Which Dosimetric Technique is Better; 3D-CRT, IMRT or VMAT in High Risk Prostate Cancer Treated by Hypofractionated radiotherapy with Elective Nodal Irradiation

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Abstract:

Background: Prostate cancer is not common in Arab countries. In this study, our aim is to investigate which dosimetric technique has better target coverage and organs sparing; 3D-CRT, IMRT or VMAT in high risk prostate cancer treated by hypofractionation with elective nodal irradiation.

Patients and Methods: The medical records of five patients of high risk prostate cancer treated by VMAT were reviewed and re-planned by 3D-CRT & IMRT. PTV70 is covering the prostate and seminal vesicle while PTV50.4 is covering the prostate, seminal vesicle and local lymph nodes drainage. Contouring of organs at risks was done according to RTOG guidelines. 3D-CRT was delivered in two phases while IMRT and VMAT were delivered in one phase using simultaneous integrated boost. Target coverage, organs at risks sparing and treatment time beam on were compared between all plans.

Results: All techniques had similar high dose target volume coverage (PTV70) while 3D-CRT had suboptimal coverage regarding to low dose target coverage (PTV50.4). OAR sparing was better and statistically significant in IMRT & VMAT while 3D-CRT failed to achieve the desired organs at risks sparing. 3D-CRT had statistically significant better lower integral dose than IMRT & VMAT. Treatment time beam on is the shortest in VMAT while longer in IMRT and medium in 3D-CRT.

Conclusion: VMAT and IMRT techniques have optimal target coverage and organs sparing in case of high risk prostate cancer treated by hypofractionated irradiation using simultaneous elective nodal irradiation while 3D-CRT technique has suboptimal target coverage and organs sparing which make it unsuitable technique for such cases.

Keywords 3D-CRT, IMRT, VMAT, prostate, dosimetric

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Background:

Prostate cancer is one of the targets which need high dose irradiation taking in consideration the dose limiting structures in the pelvis (rectum, bowel and bladder) [1].

Pelvic lymph nodes, prostate and seminal vesicle are the target volumes for irradiation of high risk prostate cancer [2,3].

Conventional irradiation of high risk prostate cancer is delivered in two phases with 45-50 Gy in first phase then 20-25 Gy in second phase; [4-6] however this dose may be insufficient to prostate and seminal vesicle so dose escalation trials were conducted [7].

The lymph node volumes of high risk prostate cancer is still variable among radiation oncologist [8], so ENI contouring of such cases is following the RTOG guidelines [9].

Conventional irradiation is delivered by 4-6 fields while 10-12 fields by IMRT and 1-2 arcs by VMAT [10-12].

Dose escalation and hypofractionation in prostate cancer can be implemented by IMRT & VMAT without increase in late GI & GU toxicity while it may not be feasible by conventional technique. [13-17].

In this study, our aim is to investigate which dosimetric technique has better therapeutic ratio 3D-

CRT, IMRT or VMAT in high risk prostate cancer using hypofractionation with ENI.

Patients and Methods:

Study design

The medical records of five patients of high risk prostate cancer treated by hypofractionation with ENI using VMAT were reviewed and re-planned by 3D-CRT & IMRT techniques at International Medical Center, Cairo, Egypt. PTV70 is contoured and covering the prostate and seminal vesicle in all techniques delivering 28 fractions with 2.5 Gy per fraction. PTV50.4is contoured and covering prostate, seminal vesicle and local lymph nodes drainage. Contouring of OAR was done according to RTOG guidelines. Details of simulation imaging, target volumes contouring and dose constraints were done as in previous study [18].

3D-CRT was planned in two phases while IMRT and VMAT were planned in one phase using SIB.

Planning system

3D-CRT, IMRT and VMAT plans were developed using the Eclipse (Varian, Treatment Planning System (TPS) with 15 MV. AAA (Analytical Anisotropic Algorithm, Varian Version 15.6) was used to calculate the dose distributions. Inverse plans for IMRT and VMAT were generated using the same dose-volume constraints.

3D-CRT technique

First phase of whole pelvis is to deliver 50Gy in 20 fractions then second phase (prostate and seminal vesicle) is to deliver 20 Gy in 8 fractions. We used 3-5 fields with different beam angles while irradiation is performed at fixed gantry angles by modulating the multi-leaf collimator (MLC).

IMRT technique

Ten to Twelve fields were calculated using the dynamic IMRT technique and Monte Carlo Algorithm at different angles 0°, 30°, 60°, 90°, 120°,150°, 180°, 210°, 240°, 270°, 300°, 330°.

VMAT technique

Plans were generated using dynamic VMAT and Monte Carlo Algorithm using full IMRT contours, central axis and isocenter in clockwise and counter clockwise double arcs (angles of approximately 181^{O}-179^{O}).

Plan evaluation

We compared target volumes coverage, critical organs sparing, integral dose and beam on treatment time between all plans.

