Physica Medica 30 (2014) 654–661

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Treatment plan comparison between stereotactic body radiation therapy techniques for prostate cancer: Non-isocentric CyberKnife versus isocentric RapidArc

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ARTICLE INFO

Article history:
Received 5 January 2014
Received in revised form
18 March 2014
Accepted 19 March 2014
Available online 13 April 2014

Keywords:
Prostate cancer
Stereotactic body radiation therapy
Volumetric modulated arc therapy
CyberKnife
RapidArc

ABSTRACT

Purpose: The aim of this study was to evaluate the feasibility and dose distribution of two different stereotactic body radiation therapy (SBRT) techniques, isocentric RapidArc (RA) and non-isocentric CyberKnife (CK), for the treatment of localized prostate cancer.
Methods: Two groups of patients (Groups 1 and 2 with ten patients per group) treated with CK were re-planned with RA. The patients were grouped according to the rectum constraint used (Group1, maximum dose for rectum; Group 2, dose–volume histogram for rectum). The prescription dose was 37.5 Gy in five fractions. The two SBRT techniques were compared by target coverage, normal tissue sparing, and dose distribution parameters. Monitor units (MUs) and the delivery time were likewise compared to assess delivery efficiency.
Results: The RA plans consistently exhibited superior PTV coverage and better rectum sparing at low doses in the both groups. The conformity and heterogeneity indices of the RA plans were better than the CK plans. Additionally, the RA plans resulted in fewer low-dose regions, lower MUs, and faster delivery times than the CK plans.
Conclusions: The good dosimetric distribution and shorter delivery time make RA an attractive SBRT technique for the treatment of localized prostate cancer.

Introduction

Stereotactic body radiation therapy (SBRT) is an external beam radiation therapy method used to very precisely deliver a high dose of radiation to an extracranial target within the body, using either a single dose or a small number of fractions. The major features of SBRT are the accurate delivery of high doses to the target area and the rapid tapering of dose delivery away from the target area. Combined with radiobiology, the use of SBRT may result in a higher biological effective dose for prostate cancer and may achieve a higher therapeutic benefit [1–4].

Recently, researchers using SBRT, including the CyberKnife (CK, Accuray, Sunnyvale, CA, USA) technique, have achieved promising clinical results in the treatment of prostate cancer [5–8]. The CK stereotactic radiotherapy system is an accurate image-guided method for delivering radiation to a precisely targeted area using multiple non-isocentric beams with steep surrounding-dose gradients [9]. RapidArc (RA, Varian Medical System, Palo Alto, CA, USA) is a volumetric-modulated arc radiotherapy (VMAT) technique that can deliver highly conformal, intensity-modulated radiation doses by a single or multiple rotations of the gantry of the linear accelerator [10]. RA allows achieving treatment plans of similar or improved quality compared to fixed-field intensity-modulated radiation therapy while reducing the treatment time per fraction [11].

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http://dx.doi.org/10.1016/j.ejmp.2014.03.008
1120-1797/

The present study aims to evaluate the feasibility and dose distribution of isocentric RA plans and to compare those to the use of non-isocentric CK plans under SBRT conditions for localized prostate cancer.

Material and methods

Study groups

The rectum is the primary dose-limiting organ when treating prostate cancer by radiotherapy. Because SBRT lacks a definite guideline for rectum constraints, we limited the rectum maximum dose (Dmax) based on a previous study [7]. Subsequently, we modified the Dmax rectum constraint to a dose–volume histogram (DVH)-based constraint [5].

Two groups of patients (Groups 1 and 2 with ten patients per group) treated with CK were re-planned with RA for the two-plan comparison. Group 1 was treated by CK using the Dmax constraint for rectum, whereas Group 2 was treated by CK using the DVH constraint for rectum.

Contouring and SBRT treatment plan requirements

The clinical target volume (CTV) was defined as the entire prostate gland and the proximal seminal vesicles. The planning target volume (PTV) was constructed by expanding the CTV by 5 mm in all direction, except 3 mm in the posterior direction. The rectum was contoured as a solid organ extending from the bottom of the ischium to the sigmoid flexure. Additionally, the entire bladder was contoured. The prescription dose was 37.5 Gy and was administered in five fractions. A minimum of 95% of the prescription dose (35.6 Gy) was assigned to cover 95% of the PTV after normalization to 80–90% isodose line.

