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Comparison of helical tomotherapy with multi-field intensity-modulated radiotherapy treatment plans using simultaneous integrated boost in high-risk prostate cancer

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Abstract

Purpose: The aim of this study is to compare the dosimetric results of Helical Tomotherapy (HT) and Multi-field IMRT treatment plans using a Simultaneous Integrated Boost (SIB) technique in the treatment of High-Risk Prostate Cancer (HRPCa) with pelvic nodal radiation.

Methods: Seventeen patients planned with HT and 7,8 and 9 fields IMRT were investigated. All plans were designed with the prescribed dose of 54.0 Gy to the PTV_{in} while simultaneously delivering 74.0 Gy to the PTV_{PS} in 30 fractions. Dosimetric data of PTV and OARs were compared.

Results: HT gives a better CI and HI of PTV_{PS} compared to multi-field IMRT plans. HT plans significantly improved target coverage (HT:0.95 vs multi-field IMRT: 0.52, 0.49 and 0.49 respectively, $p < 0.001$). Bladder mean dose(Gy) (HT: 45.6 vs multi-field IMRT: 53.6, 53.3 and 52.7 respectively, $p = 0.004$) and D_{66%}(Gy) dose (HT: 35.3 vs multi-field IMRT: 46.7, 47.0 and 44.9 respectively, $p = 0.006$) were lower in HT. But multi-field IMRT plans significantly reduced the rectum volume receiving more than 75 Gy ; (HT V_{75%} (%) 2.7 vs multi-field IMRT 0.8, 1.4 and 0.9 respectively, $p = 0.008$). HT provided better sparing of the right and left femoral head receiving a mean dose. The penile bulb and small bowel doses were the highest in HT compared with multi-field IMRT.

Conclusions: HT achieved better dose distribution to target compared to multi-field IMRT. This study suggests HT as a reasonable option for the treatment of HRPCa patients.

Key words: prostate cancer; tomotherapy; intensity-modulated radiation therapy; simultaneous integrated boost.

Introduction

Prostate cancer (PCa) is the most common type of cancer for men. Approximately one-tenth of all cancer deaths are related to PCa.¹⁻² Radiotherapy (RT) has an important role in the treatment of PCa. Using new technologies in RT, dose escalation is aimed at superior local control, better survival rates, and simultaneous improvement in quality of life.³⁻⁴ Owing to the Simultaneous Integrated Boosting (SIB) technique, different doses can be given simultaneously to different target volumes in a single fraction.⁵ In this way, SIB makes it possible to simultaneously deliver different doses to the prostatic region and pelvic LN for PCa.⁶ Owing to the advances in technology (tomotherapy, IMRT, stereotactic RT, etc.) and improvements in planning methods, RT can be applied with a narrower limit⁷ and less toxicity. As a result of technical developments in RT, conventional and three-dimensional conformal RT have been replaced by IMRT and tomotherapy techniques. IMRT is a

method that enables better conformity in dose changes within the treatment area and allows to increase the tumor dose while the risk organ dose is decreased. Since PCa has a long-life expectancy, it is necessary to increase the effectiveness of the treatment. It is vital to increase the target volume by applying new RT techniques to patients and to protect organs at risk (OAR). The IMRT method used in PCa irradiation is a successful method for increasing the dose of the target by protecting the rectum and bladder and reducing genitourinary and gastrointestinal toxicity. In the linac-based IMRT technique, using the dynamic or static segments with 7-8-9 or more fields, the desired dose distribution is achieved in the target region while critical organs are protected. The recommended gantry angles and dose limits are not optimal, and each case should be handled individually according to anatomy. Recently, IMRT plans made with HT have become an attractive method in PCa radiation by creating higher conformity and homogeneity at target volume and superior plans in organ preservation.

However, by using higher monitor units (MU) increases the time required for RT application. It is possible to eliminate this disadvantage of IMRT by using SIB. In the study of Cuccia et al. found that SIB technique provided homogeneous dose distribution to more than one tumor target and simultaneously gained saved up to 25% of the total treatment time.⁸ In an important review, Morikawa and Roach et al.⁹ highlighted the roles of all pelvis RT, volume identification and especially clinical target volume (CTV). In this study, we aimed to compare the plans made with the HT device and the linac based multi-fields IMRT plans (7, 8 and 9 fields) using the SIB technique for High-Risk Prostate Cancer (HRPCa).

