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Assessment of the Performances of Four Commercial Treatment Planning Systems for Simultaneous Integrated Boost IMRT of Prostate Cancer

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ABSTRACT

Introduction: This study aims to use the Intensity Modulated Radiation Therapy (IMRT) technique for prostate cancer patients to evaluate the effectiveness of four different commercial Treatment Planning Systems (TPS): (Eclipse, Monaco, Ray plan, and Prowess). In terms of Conformality Index, Homogeneity Index, the dose distributions, the mean dose, the maximum dose, number of segments in each plan for each TPS, Monitor Units per fraction for each treatment plan for each TPS, coverage of the PTVs, and avoidance of Organs At Risk (OARs) for Simultaneous Integrated Boost (SIB) for cancer prostate treatment plans.

Material and Methods: CT images and volumes structure of 10 patients were used to make IMRT plans. The target volume's structure was contoured according to RTOG 0534 protocol. Fixed beam geometry and clinical goals were set for all individual patient plans. The results were analyzed in terms of dosimetric parameters, the number of segments, and monitor units per segment.

Results: All TPSs achieve similar coverage, and dose distributions to the PTVs. For PTV60 Eclipse achieved the lowest coverage relative to other planning and the nearest mean dose to prescription dose and significant difference relative to other planning. For PTV 44: the Ray plan achieved the best coverage with a significant difference relative to other systems, but Eclipse achieved the nearest mean dose to the prescribed dose with a significant difference relative to the ray plan. Prowess achieved the lowest MU/fraction with a significant difference relative to Monaco the highest in Mus and the lowest possible number of segments.

Conclusion: The four planning systems achieve close dose distributions and confirmation numbers but there is a significant difference in total segments per fraction and total monitor units per fraction which affect the long life of the machine and the session treatment time.

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Introduction

Presently prostate cancer is the most common cancer among males in the USA. Based totally on the degree, the treatment options available to prostate cancer patients consist of surgical treatment, radiation therapy, hormonal therapy, chemotherapy immunotherapy, or an aggregate of those alternatives. The conventional treatment options include radical prostatectomy, external-beam radiation therapy, brachytherapy, and watchful ready. However, at some stage in radiation, non-involved tissue might receive a significant quantity of dose, leading to an improved chance of genitourinary and gastrointestinal toxicities as well as a small danger of developing radiation-brought malignancies. Currently, modern-day modifications of radiotherapy answers supply better coverage with sparing surrounding normal tissue [1-3].

Three Dimensional-Conformal Radiation therapy (3DCRT) turned into the usual treatment planning technique in clinics across the world till the appearance of intensity Modulated Radiation therapy (IMRT) within the last 1-2 decades [4-11]. The latter has been shown to supply a greater conformed dose to the targeted treatment region, even as presenting higher sparing of adjacent normal organs. It may be concluded that IMRT is a powerful definitive control tool for prostate cancer with stepped forward normal organ sparing and high-quality dose homogenization in target organs of prostate and seminal vesicles. [12]. SIB could be delivered without increasing acute toxicity with new RT techniques, such as intensity-modulated RT (IMRT) Speedy modifications and improvements in treatment techniques have come about in the latest years because of developments in computer generation which meditated within the

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treatment planning systems. The capability to combine several target volumes with specific dose ranges during the planning is this kind of upgrade related to intensity-modulated radiotherapy (IMRT) algorithms, and it is extra complicated and requires specific experience and understanding. Advances in radiotherapy technology (RT), such as intensity-modulated radiotherapy (IMRT), now allow treating multiple planning target volumes (PTVs) in a single plan (simultaneous integrated boost; SIB) [13-16]. The treatment planning system (TPS) has a main core in the IMRT optimization process and perfect dose distribution. TPS needs to have a lot of capabilities to deal with sophisticated situations especially related to the very small field size that is used in IMRT. These small fields or segments must also be delivered by accurate simulation of linear accelerator and multi-leaf collimator configuration [17].

