Critical organ-preserving treatment planning for prostate cancer treatment: A Comparison of intensity-modulated therapy (IMRT) and volumetric intensity modulated therapy (VMAT) plans.

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ABSTRACT

Objective: This study aims to compare density-adjusted radiotherapy (IMRT) and volumetric intensity-adjusted arc treatment (VMAT) techniques with patient treatment plans. Plans were made using linac-based 8-field IMRT and dual-arc VMAT techniques that generate X-rays at 6MV energies using the Treatment Planning System (TPS). The two planning techniques were compared with the dose winding and homogeneity index (HI) and the conformity index (CI) values in the planned target volume PTV 56, PTV 76 structures. In critical organs, V50, V25, and V15 (dose volts) values for the rectum were analyzed for bladder V50, V40, and V20, values for femur heads and V50, and V10 for femur heads. The treatment times, segment numbers, and monitor unit (MU) values of the plans obtained with both techniques were compared. Close dose conditions were obtained for IMRT and VMAT techniques and target volumes. The calculated Hi and CI values for PTV 76 be similar in both methods. All critical organs can be kept below dose limitations with both planning techniques. In general, close results were obtained with both methods in terms of organ doses at risk. However, a significant difference has occurred between the two techniques regarding the V50 values in the rectation. The number of segments and MU derived from plans created by the VMAT technique was higher than plans created by the IMRT technique, but the treatment time was shorter. Compared to the 8-field IMRT and VMAT techniques used in prostate cancer radiotherapy, similar dosimetric results have been achieved in both PTV conditions and critical organ protections. Regarding treatment time only, the IMRT technique of VMAT has a distinct advantage.

Keywords: Prostate cancer, Treatment plan, IMRT planning, VMAT planning, Dosimetric comparison

İntroduction

Prostate cancer is the second most common type of cancer in men worldwide and ranks fifth in cancer deaths. It has been calculated that prostate cancer will cause approximately 1.3 million new cases and about 360,000 deaths worldwide in 2018 (Bray et al. 2018). An estimated 164,690 new prostate cancer cases and 29,430 deaths were estimated in the United States in 2018. Although the incidence of new cases has been relatively stable since 1994 due to prostate-specific antigen (PSA) screening, the mortality rate is decreasing due to early diagnosis and treatment.

During radiotherapy, the surrounding critical organs may be exposed to significant radiation doses. Thanks to the radiotherapy devices developed in recent years, it has been possible to reduce this radiation exposure significantly and to give high doses to the tumor. One of the most important advantages of radiotherapy is that it is not invasive and has few treatment side effects. With the developing imaging system, image guided radiotherapy (IGRT), planning systems IMRT, VMAT, treatment can be applied much more precisely. In IMRT, multiple beam angles are used and the intensity of each beam can be modulated using multi-leaf collimators (MLCs). VMAT has attracted increasing attention due to its greatly improved transmission efficiency over fixed field IMRT. Unlike IMRT, which typically includes less than 10 fixed beam angles, VMAT includes multiple beam directions from an arc trajectory and dynamically delivers doses during the rotation of the portal. However, in all directions, there is no beam modulation by MLCs. Therefore the intensity from each beam direction is the same in VMAT (Otto 2007). When using multiple arcs in VMAT in some cases, the modulation level from each beam direction is still much lower than the modulation level from each beam in fixed-field IMRT. Comparisons have been made for IMRT and VMAT for different regions before (Emami et al. 1991) (Ishii et al. 2013). Although in practice VMAT has been found to result in better efficacy than IMRT, it is still unclear whether VMAT provides a better plan quality than IMRT for prostate cancer treatment planning (Quan et al. 2013).

In our study, dosimetric comparisons of the patient treatment plans created by IMRT and VMAT techniques of patients with prostate cancer were made. The most suitable technique for bladder, rectum and femoral head, which is the dose limiting organ, which gives the most homogeneous dose distribution for PTV and CTV, was investigated.

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Materials and Methods

Our study was conducted on 10 randomly selected high-risk prostate cancer patients who applied to the Fac** of Med**, Dep** of Rad** Onc**, At** Uni** between 2018-2019. All patients were taken to the Computed Tomography (CT) device by making them drink water 1-1.5 hours beforehand, with their bladders full. Patients were stabilized in supine position with hands on chest using knee support and foot stabilizer in accordance with clinical protocol. Images were taken with a slice thickness of 3 mm, covering the entire pelvis. While obtaining CT images of the patients, it was tried to ensure that the rectum was empty before the extraction. In addition, after their bladders were emptied before imaging, they were made to drink 500 mL of water, and imaging was performed approximately 1 hour later. Afterwards, the images were transferred to the treatment planning system for critical organ identification. The clinical target volume (CTV) is contoured as CTV 76 for the prostate and CTV 56 to cover the prostate and seminal vesicle. Planning target volume (PTV) 76 and PTV 56 were created by giving 5 mm margins posteriorly and 8 mm margins in other directions to CTV 76 and CTV 56. Bladder, rectum, right and left femoral heads are contoured as risky organs.

CT images of the patients were uploaded to the Eclips treatment planning system, and IMRT and VMAT plans for all patients were designed using the same co-center with the 6 MV photon energy of the linear accelerator device. For IMRT plans; Eight areas were created by choosing 30º, 65º, 100º, 135º, 225º, 260º, 295º, 330º gantry angles. Here, the purpose of not creating an anterior (0º) and posterior (180º) area is to keep the rectum dose low. VMAT plans, on the other hand, are designed to have two full rotations, starting from a 180º gantry angle, 360º clockwise, then 360º counterclockwise again.