Methods

Patient selection and Simulation

17 patients admitted to our clinic with the diagnosis of HRPCa were included in the study. As a result of the clinical evaluation, RT was planned for the pelvic lymph node (LN) region as well as the primary prostate and seminal vesicle, which have a high risk of pelvic relapse according to the Roach formula. According to our clinical protocol, bladder and rectum were emptied 30 minutes before the computerized tomography (CT) was taken. After emptying the bladder and rectum, patients were asked to drink 500 cc water. Patients were applied 50 cc IV contrast medium 20 minutes before the CT simulation. All patients were immobilized with a supine position with hip & pelvic Vac-Lok and CIVCO “kneefix and footfix” (CIVCO, Civco Medical Solutions, Kalona, IA, USA). CT images were taken with 3mm slice thickness and were transmitted to the contouring workstation through Digital Imaging and Communications in Medicine (DICOM).

Critical structure and target volume definitions

The target and the critical organ volumes were outlined with a Focal (Elekta TM) workstation. CT images of patients were contoured by the radiation oncologist and reviewed by the 2nd specialist according to the report of the International Commission on Radiation Units and Measurements (ICRU-83). The prostate and seminal vesicles were contoured as the target organ volume; the rectum, bladder, femur and penis bulb, sacral plexus and intestines are contoured as OAR volumes.

The Radiation Therapy Oncology Group (RTOG) prostate contouring atlas was used as a reference in the target volume drawing. RTOG GU Consensus pelvic LN CTV (CTV_{ln}) volumes were used for pelvic CTV_{ln} contours.¹⁰ L5 / S1 is contoured starting from the level of interspace (the level of the distal common iliac and proximal presacral lymph nodes) until femoral heads are removed. To create the CTV_{ln}, 7 mm margin was given around the external and internal iliac vessels in each section. Furthermore, CTV prostate (CTV_{ps}) was created by contacting the presacral lymph nodes from S1 to S3 with a thickness of about 10 mm from the front of the sacrum. According to the clinical stage of the patient, CTV_{ps} was created

by contouring the prostate ± seminal vesicle previous to the planning target volume of prostate plus seminal vesicles (PTV_{ps}) and planning target volume of pelvic lymph node (PTV_{ln}). A margin of 4mm was given from the posterior and 7mm from other directions added to CTV_{ps} and a margin of 3 mm was given to CTV_{ln}.^{11,12} The 3D images obtained were sent to the Hi-Art Tomotherapy and Linear Accelerator treatment planning system. The standard practice in our clinic is based on the Daily image guidance protocol using cone-beam CT for the patients during treatment.¹³ For this reason we reduced the planning margin for IGRT to provide the most conformal dose distributions in the study group.

Treatment planning

IMRT plans of 17 patients were made by 6 MV photon energy and the data was uploaded to Synergy model, CMS, XIO (Elekta AB, Stockholm, Sweden) planning system. Three different step and shoot IMRT plans were made for each patient, from 7, 8 and 9 fields. Tomotherapy plans of 17 patients were made with Hi-Art HT planning system (Accuray Inc., Madison, USA) and 2.5-cm field width, a pitch of 0.3, and a modulation factor of 2-2.5 were used. 68 plans were obtained in total. The same dose limitations were used when making both device plans. The SIB technique was adopted in all planning. All plans were created to give a fraction dose of 2.46 Gy for PTV_{ps} and a fraction dose of 1.8 Gy for PTV_{ln} in 30 fractions. The prescribed dose was normalized to 98% volume. (The 100% of the PTV covered by 98% of the prescribed dose). Median dose (D_{50%}) was as close as possible to 54.7 Gy and 73.8 Gy for PTV_{ln} and PTV_{ps}, respectively. As a clinical protocol, it was aimed to deliver at least 76.98 Gy and 80.95 Gy equivalent dose in 2 Gy fractions (EQD2) to 98% of PTV_{ps} volume (D_{98%}) based on α/β ratio of 10Gy and 3 Gy respectively. For OARs, the total dose was limited to 75.3 Gy for bladder and 75.8 Gy for rectum and small bowel. D_{max}, D_{mean}, D_{min}, D_{98%}, D_{2%}, HI, CI, target coverage for PTV_{ps} and the median dose, V_{65%}, V_{70%} and V_{75%} doses for OARs obtained from the dose-volume histograms (DVH) of HT and linac-based IMRT plans were examined for all patients.