Different TPS uses special optimization algorithms. Eclipse uses a photon optimization (PO) algorithm that is presently launched instead of a Dose-volume Optimizer (DVO) for static IMRT optimization. As it is recognized, DVO optimizes the arena form and intensity using a simple gradient optimization to approach the preferred dose-volume objectives. The influences are returned-projected from the derivatives of the charges at every cloud aspect representing the patient volume. The new PO offers a modern-day volume illustration changing the vintage element cloud version of DVO. It additionally gives an approximation of the dose distribution proven in the 2d view during optimization. Ray plan uses multi-requirements optimization (MCO) algorithm. Monaco optimizes plans in levels, the first phase is fluency map optimization using pencil beam algorithm and phase generation using X-ray voxel primarily based Montecarlo algorithm (XVMC) [18-19]. Previous work compares TPSs according to the most accurate dose calculation **and** compares commissioning algorithms used in the optimization process, and the clinical functionality of the plan[20]. Compared the iso-center dose calculated by each a commercial IMRT treatment planning system and an independent monitor unit verification calculation software to estimate the tolerance for monitor unit calculations. The objective of this work is to evaluate the performance of four different IMRT treatment planning systems (Monaco, Ray plan (RaySearch Laboratories Stockholm, Sweden), Eclipse (Varian Medical Systems, Palo Alto, CA, USA), and Prowess.

Materials and Methods

Patients, Anatomic data acquisition, volumes definition, and dose

All patient data were acquired at the same CT scanner and the information was transferred via DICOM format to different TPS stations. The patient cases were selected from the clinical database at one of the participating centers (National Cancer Institute). All studies were performed with abutted 0.3 cm thick slices and all identification tags were removed to avoid future reference to the original patient. The CT image sets for 10 SIB Prostate cancer patients, were sent through the department network system to four different (TPSs), Eclipse, Monaco, Ray plan, and Prowess. the 10 prostate high-risk patients referred to our institutions for radical external beam irradiation to the prostate and lymph nodes (LN) were considered for this dosimetric comparative analysis. The first clinical target volume (CTV1) comprised the prostate and LN. The CTV2 was limited to the prostate only. Planning target volumes (PTVs) were automatically generated by adding a 3D 1 cm uniform margin around the CTVs, except in the posterior direction, where a 0.5 cm margin was added to protect the rectum. The target volume's structure was contoured according to RTOG 0534 protocol. The PTV1 was received 44Gy in 20 fractions and the PTV2 was simultaneously treated up to 60Gy in 20 fractions. The contouring of all organs at risk or clinical target volume was done by a qualified oncologist as a part of the routine work at NCI before the transformation process to ensure that one person was contouring all patients for all TPSs. To reduce variability, fixed beam geometry and clinical Goals were set in treatment plans for all individual patient plans for each system.

Treatment plans comparisons (Dose distribution)

Using the same machine neutralizes any limitation, due to machine configuration such as the leaf width or radiation leakage. On each of the four planning systems, three objectives were fulfilled before the plan was accepted:

i) target coverage heterogeneity within +7% and -5% of the prescribed dose (according to the International Commission on Radiation Units and Measurements (ICRU)),
ii) OAR sparing to at least the limits stated in Table 1, and
iii) sparing of healthy tissue (the CT dataset patient volume minus the volume of the largest target). The number of fields and the beam geometry were fixed to avoid variability in the results due to different beam arrangements.

Table 1, a summary of clinical objectives for PTV and organs at risk (OAR)

Organ	Tolerance
Rectum	V60 Gy < 15%, V56 Gy, 25%, V52 Gy < 35%, V48 Gy %<50%
Bladder	V60Gy <25%, V56 <35%, V52<50%
Penile Bulb	Mean Dose <42 Gy
Femoral Heads	Maximum Dose <45 Gy
Small Bowel Bag	V45 Gy < 200 cc, D5cc <60 Gy
PTV	2% Volume < 66 Gy

Evaluation tool

The analysis was based on isodose distributions and on dose-volume histograms (DVHs) for planning target volume (PTV) and the relevant OARs, as well as the mean dose, maximum dose, and D95 (dose to 95% of the PTV). Volumes receiving 2 Gy and 5 Gy were calculated and compared. Also, the total number of segments, MU/segment, and the number of MU/cGy were investigated. Confirmation number (CN) was used because it considered irradiation of the target volume and irradiation of healthy tissues, this number was defined as follows:

$$CN = TVRI/\ TV*TVRI/VRI \quad (1)$$

where *CN* = confirmation number, *TVRI* = target volume covered by the reference isodose, *TV* = target volume, and *VRI* = volume of the reference isodose. The used reference isodose was the isodose 95% of the prescribed dose (according to the ICRU). The first fraction of this equation defines the quality of coverage of the target (local control), while the second fraction defines the volume of healthy tissue receiving a dose greater than or equal to the prescribed reference dose. The CN ranges from 0 to 1, where 1 is the ideal value. Analysis of variance (ANOVA) test was performed as a statistical model used to study the significance level all through the data, and a p-value less than 0.05 was considered statistically significant. In the study, alpha (α) = 0.05.

