 mm margin from the CTV was set as the target volume for the tri-Co-60 IMRT planning on the assumption that the margins for daily patient setup and internal organ motions could be minimized by the ART with MR imaging and internal anatomy-based gating of the ViewRay system [2].

The prescription dose for the tri-Co-60 IMRT plans was the same as that of the VMAT plans, *i.e.* 50.4 Gy in 28 fractions. A total