The resulting plans were compared and proposed by RTOG as evaluation criteria.¹⁴ The CI and HI, D_{max}, D_{mean}, D_{min}, of PTV_{ps} defined in report 83 of the International Commission on Radiation Units and Measurements (ICRU).¹⁵ All plans have been approved by the expert radiation oncologist and the OAR constraints were defined according to the Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC).^{16,17}

Homogeneity and conformity indices

The concept of HI has been developed as an extension of the dosimetric analysis of treatment plans. Using HI was first proposed by RTOG in the routine evaluation of stereotactic RT (SRT) plans in 1993. HI was defined by $RTOG = \text{maximum isodose at target} / \text{reference isodose}$. If $HI \leq 2$, the treatment was considered as *following the protocol*, if index is between 2 and 2.5 considered a minor violation, but an HI exceeding 2.5 is considered a major violation. However, the following formula for the calculation HI is more descriptive and widely used in the literature:^{18,19}

$$HI = \frac{\text{minimum dose to 2\% of the target volume} - \text{dose to the 98\% of the target volume}}{\text{prescribed dose}} \times 100$$

HI is the ratio of the difference between maximum and minimum doses in the target volume so that low values of HI indicate a more homogeneous dose distribution in the volume. If HI is equal to or close to 0, it indicates that the absorbed dose distribution is homogeneous.¹⁷

CI was developed by ICRU as part of the dosimetric analysis. CI is defined as a ratio between the volume covered by the reference isodose, which is 95% according to the ICRU.

CI RTOG = Reference isodose volume / Target volume

When the CI value is equal to 1, ideal conformity is achieved. CI greater than 1 means that the irradiated volume is larger than the target volume and contains healthy tissues. If CI is less than 1, only part of the target volume is irradiated.²⁰

Statistical analysis

SPSS 18.0 for Windows (SPSS Inc., Chicago, IL) was used for statistical analysis of all data obtained from the study. Frequency tables for categorical variables and descriptive statistics including mean, standard deviation (SD), median, minimum and maximum for numerical variables are given. In the categorical comparisons between groups, cross-table statistics were given, and their significance levels were checked with the Chi-Square test. If the data was suitable for normal distribution, the results

were given as “Average $\pm$ SD” and “Median (Minimum-Maximum)”; otherwise, $p < 0.05$ value was considered significant.

Results

A total of 68 plans were created with the SIB technique. As a result of statistical analysis, obtained from HT and multi-field IMRT plans $D_{\max}$, $D_{\min}$, D_{mean} , $D_{98\%}$, $D_{2\%}$, HI, CI for PTV_{In} and PTV_{ps} are shown in **Table 1**.

$D_{\max}$ (76.6 Gy) obtained with the HT plan for PTV_{ps} was lower than the other IMRT plans, but the difference was not statistically significant ($P > 0.05$). When we look at the $D_{98\%}$ dose value of PTV_{ps} , HT and 7, 8 and 9-field IMRT doses were 71.7 Gy, 68.2 Gy, 68.5 Gy and 68.4 Gy, respectively and the difference was significant in favor of HT ($P = 0.021$). HI value of PTV_{ps} found that 0.05 ($SD \pm 0.02$), 0.10 ($SD \pm 0.28$), 0.09 ($SD \pm 0.09$), and 0.09 ($SD \pm 0.03$) for HT and 7, 8 and 9-field IMRT plans respectively and the difference was significant in favor of HT ($P < 0.05$). The values of CI were found 1.47 ($SD \pm 0.45$), 0.69 ($SD \pm 0.23$), 0.66 ($SD \pm 0.04$), and 0.62 ($SD \pm 0.19$) ($P < 0.001$) for 4 plans respectively. The best coverage for PTV_{ps} was HT among these 4 plans (0.95 ($SD \pm 0.01$)), ($P < 0.05$). When the $D_{98\%}$ value of PTV_{In} was examined, HT and 7, 8 and 9-field IMRT doses were 54.74 Gy ($SD \pm 0.78$), 49.65 Gy ($SD \pm 4.66$), 49.99 Gy ($SD \pm 3.63$) and 50.39 Gy ($SD \pm 4.04$) respectively and the difference was significant in favor of HT ($P < 0.05$). The best coverage for PTV_{ps} was HT among these plans (0.92 ($SD \pm 0.05$)) ($P < 0.05$).