Finally, the delivered doses had a complex, non-intuitive relationship to the number of monitor units. It was also impossible to predict the exact combination of field segments or the leaf motion patterns. Therefore, all the IMRT plans, which were performed using the MLC to produce fluence modulations, should establish a precise and reliable method for the dosimetric verification of IMRT plans. The phantom substitution method was often used since verifying dose distributions within a real patient was not possible [21-22].

Results

The dose distributions obtained from the four TPSs are found to be similar with minor differences. All the plans achieve similar coverage to the PTVs. It is also demonstrated that although the dose distributions are similar. According to Table 2, For PTV60 Eclipse achieved the lowest coverage by a significant difference ($p< 0.05$) relative to other planning by about (1.7-2.6%). Eclipse on the other hand achieved the nearest mean dose to the target prescription by about 1.5% and a significant difference ($p < 0.05$) relative to other planning by about 2-3%. For PTV 44 Ray plan achieved the best coverage with a significant difference relative to other systems ($p= 0.001$) by about 1.8-2.5 % Eclipse achieved the nearest mean dose to the prescribed dose with a significant difference relative to the ray plan and not significant relative to other TPS. Ray plan achieved the highest and worst mean dose by borderline significance relative to Prowess and not significant relative to other systems. Prowess achieved the lowest MU /fraction with a significant difference relative to Monaco the highest in MUs. Ray plans the second-lowest in MUs with a significant difference relative to Monaco and Eclipse. The prowess plan was done with the lowest possible segment number relative to other systems. The difference is significant relative to all systems except Monaco. The dose distributions are presented as a color wash overlaid on the transverse, coronal, and sagittal CT slice at the center of PTV, and the Dose distribution is presented in two colors the blue is the 95% of PTV 44 Gy and orange is 95% of PTV 60 Gy. Comparing the dose distribution through the patient volume makes it possible to qualitatively analyze the different degrees of conformity, and the ability of TPS to confirm two different levels of dose simultaneously.

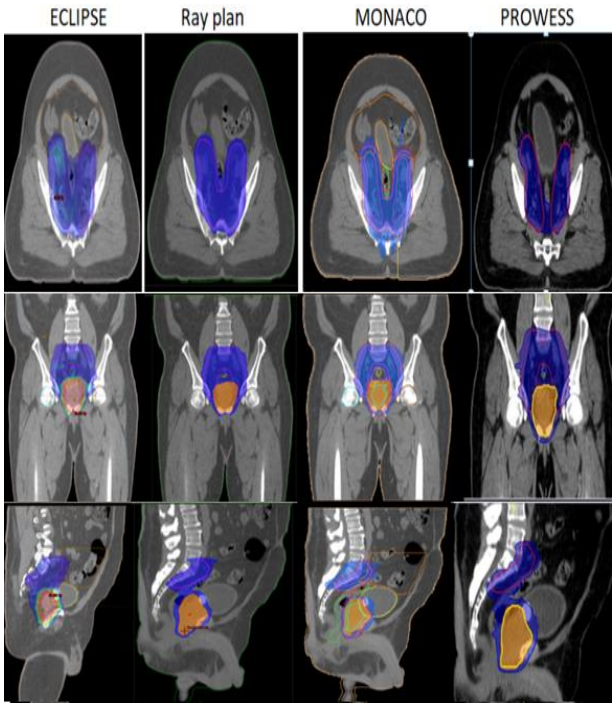

Figure 1. Dose distribution comparison between four different TPS Eclipse, Ray plan, Monaco, and Prowess. The blue color is 95% for PTV 44Gy and the orange color is 95% for PTV 60Gy.