Statistical analysis

Quantitative data were expressed as the mean & range. Continuous variables were checked for normality by using Shapiro-Wilk test. Friedman test was used to compare more than two dependent groups of non-normally distributed variables. All tests were two sided. A p-value <0.05 was considered significant. All statistics were performed using SPSS 22.0 for windows (IBM Corp., Armonk, NY, USA).

Results:

All patients' characteristics and statistics are showed in table 1,2.

Target volumes

All techniques have comparable target coverage regarding to PTV70 (P 0.83). PTV50.4 is statistically significant and better in IMRT & VMAT contrary to 3D-CRT (P 0.015).

Organ at Risk sparing

All OAR have statistically significant better sparing in case of VMAT & IMRT than 3D-CRT. IMRT & VMAT have comparable sparing in case of small bowel, colon, femur and bone marrow. IMRT has relatively better sparing than VMAT in case of bladder, rectum and penile bulb.

Integral Dose

3D-CRT has statistically significant better lower integral dose than others, in addition to VMAT is relatively better than IMRT (p value 0.007).

Beam on treatment time

VMAT has the shortest treatment time beam on (1.03-1.2 minutes), followed by 3D-CRT (1.33-1.6 minutes) then IMRT (3-3.22 minutes).

Discussion:

Hypofractionated irradiation is a recent trend in treatment of prostate cancer since last decade. In our previous study [18], we applied hypofractionated irradiation in high risk prostate cancer using VMAT technique so in this study we try to get answer about which technique is better in dealing with such cases of cancer especially if elective nodal irradiation is applied.

In this study, high dose primary target coverage is comparable in all techniques and this is in line with different studies by Ishii et al [19] and others [20-26] which are applied dose escalation, hypofractionation or both however; Crowe et al [27] reported that IMRT and VMAT had better target coverage than 3D-CRT while Tao et al [28] noted that IMRT had better target coverage than 3D-CRT.

Table 1: Target and organs at risk doses.

	Patient 1			**Patient 2**			**Patient 3**			**Patient 4**		**Patient 5**			
	3D	IMRT	VMAT	3D	IMRT	VMAT	3D	IMRT	**VMAT**	IMRT	**VMAT**	IMRT	**VMAT**	IMRT	**VMAT**
PTV70															
Mm	93	83.4	87	92	80	89.3	91	85	**89**	90	77	88	87	80	**85**
Mx	104.5	102.5	104.6	103.2	103.3	106.7	105	102	**103.6**	102.5	103	105	101	102	**104**
Mn	100.6	99	101	100	100	99.5	100.9	99.9	**100**	101	101	100.2	100.5	101	**101**
PTV50.4															
Mm	65.6	54.4	56	57.5	64.4	63	63	65	**66**	60	66	67	58	65	**68**
Mx	104.5	102.5	104.6	103.1	101.8	100.9	105	103	**104**	104	102	101	103	101.5	**102**
Mn	83	74.2	74	79.2	74.4	74.2	84	75	**73.9**	78	73	72.5	80	74	**73.6**
Bladder															
Mm	62.4	34.4	32.6	55	35	33	55	36	**37**	58	37	35	55	35	**32**
Mx	104.5	101.4	104.4	103.2	101.5	103.8	101	102	**103**	103	102	104	102	101	**103**
Mn	87.2	66.4	65.7	84	60.3	67.2	85	64	**67**	81	57	65	79	56	**66**
Rectum															
Mm	33.3	13.4	7.5	15.3	5.6	5.6	25	12	**10**	16	7	8	13	5	**4.5**
Mx	101	102.5	104.4	100	101.6	101.3	100	101	**103**	100	101	101.5	101	101	**102**
Mn	79	65	64.5	80	54	64.4	75	60	**63**	75	52	60	70	49	**58**
SB															
Mm	4.3	18	19	2.7	3.5	4	5	20	**22**	3.5	5	6	4	6.5	**7**
Mx	88	72	75.4	75.6	52.7	48	85	74	**73**	68	43	45	70	44	**46**
Mn	54	48	46.4	23.3	18.3	16.2	45	36	**37**	24	17	15	25	16	**13**
Colon															
Mm	33.6	50.3	35	8.4	9.6	8.2	22	40	**35**	9.2	10	9	8.5	9.5	**9.2**
Mx	73.3	72.2	74	76	77.2	77.8	62	65	**68**	77	78	79	74	75	**76**
Mn	68	65	62.2	64	54.8	53	60	58	**53**	65	53.2	52	63	51	**50.2**
RF															
Mm	7	4	4.6	2.8	1.7	1.6	6	2.5	**2**	3	1.8	1.5	3.5	1.4	**1.2**
Mx	89	64	65.2	72	59.5	52.3	85	60	**64**	70	60	51	72	58	**50**
Mn	55.4	23.5	28.4	49	21.4	20.7	50	28	**25**	50	20	22	51	23	**24**
LF															
Mm	3.2	3.5	4.8	2.7	1.5	1.8	3	3.6	**4**	3.8	2	2.5	4	1.5	**2**
Mx	91	63.5	60	72.3	58.7	55.5	80	60	**57**	75	60	56	71	58	**57**
Mn	49	23.5	25	50.2	22.5	23	49	25	**24**	51	23.5	24	48	21	**21**
BM															
Mm	1.2	1	0.9	0.4	0.3	0.3	1	0.8	**0.5**	0.7	0.6	0.5	1.2	1	**0.8**
Mx	104.5	102	104	103.2	103.3	104.5	100	98	**102**	102	101	100	103	102	**101**
Mn	48.2	36.4	36.3	43	34.3	32.6	49	38	**36**	45	30	28	51	32	**29**
PB															
Mm	88	46	51	89.2	48	55.3	90	50	**53**	88	50	56	91	53	**59**
Mx	99	99	102	97.9	98.4	101.8	100	99	**102**	99	98	101	100	97	**100**
Mn	96	80	89	95	82	91	95	83	**91**	100	80	89	93	81	**89**
ID															
V5	15822	20833	19654	12100	15473	14317	16200	21020	**20800**	17150	20250	19820	14260	16200	**15750**
V10	13131	17682	16835	10015	12970	11178	14300	18200	**17550**	14200	17840	16900	12050	14520	**13950**
V15	11463	14938	13288	8810	11362	9409	12450	16650	**15400**	10400	12900	12050	9840	11750	**11050**