An example image of HT and multi-field IMRT plans in PCa RT is presented in **Figure 1**. When the OAR doses were examined, HT and 7, 8 and 9-field IMRT D_{mean} doses were 53.6 Gy ($SD \pm 6.16$), 53.3 Gy ($SD \pm 7.68$), 53.3 Gy ($SD \pm 7.68$), and 52.7 Gy ($SD \pm 7.0$) respectively for the bladder and the difference was significant in favor of HT ($P < 0.05$). $D_{66\%}$ doses were 35.3 Gy ($SD \pm 11.79$), 46.7 Gy ($SD \pm 9.39$), 47.0 Gy ($SD \pm 12.53$), and 44.9 Gy ($SD \pm 10.54$) respectively for the bladder and the difference was significant in favor of HT ($P < 0.05$).

Table 1. HT and multi-field IMRT plans $D_{\max}$, $D_{\min}$, D_{mean} , $D_{98\%}$, $D_{2\%}$, HI, CI for PTV_{In} and PTV_{ps}

Variable	Helical Tomotherapy		7-field IMRT		8-field IMRT		9-field IMRT		P-value
	mean	SD	mean	SD	mean	SD	mean	SD	
PTV_{ps}									
$D_{\max}(\text{Gy})$	76.6	3.70	78.9	4.08	78.0	4.16	77.3	3.37	0.323
$D_{\min}(\text{Gy})$	64.4	3.87	57.8	7.39	57.4	7.90	57.3	10.1	0.016
$D_{\text{mean}}(\text{Gy})$	73.8	3.34	72.4	3.20	72.3	3.46	72.3	3.32	0.904
$D_{98\%}(\text{Gy})$	71.7	3.65	68.2	3.74	68.4	3.97	68.5	3.85	0.021
$D_{2\%}(\text{Gy})$	75.1	3.39	75.6	3.39	75.3	3.62	74.9	3.24	0.920
CI	1.47	0.45	0.69	0.23	0.66	0.12	0.62	0.19	$p < 0.001$
HI	0.05	0.02	0.10	0.28	0.09	0.04	0.09	0.03	$p < 0.001$
Coverage	0.95	0.01	0.52	0.16	0.49	0.09	0.49	0.09	$p < 0.001$
PTV_{In}									
$D_{\max}(\text{Gy})$	72.5	3.89	71.6	3.51	71.8	4.5	71.44	3.92	0.961
$D_{\min}(\text{Gy})$	43.9	6.92	35.9	12.85	35.8	12.7	36.14	13.8	0.531
$D_{98\%}(\text{Gy})$	54.7	0.87	49.7	4.66	50.0	3.61	50.39	4.04	0.050
$D_{2\%}(\text{Gy})$	67.6	4.61	63.6	3.37	63.0	3.63	63.62	3.72	0.146
Coverage	0.92	0.05	0.57	0.08	0.52	0.03	0.55	0.09	$p < 0.001$

Figure 1. a. Axial view of dose distributions for helical tomotherapy. b. Axial view of dose distributions for 7-field IMRT. c. Axial view of dose distributions for 8-field IMRT. d. Axial view of dose distributions for 9-field IMRT.