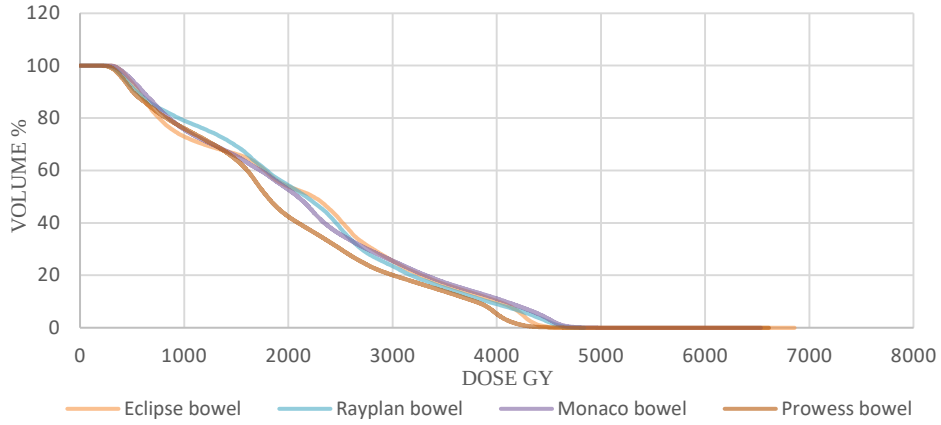

Figure 2 (a). Comparison between PTVs DVH

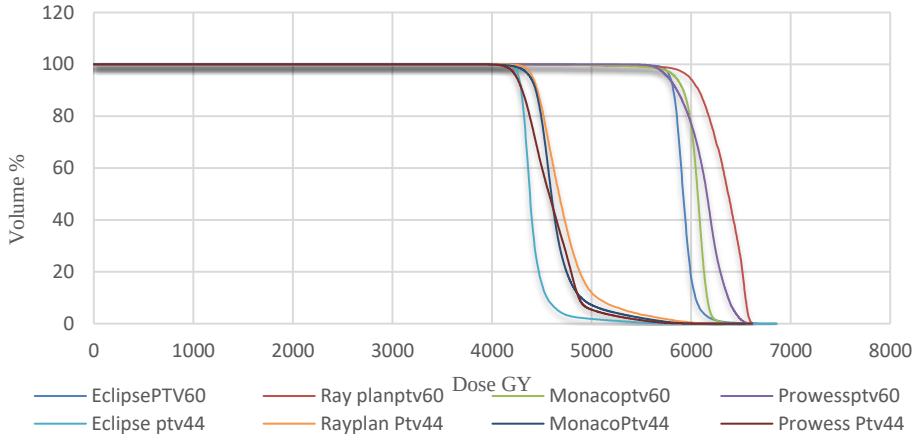

Figure 2 (b). Comparison of Bowel bag DVH

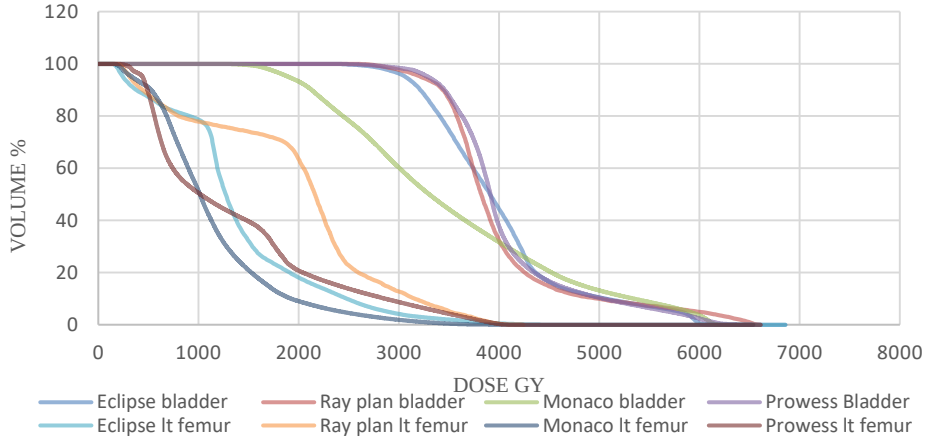

Fig.2c- Comparison of both right femur and rectum

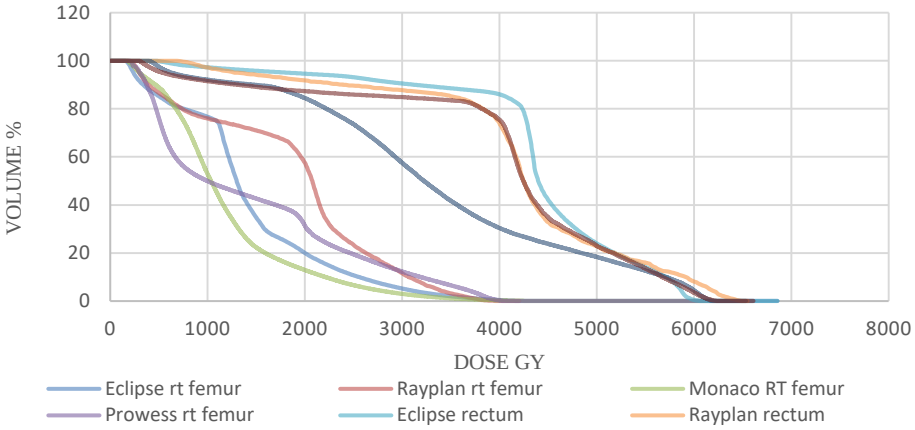

Fig.2 (d). Comparison of both left femur and bladder

Table 2 (a). The mean dose, maximum dose, and the D95 for PTV 60

PTV60	*Maximum Dose (Gy)*				*D95 (Gy)*				*Mean Dose (Gy)*			
Case	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS
1	68.6	65.9	65.4	65	57.9	59.8	58.4	59.4	59.3	63.3	60.4	61.6
2	62.8	61.1	66.6	65.3	57	58.1	58.7	59.3	59.4	60	61.2	61.8
3	66.7	63.3	69.2	64.1	57.5	58.5	59.1	57.6	58.6	60.4	61.3	60.2
4	63.7	66	67	64.5	57.6	57.9	59.2	58.8	59	62.3	61	61
5	63.1	66.2	66.1	65.4	57.9	58.7	59.9	60.3	59.3	62.9	61.7	62.8
6	64	65.1	67.1	65	57.7	58.1	60	58.6	59.1	62.3	61.7	60.5
7	64.7	65.9	65.7	63.3	57.9	57.5	59.7	58.8	59.2	62.6	61.8	61.2
8	62.3	63.6	66.7	67.3	57.9	61.5	58	59.5	59.2	60.8	60.2	63
9	64.4	64.7	66.9	62.9	57.5	57	59.2	57	59.2	61.4	61.6	59.8