PTV planning Target Volume, Mm minimum, Mx maximum, Mn mean, SB small bowel, RF right femur, LF left femur, BM bone marrow, PB penile bulb, ID integral dose

Table 2: Statistics, P values and Mean of target and organs at risk.

	3D	IMRT	VMAT	P value
Mean PTV70	100.4	100	100.34	0.838
Mean PTV50.4	80.84	74	73.64	0.015
Mean Bladder	83.24	60.74	66.2	0.015
Mean Rectum	75.8	56	62	0.015
Mean SB	34.3	27.1	25.5	0.015
Mean Colon	64	56.4	54.1	0.007
Mean RF	51.1	23.2	24.02	0.022
Mean LF	49.6	23.1	23.4	0.016
Mean BM	46.6	34.1	32.4	0.007
Mean PB	95.8	81.2	89.8	0.007
Mean ID				
V5 (cc)	15106	18755	18068	0.007
V10 (cc)	13771	17060	16627	0.007
V15 (cc)	10593	13520	12239	0.007

Regarding to low dose target coverage, this study recorded better coverage by VMAT and IMRT while it was suboptimal by 3D-CRT as in series by Ishii et al [19], Gozal et al [20], Wolff et al [24] and Crowe et al [27], however Salimi et al [26] reported that IMRT had better coverage than 3D-CRT.

Regarding to OAR sparing especially rectum and bladder, our study noticed that VMAT and IMRT have better sparing than 3D-CRT as reported in other series by Gozal et al [19], Cakir et al [21], Palma et al [23], Wolff et al [24] and Crawe et al [27].

In our series VMAT and IMRT had similar sparing to small bowel, colon, both femurs and bone marrow; while IMRT had slightly better sparing than VMAT in case of bladder, rectum and penile bulb similar to data reported by Ishii et al[19] who used the same dose of hypofractionation plus nodal irradiation and got better sparing to rectum and bladder by 9-field IMRT than VMAT and 7-field IMRT, while other studies showed similar results between IMRT and VMAT plans as reported by Gozal et al [19], Cakir et al [21], Palma et al [23], Wolff et al [24], Davidson et al [25] and Crowe et al [27].

Regarding to integral dose, all recent modalities in radiotherapy including IMRT and VMAT make big volume of the body exposed to low doses of irradiation and this is noticed in all studies [20-21, 23-24, 27-28] including this study which noticed that 3D-CRT had better lower integral dose than IMRT and VMAT.

In this study, VMAT had relatively better lower integral dose than IMRT contrary to Cakir et al [21] where IMRT had better lower integral dose than VMAT.

VMAT had the shortest treatment time beam on in this series as in other series [19-21, 23-25, 27].

3D-CRT had shorter or comparable treatment time beam on than IMRT in this study as noticed in most series [20-24, 26-27] according to the number of fields delivered in each plan.

Conclusion:

VMAT and IMRT techniques have optimal target coverage and organs sparing in case of high risk prostate cancer treated by hypofractionated irradiation using simultaneous elective nodal irradiation while 3D-CRT technique has suboptimal target coverage and organs sparing which make it unsuitable technique for such cases.

Abbreviations

ENI Elective Nodal Irradiation
RTOG Radiation Therapy Oncology Group
GI Gastro-Intestinal
GU Genito-urinary
IMRT Intensity Modulated Radiation Therapy
VMAT Volumetric Modulated Arc Therapy
3D-CRT 3Dimensional-Conformal Radiation Therapy
PTV Planning Target Volume
OAR Organs at Risk
SIB Simultaneous Integrated Boost

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