D_{mean} doses were 41.9 Gy (SD $\pm$ 6.10), 44.5 Gy (SD $\pm$ 5.05), 45.5 Gy (SD $\pm$ 5.82), and 45.2 Gy (SD $\pm$ 5.00) respectively for rectum, and difference between them was not statistically significant ($P > 0.05$). However, when we look at the results of the subgroup analysis, it was revealed that the HT was superior compared to the other three plans. $D_{66\%}$ doses were 75.8 Gy (SD $\pm$ 3.71), 76.2 Gy (SD $\pm$ 3.62), 76.6 Gy (SD $\pm$ 4.58), and 75.3 Gy (SD $\pm$ 3.51) for rectum, and the difference between them was not statistically significant ($P > 0.05$). However, in subgroup analysis, HT was superior when compared with 7 and 8-field IMRT plans.

OAR doses of HT and multi-field IMRT treatment plans are shown in **Table 2**. We found that D_{mean} value was 15.9 Gy (SD $\pm$ 7.65) ($P < 0.05$) and 16.1 Gy (SD $\pm$ 7.62) ($P < 0.05$) for the right and left femur, respectively. HT has proven to be significantly successful in protecting critical organs from the other three IMRT plans. Besides comparing the doses received by the sacral plexus values were determined according to the QUANTEC data, but there was no significant difference between the plans ($P > 0.05$). The penile bulb and small bowel doses were the highest in HT.

Discussion

HRPCa is one of the most common tumors treated with IMRT. Therefore, this is a reasonable point for the evaluation of alternative IMRT techniques, such as HT simultaneously delivering technique or multi-field IMRT. In our study, we compared the DVH of the HT and 7, 8 and 9-field IMRT in the

treatment of HRPCa patients with pelvic RT. In the process of dosimetric comparison, CI and HI are found to be closely related to the complexity of target volumes as well as the delineation of volumes, the delivery equipment, the RT technology, and the optimization algorithm.²¹ In cancer treatment, more adaptation to the target volume and less damage to critical organs are the most important factors for choosing a radiation therapy modality. IMRT is successful in providing concave dose distribution for PTV_{ps} wrapped with bladder and rectum. With advancing technology, the use of different planning methods of IMRT is increasing, especially in prostate cancers.

In the present study we used a 2.5-cm field width, a pitch of 0.3, and a modulation factor of 2-2.5 for HT planning. These parameters are similar to Skórska M and Piotrowski T's study of the tomotherapy parameter for prostate cancer.²² In our study showed that HT resulted in slightly superior conformity and homogeneity of PTV_{ps} compared with 7, 8 and 9-field IMRT, respectively. HT significantly improved target coverage of PTV_{ps} compared to 7, 8 and 9-field IMRT, respectively. The IMRT plans were similar in regard to rectum and bladder sparing, whereas the 9-field IMRT plan was superior to HT, 7 and 8-field IMRT plans. Most dosimetric comparison studies found that in treatment of prostate or prostate with seminal vesicles Modulated Arc Therapy provided equal or improved target coverage and OAR sparing compared to multi-field IMRT.²³ However, there is very little published data on dosimetric comparisons between HT and multi-field IMRT in the treatment of HRPCa.²⁴