10	64.5	64.6	66.7	65.4	57.6	58.6	59.1	59.7	59.1	61.8	61.2	62.1
Mean SD	64.5±1.9	64.6±1.6	66.7±1.03	64.8±1.2	57.6±0.3	58.6±1.3	59.1±0.6	58.9±0.9	59.1±0.2	61.8±1.1	61.2±0.54	61.4±1.1

Table 2 (b). The mean dose, maximum dose, and the D95 for PTV 44.

PTV44	Maximum Dose (Gy)				D95 (Gy)				Mean Dose (Gy)			
Case	Eclipse	Ray Plan	Monaco	PROWESS	Eclipse	Ray Plan	Monaco	PROWESS	Eclipse	Ray Plan	Monaco	PROWESS
1	58.5	58.7	62.1	61.3	42.7	44.1	43.8	42.4	44.2	47.3	46.5	45.9
2	64	57.7	64.7	64	43.8	43.7	42	42.7	45.7	47.1	46.2	45.7
3	58.7	60.2	63.8	62.2	42.7	44.1	43.6	42	44	46.7	46.5	45.3
4	59	58.1	63.3	57.8	43	43.6	42.1	42.6	44.7	46.4	45.6	45.3
5	59.3	57.4	64.5	59.9	42.7	43.7	43.5	42.8	44.4	46.8	45.4	45.9
6	60.3	57.7	63.6	58.8	43	43.5	42.9	41.9	44.7	46	45.5	44.5
7	59.1	60.8	64.2	58.8	42.9	44	43.2	42.4	44.8	47.4	46.1	45.2
8	56.3	55.9	65.4	63.1	42.8	44.1	39.1	42.4	44.6	44.6	44.4	45.4
9	60.4	58.4	64.2	59.6	42.6	42.9	42.8	42.3	44.6	46.6	45.9	45.9
10	59.5	58.3	64	58.1	42.9	43.7	42.6	42.8	44.6	46.5	45.8	45.2
SD	59.5±1.9	58.3±1.4	63.9±0.8	60.4±2.2	42.9±0.4	43.7±0.4	42.6±1.4	42.9±0.4	44.6±0.5	46.5±0.8	45.7±0.6	45.4±0.4