For Group 1, the Dmax constraint of the rectum was defined such that less than 1 cm^3 of the rectal volume would receive more than 36 Gy [7]. For Group 2, the rectum dose constraints were specified as: the volume receiving 50% of the prescribed dose <50% (V50 < 50%), the volume receiving 80% of the prescribed dose <20% (V80 < 20%), the volume receiving 90% of the prescribed dose <10% (V90 < 10%), the volume receiving 100% of the prescribed dose <5% (V100 < 5%) [5]. In Group 1 and Group 2, the constraint for the urinary bladder was defined that the urinary bladder volume receiving 100% of the prescribed dose less than 5 cm^3 (V100 < 5 cm^3) [6,7,12].

CyberKnife treatment plans

All treatment plans of the enrolled 20 patients were generated by MultiPlan software (version 2.2.0, Accuray) with 6 MV photon beams from the CK using the appropriate cone collimators (fixed aperture with a radius range from 5 mm to 60 mm). The cone size of the CK was selected using 50% of the longest dimension of the PTV. To achieve better target coverage or normal tissue sparing, extra cone collimators (up to three cones) were used. Non-isocentric beam arrangement was applied in all cases. The Simplex optimization algorithm was used, which generated a minimum monitor unit (MU) of 10 and a maximum MU of 150 per beam, as appropriate. The photon dose was calculated using the Ray-Tracing algorithm. The numbers of cones and beam nodes were arranged to optimize the target volume coverage and the sparing of normal tissue.

RapidArc treatment plans

Computed tomography data sets and target/normal organ contours for the 20 selected patients were imported into the Eclipse treatment planning system (version 8.6.10, Varian Medical System). Then, the corresponding RA plans were generated for comparison. The Group 1 RA plans were generated using the Dmax rectum constraints used in the Group 1 CK plans. The Group 2 RA plans were generated following the DVH rectum constraints used in the Group 2 CK plans. The treatment criteria for the target volumes and other critical organs were the same as those used for the CK plans.

The RA plans were calculated on the Varian Eclipse treatment planning system using 6 MV photon beams from a Varian Clinac iX equipped with a 120-leaf multileaf collimator (with a dynamic beam aperture and a spatial resolution of 5 mm at the isocenter for the central 20 cm and 10 mm in the lateral 2 × 10 cm).

The isocenter was set at the center of the PTV. The collimator rotation was 45° [13]. The single arc technique (counterclockwise rotation from 179° to 181° with 177 control points) was applied for all the RA treatment plans. For all RA plans, the optimization algorithm and the calculation algorithm were the Progressive Resolution Optimizer and Anisotropic Analytical Algorithm, respectively. Plan Normalization Value was used for RA normalization if the plans need to be scaled up or down by a percentage to meet SBRT treatment plan requirements.

Plan evaluation statistics

The parameters used to evaluate the quality of the planned dose distributions for both SBRT plans (RA and CK) were target coverage, normal tissue sparing, and dosimetric parameters mainly recommended by the report of AAPM Task Group 101 [14].

Target volume coverage

The percentages of the CTV and PTV that received 100% and 95% of the prescription dose (V100 and V95) were compared between the CK and RA plans.

Dosimetric parameters

The conformity index (CI), as previously described [15], was defined as the following: (prescription isodose volume × target volume)/(volume of the target covered by the prescription isodose volume)^2. The dose homogeneity index (HI) was determined to be the ratio of the highest dose received by 5% of the PTV to the lowest dose received by 95% of the PTV.

The maximal dose of rectum and the percentages of the rectum that received 100% (V100), 90% (V90), 80% (V80), 60% (V60), 50% (V50), 40% (V40), 30% (V30), 20% (V20), and 10% (V10) of the prescription dose were compared between the CK and RA plans. The dosimetric comparison for urinary bladder between the CK and RA plans used the same parameters as described above.

Dose gradient index was defined as the ratio of the volume of half the prescription isodose to the PTV. Additionally, we calculated the radius of the dose gradient, measured in cm, as the difference between the equivalent sphere radii of the volume of 50% of the prescription isodose curve (the volume receiving 18.75 Gy) and the prescription isodose volume (the volume receiving 37.5 Gy) [16]. The low-dose region (V5) was evaluated based on the volume of 5% (the volume receiving 187.5 cGy) of the prescription isodose curve for each group.

Treatment efficiency

Monitor units (MUs) and the estimated delivery time (MU per fraction/maximal dose rate) were used to assess the treatment efficiency.

Statistical analysis

The dosimetric endpoints of the target volumes (CTV and PTV), normal organ (rectum and bladder) CI, HI, dose gradient index, radius