Table 2. Comparison of DVH parameters of OARs for HT and multi-field IMRT plans

Variable	Helical Tomotherapy		7-field IMRT		8-field IMRT		9-field IMRT		P-value
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Bladder									
D _{max} (Gy)	75.3	3.44	76.7	4.03	76.3	3.92	75.5	3.88	0.660
D _{mean} (Gy)	45.6	7.88	53.6	6.16	53.3	7.68	52.7	7.00	0.004
D _{33%} (Gy)	55.9	7.39	60.2	7.46	61.1	6.11	60.4	5.29	0.086
D _{66%} (Gy)	35.3	11.79	46.7	9.39	47.0	12.53	44.9	10.54	0.006
D _{99%} (Gy)	19.9	10.83	22.6	14.67	22.8	15.43	23.8	16.17	0.866
V _{65%} (cc)	27.3	15.77	38.5	23.72	40.0	28.64	35.7	22.27	0.415
V _{70%} (cc)	16.1	14.16	21.3	20.38	21.2	19.78	19.7	18.84	0.876
V _{75%} (cc)	5.4	6.86	4.1	5.99	3.4	4.09	2.6	3.41	0.351
Rectum									
D _{max} (Gy)	75.8	3.71	76.2	3.62	76.6	4.58	75.3	3.51	0.787
D _{mean} (Gy)	41.9	6.10	44.5	5.05	45.5	5.82	45.2	5.00	0.199
D _{33%} (Gy)	49.9	9.89	54.1	4.96	54.5	5.37	54.1	7.25	0.185
D _{66%} (Gy)	32.3	15.35	35.6	10.07	36.7	9.41	36.3	9.78	0.641
D _{99%} (Gy)	8.7	6.29	7.1	6.09	9.1	9.52	8.2	8.02	0.880
V _{50%} (cc)	37.5	23.15	42.0	25.24	41.9	23.99	42.0	25.05	0.957
V _{60%} (cc)	24.8	13.08	25.6	13.79	25.4	13.67	26.1	15.87	0.999
V _{65%} (cc)	17.7	10.59	16.5	10.23	17.6	10.59	18.1	12.23	0.959
V _{70%} (cc)	10.9	7.45	6.5	6.01	8.8	6.17	8.5	7.12	0.175
V _{75%} (cc)	2.7	2.98	0.8	1.25	1.4	1.80	0.9	1.52	0.008
R. Femoral H.									
D _{max} (Gy)	43.8	12.77	44.8	10.67	47.6	9.01	46.3	10.43	0.729
D _{mean} (Gy)	15.9	7.65	15.9	8.26	21.7	6.61	21.6	7.64	0.021
D _{33%} (Gy)	21.3	12.75	20.5	9.45	27.6	4.84	27.2	7.11	0.030
D _{66%} (Gy)	10.1	6.76	9.7	10.12	16.4	9.66	16.7	9.85	0.031
D _{99%} (Gy)	4.3	5.22	2.5	4.54	4.2	7.21	4.7	8.13	0.735
L. Femoral H.									
D _{max} (Gy)	44.0	12.11	45.8	8.44	48.4	7.72	45.4	7.49	0.534
D _{mean} (Gy)	16.1	7.62	17.6	7.52	22.7	5.91	22.2	6.84	0.011
D _{33%} (Gy)	19.6	8.94	22.5	7.78	28.3	4.24	27.4	6.15	0.001
D _{66%} (Gy)	11.2	7.74	11.6	10.02	18.8	8.18	18.6	8.99	0.009
D _{99%} (Gy)	4.7	5.5	2.5	4.23	4.2	7.25	4.7	7.28	0.686
Small Bowel									
D _{max} (Gy)	60.3	19.39	63.2	21.00	62.6	20.28	60.6	20.48	0.979
D _{mean} (Gy)	10.74	9.53	9.1	8.25	8.9	8.70	9.3	9.25	0.951
D _{33%} (Gy)	15.2	16.39	8.2	11.58	8.0	11.56	8.4	12.11	0.351
D _{66%} (Gy)	9.3	11.37	4.8	7.90	4.8	7.80	5.1	8.49	0.431
D _{99%} (Gy)	4.9	7.56	0.3	0.37	0.4	0.65	0.4	0.54	0.006
Penile Bulb									
D _{max} (Gy)	45.6	18.34	47.6	17.29	49.6	17.44	44.3	18.85	0.856
D _{mean} (Gy)	31.1	14.40	25.2	9.73	26.3	10.34	22.8	9.63	0.240
D _{33%} (Gy)	35.9	15.83	30.6	13.69	31.5	13.83	27.2	13.31	0.387
D _{66%} (Gy)	27.1	17.23	21.3	14.51	18.4	10.32	15.6	7.58	0.097
D _{99%} (Gy)	22.5	20.67	10.0	6.05	11.5	8.6	9.1	4.93	0.012
Sacral plexus									
D _{max} (Gy)	37.3	26.79	39.7	29.8	37.9	28.15	37.1	27.43	0.996
D _{mean} (Gy)	11.6	10.27	22.1	20.5	20.3	18.48	19.4	18.07	0.512
D _{33%} (Gy)	10.5	10.46	24.2	23.75	22.4	21.78	20.3	20.22	0.195
D _{66%} (Gy)	5.7	4.77	15.9	19.25	14.9	16.94	14.2	16.62	0.191
D _{99%} (Gy)	4.1	2.83	11.3	15.06	6.2	8.60	8.1	11.58	0.279