Table3 (a). Represents MU/fraction and Total segment for all cases

	MU / fraction				*Total segment*			
case	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS
1	1659	1248	1389	733	190	133	114	90
2	1783	1028	1583	698	191	135	123	90
3	1659	923	1815	731	200	133	130	90
4	1040	1226	2040	610	196	134	130	90
5	1209	1022	1940	642	155	124	127	90
6	1546	1131	1704	652	191	133	119	90
7	1510	951	1702	736	185	135	128	90
8	1408	1067	1188	685	187	134	115	90
9	1677	1074	1736	656	206	133	125	90
10	1490	1070	1670	627	199	134	122	90
Mean	1499.1±228.3	1076.4±105.2	1677.8±248.4	676.8±46.3	189.0± 13.5	133.0± 3.3	123.5±5.7	90.0±0

Table 3 (b). Represents the shortest and longest segment MU and monitor units per segment

	shortest segment (MU)				Longest segment (MU)				MU/seg			
case	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS
1	7.93	1.97	6.4	3	12.56	27.2	41.7	25.03	8.73	9.38	12.19	8.14
2	7.97	2	5	3.15	13.79	46.2	31.2	30.52	9.34	7.61	12.87	7.75
3	7.3	2	4	3.09	12.9	21.8	71.68	30.23	8.30	6.94	13.96	8.12
4	6	2.2	4	3.04	14	33.5	43.4	25.68	5.31	9.15	15.69	7.14
5	6.7	3.1	4.09	3.21	11.3	24.6	40.09	22.32	7.80	8.24	15.28	7.14
6	5.1	2	4	3.03	8.3	50	40.2	25.42	8.09	8.50	14.32	7.24
7	6.8	1.9	4.64	3.05	9.8	41.9	34.5	30.74	8.16	7.05	13.30	8.17
8	6.6	2.1	4	3	10.8	35	37.46	24.8	7.53	7.96	10.33	7.61
9	4.7	2.2	4.5	3.2	8.3	34.5	42.5	23.8	8.14	8.10	13.89	7.29
10	6.5	1.9	5	3.08	10	35.5	41	26.9	7.49	7.99	13.69	6.97
Mean	6.6	2.1	4.55	3.08	11.2	35	42.4	26.54	7.9±1.1	8.1±0.8	13.5±1.5	7.6±0.5

Table 4. Represents V2 Gy and V5Gy of patient volume excluding PTV volume and conformation number (CN)

	V2Gy (%)				V5Gy (%)				CN			
Case	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS	Eclipse	Ray plan	Monaco	PROWESS
1	59	48.5	50.5	48	44	36.5	36.8	36	0.58	0.71	0.55	0.65
2	59	55.4	55.8	59	48.2	42.4	44.9	49	0.7	0.61	0.64	0.69
3	54	62.3	53.3	53	41.6	50.3	40.2	39	0.55	0.51	0.65	0.7
4	46	46.5	43	45	34	34	30.5	53	0.74	0.61	0.55	0.57
5	44	45.5	46	46	32	33	34	33	0.8	0.65	0.51	0.66
6	36.4	53	49	50	40	41.5	37	41	0.72	0.58	0.56	0.59
7	52	38.5	35.7	36	27	28.5	26.4	28	0.72	0.61	0.57	0.62
8	51	52	50.5	50	38.6	39	40.9	39	0.82	0.73	0.35	0.73
9	47	49.5	46.4	46	36	38	35	36	0.8	0.7	0.62	0.64
10	48	49	46.5	50	37	38	36	40	0.71	0.65	0.557	0.59
Mean	49.8±6.9	50.1±6.3	47.8±5.6	48.3±5.9	37.9±6.1	38.1±5.9	36.2±5.3	39.4±7.3	0.74±0.1	0.66±0.1	0.57±0.1	0.65±0.1

All the plans achieve similar coverage to the PTVs. It is also demonstrated that although the dose distributions are similar, the relative beam weights of the fields can be different, depending on the treatment planning system.

Figure (2) presents a comparison of the DVHs of the sample case from the four TPSs

a) Comparison between PTVs DVH,
b) Comparison of Bowel bag DVH,
c) Comparison of both right femur and rectum,
d) Comparison of both left femur and bladder.

Such a comparison provides more quantitative results compared to the qualitative comparison of the dose distributions.