Both planning techniques were used for PTV 46, 56 and 76 in terms of percent volume covered by 95% of the administered doses, conformity index (CI) values, homogeneity index (HI) values and doses received by critical organs. have been compared. CI values were calculated by the method suggested by Paddick (Paddick 2000).

$$C = \frac{{TV_1}^2}{TV*VR_1} \tag{1}$$

TV1: The volume of the administered dose in the target structure (cc).

TV: Target volume (cc).

VR1: Total volume of dose administered (cc).

HI values were calculated in accordance with the recommendations of the ICRU 83 report. The ICRU-83 report recommends using 98% as a percentage of low dose and 2% as a percentage of high dose (The International Commission on Radiation Units and Measurements 2010).

X: Percent value of high dose volume in the relevant structure.

$$H1=X/Y \tag{2}$$

Y: Percent value of low dose volume in the respective structure.

For the rectum; While the percent volume values (V50, V60, V65 and V70, respectively) receiving 50, 60, 65 and 70 Gy were compared, the percent volumes occupied by the 65 and 70 Gy dose for the bladder were compared (Emami et al. 1991). Percent volumes receiving the 40 Gy dose were evaluated for the right and left femoral heads. While evaluating critical organs, the criteria suggested by Emami were taken into account (Emami et al. 1991). The percent volume values covered by 50 percent (37 Gy) of the treatment dose in all non-target healthy tissues were compared. In addition, segment numbers, MU values and treatment times (irradiation times) were evaluated.

Findings

Plans created with IMRT and VMAT techniques; PTV 56 and PTV 76 were compared in terms of the percent volumes that were absorbed by 95% of the administered doses (54.2 and 73.5 Gy, respectively) for the target volumes (Table 1). In terms of both techniques, no statistically significant difference was found between the percent volume values of the doses applied to the determined target volumes.

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Table 1. Percent volume values covered by 95% of the doses administered in the IMRT and VMAT plans.

PTV	IMRT (% volume)	VMAT (% volume)
PTV56	100	100
PTV76	99,3	99,3

PTV: Planned Target Volume; IMRT: Intensity Modulated Radiotherapy; VMAT: Volumetric İntensity Modulated Arc Therapy.

When evaluated in terms of CI, the mean conformity index values for PTV 76 were 0.95 in the D-IMRT technique and 0.96 in the VMAT technique, and these results were found to be statistically significant. In the HI evaluations, it was observed that the mean homogeneity index values for PTV 76 were 1.03 in the IMRT technique and 1.05 in the VMAT technique. When analyzed statistically, it can be said that the difference is significant.

As critical organs; bladder, rectum and femoral heads, the doses they received with both treatment techniques were evaluated. Percent volumes covered by 65 and 70 Gy doses (V65 and V70, respectively) were evaluated in plans created with IMRT and VMAT techniques for the bladder. No statistically significant difference was found between the V65 and V70 values obtained for both techniques (Table 2).

Table 2: Comparison of the planned patients' mean critical organ dose values for IMRT and VMAT techniques

Critical Organ	IMRT Critical Organ (% volume)	VMAT Critical Organ (% volume)
Bladder		
V65	33,1	25,3
V70	35,2	27,4
Rectum		
V50	40,5	23,7

V60	35,4	19,5
V65	30,1	14,2
V70	23,5	11,1
Right Femoral Head		
V40	4,2	0,8
Left Femoral Head		
V40	3,9	0,7

For the IMRT and VMAT techniques, when the total MU values of the treatment were evaluated, the mean MU values were observed as 1955.4 for the IMRT, while it was observed as 1577.5 in the VMAT technique. A statistically significant difference, albeit a small one, was found between them. When the treatment times of both techniques were compared, the average treatment time was found to be 4.9 minutes, since the dose rate for the IMRT technique was 400/min. Since the dose rate for the VMAT technique was 600/min, it was determined as 2.6 s. Thus, a significant statistical difference emerged between them. In other words, the mean treatment times calculated for the VMAT technique appear to be significantly shorter than the mean treatment times calculated for the IMRT technique. Considering that the IMRT technique stops and irradiates at each angle during the gantry rotation, it can be predicted that there will be a slight decrease in the treatment time in the VMAT technique.

Discussion and Conclusion

In our study, both techniques were compared in terms of segments and MU numbers. It was observed that the IMRT technique had statistically significantly smaller segments and MU numbers than the VMAT technique. However, when compared in terms of treatment times, the VMAT technique takes significantly less time than the IMRT technique (Table 2). The high number of MU and segments for the same technique prolongs the treatment time. The VMAT technique was found to be approximately five times faster when compared to the nine-field static IMRT technique (Ishii et al. 2013).

In studies comparing VMAT and IMRT techniques in the literature, shorter treatment times were obtained in the plans created with the VMAT technique compared to the plans created with the IMRT technique (Xia et al. 2006). The shortening of the treatment period reduces both the errors caused by the patient's movements during the treatment and the errors caused by the patient's internal organ movements. Since there may be significant volume changes in the rectum and bladder during the time period required for the application of the treatment, the duration of treatment is a very important factor in prostate radiotherapy (Teoh et al. 2011).

As a result; In prostate cancer radiotherapy, quite high doses are used; Being able to reach high doses while protecting the organs at risk is clearly related to the technique used. Only during the treatment period, the obvious superiority of the VMAT technique over the IMRT technique is observed. The dosimetric effects of the differences between the treatment periods in terms of organ movements during the treatment should be examined.

Conflict of Interest

There is no conflict of interest of the authors and/or family members regarding this study.

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Author Contribution Statement

Yılmaz SAHİN; designed the study, scanned the literature, determined the method, organized, analyzed and interpreted the data, authored and revised the study. Abdulsamet ZORTUL; organized the data, reviewed the work. Korkmaz SERİFOGLU; designed the study, scanned the literature, organized the data, reviewed the work, interpreted it, revised the discussion and the abstract.

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