Rong Y et al. suggested that HT provided superior dose sparing for the rectum, whereas rapid arc showed superior dose sparing in the bladder in a patient treated with pelvic and a sequential boost to the prostate.²⁵ Ishii K. et al. compared treatment delivery efficiency among RapidArc, 7-field IMRT, and 9-field IMRT with hypofractionated SIB to the prostate. They concluded that treatment delivery efficiency is significantly higher for Rapid Arc.²⁶

Davidson MT et al. quantified the differences in treatment delivery efficiency and dosimetry IMRT, Volumetric Modulated Arc Therapy (VMAT), and HT for prostate treatment. They found that HT resulted in a slightly higher integral dose and mean doses to the OAR, yielding a lower D_{max} to all OAR examined.²⁷ Pasquier et al. compared VMAT and HT in the

treatment of HRPc with pelvic nodal RT for the whole pelvis. They found that HT was able to provide a higher D_{98%} than VMAT (44.3 ± 0.3 Gy and 43.9 ± 0.5 Gy, respectively; P = 0.032) and a lower D_{2%} than VMAT (47.3 ± 0.3 Gy and 49.1 ± 0.7 Gy, respectively; P = 0.005), leading to a better HI.²⁸

Servagi-Vernat S et al. compared the dosimetric results of different techniques of dynamic IMRT in patients treated for pelvic cancer with nodal irradiation. Their results showed that despite of some dosimetric differences, HT and Rapid Arc provided very similar and highly conformal plans. Regarding OARs, Rapid Arc provided better pelvic bone sparing with a lower non-tumoral integral dose.²⁹

Abu-Gheida I et al. reported 10-year outcomes for patients treated with IMRT with hypofractionated radiation therapy for prostate cancer in Cleveland Clinic. In median follow-up of 11.3 years, the 10-year clinical relapse-free survival rates were 95% and 72% for patients with low risk and high risk, respectively ($P < 0.0001$). They concluded that high-dose moderately hypofractionated IMRT with daily image guidance for prostate cancer was found to deliver favorable 10-year oncologic outcomes with a low toxicity rate.³⁰

Widesott L et al. compared intensity-modulated proton therapy (IMPT) and HT treatment plans for HRPc patients. They concluded that IMPT was expected to allow a small reduction in rectal toxicity, and a significant dosimetric gain was observed with IMPT, both in medium-dose and in low-dose range in all OARs.³¹

Barelkowski T et al. evaluated treatment outcomes for patients with HRPc who were treated with dose-escalated radiation therapy with helical tomotherapy (HT) up to 84 Gy. They demonstrated that this scheme was both feasible and well-tolerable.³² According to the results of our study, the fractionation schedule appears to be acceptable with 74 Gy in 30 fractions at 2.46 Gy per fraction to PTV_{ps}. In comparison, HT allowed for dose escalation to the prostate with better sparing of the rectum than 7, 8, and 9-field IMRT. Beck M et al.

investigated dose-comparison in postoperative PCa patients using dose-intensified SIB in HT and found that this method was feasible and associated with favorable acute and late GU and GI toxicity rates.³³

The present study had some limitations that need to be mentioned. It was difficult to ensure that patients go into treatment fields in the same position at every treatment session. This could introduce some error and uncertainty to the measured values presented in this article. Another limitation is that this study includes only treatment planning parameters of different planning techniques. However, the effectiveness of the plans was not evaluated in terms of long-term clinical outcomes. Therefore, clinical investigations need to be done to evaluate likely correlations between dosimetric and clinical parameters for the defined techniques.

Conclusion

In conclusion, the dosimetric evaluation comparing HT to multi-field IMRT underlines the potential of HT planning with SIB for HRPc. There is a significant dosimetric advantage of HT over other multi-field IMRT techniques. This study suggests HT as a reasonable option for the treatment of HRPc patients.

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