Table 2a, the mean dose, the dose received by 95% of the volume (D95), and the maximum dose (Dmax) to the PTV60 for the Eclipse, Ray plan, Monaco, and Prowess plans. The mean value and standard deviation (SD) of all parameters in the last cell the objective for PTV is to achieve the highest possible dose to 95% of the target volume keeping the mean dose near to prescribed dose as possible and the lowest maximum dose. Eclipse achieved the lowest coverage by significant difference ($p< 0.05$) relative to other planning by about (1.7-2.6%). Eclipse on the other hand achieved the nearest mean dose to the target prescription by about 1.5% and a significant difference ($p < 0.05$) relative to other planning by about 2-3%.

Table 2b, the mean dose, the dose received by 95% of the volume (D95), and the maximum dose (Dmax) to the PTV60 for the Eclipse, Ray plan, Monaco, and Prowess plans. The mean value and standard deviation (SD) of all parameters in the last cell. For PTV 44 Ray plan achieved the best coverage with a significant difference relative to other systems ($p= 0.001$) by about 1.8-2.5 % Eclipse achieved the nearest mean dose to the prescribed dose with a significant difference relative to the ray plan and not significant relative to other TPS. Ray plan achieved the highest and worst mean dose by borderline significance relative to Prowess and not significant relative to other systems. Increasing mean dose and Dmax is an indicator of dose spillage of high dose level 60 Gy to the low dose area PTV44 in SIB treatment.

According to table Tables, 3(a) and 3(b), Prowess achieved the lowest MU /fraction, the total number of segments, and shortest monitor unit per segment with a significant difference relative to Monaco the highest in MU/fraction and monitor unit per segment [23-25]. Ray plan is the second-lowest in MUs with a significant difference relative to Monaco and Eclipse. The prowess plan was done with the lowest possible segment number relative to other systems. Eclipse shows the highest number of segments.Table4 shows that Eclipse has the highest Confirmation number with a significant difference relative to Monaco the lowest confirmation number.

Discussion

The study aimed to address the effectiveness of IMRT treatment planning on various prostate cancer indications. The study compared four TPS with a common data set and planning guidelines, reproducing the model already adopted in a previous study on breast treatment [26]. Differences in plans from various TPS, both in terms of PTV coverage(V95%), conformity, and other dosimetric parameters, were observed. Care must be taken in ranking the TPS since the influence of user preferences on the planning results has to be considered too: where goals cannot be achieved simultaneously, some trade-off must be found that satisfies the individual planner. In this context, the mean scores do allow an assessment of both the TPS quality and the user preferences.

The present study showed that the dose distributions obtained from the four TPSs (Eclipse – Ray plan-Monaco –Prowess) for the sample of investigated cases were not significantly different. But there are some differences in the dosimetric evaluation that can be considered. By investigating the DVHs comparing Monaco, Eclipse, Ray plan, and Prowess, it is assumed that Eclipse is the best choice to achieve the nearest mean dose to the prescribed dose and confirmation number with acceptable coverage but it has the highest number of segments, these results agree with Ahmed El dib et al., (25) results according to mean dose when he compared Monaco and Eclipse only and didn't care about monitor unit per fraction or number of segments.

Ahmed Eldib et al., (25). Had studied and evaluated two optimization systems available from two commercial treatment planning systems. The two systems used in his study were the Eclipse and Monaco. Monaco achieves the highest maximum dose, and this result agrees with Ahmed Eldib et al., (25).

Prowess achieved the lowest MU /fraction and the number of segments per plan, and the shortest monitor unit per segment, on the other hand, Monaco presents the heist MU /fraction and monitor unit per segment. Eclipse has the highest Conformity but there was no significant difference in V2Gy or V5Gy.

Four TPS were compared to assess the capability to plan IMRT in different patients. All the TPS allowed the design of plans mostly respecting initial objectives even if with a range of differences. Emphasis should be made on the importance of avoiding hot spots outside targets and on the maximal reduction of his involvement. This normal tissue and OAR sparing leads inevitably to more heterogeneity in the target dose distribution. Some systems provided better capabilities (as measured by the scoring indexes), within the limits of user preferences than others but performance should be evaluated case by case according to clinical requirements and strategies. The key message concerning, if considering IMRT for prostate cancer treatments, all systems proved to offer sufficient performance from the technical point of view.

Conclusion

The four planning systems achieve close dose distributions and confirmation numbers but there is a significant difference in total segments per fraction and total monitor units per fraction which affect the long life of the machine and the session treatment time.

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