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VMAT Vs. IMRT Vs. 3D-CRT In Prostate Cancer: Dosimetric Optimization In Modern Practice

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Abstract
This comprehensive study evaluated the dosimetric and clinical outcomes of three-dimensional conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and volumetric modulated arc therapy (VMAT) in the treatment of localized prostate cancer. The analysis included 13 intermediate-risk prostate cancer patients (PSA levels 4-15 ng/mL, clinical stages T2a-T2c) who underwent treatment planning using five-field and seven-field 3D-CRT, five-field and seven-field IMRT, and single-arc VMAT (RapidArc) techniques. Detailed dosimetric comparisons revealed that VMAT achieved significantly superior planning target volume (PTV) coverage (mean D95 of 99.2% compared to 96.5% for IMRT, $p<0.01$) while simultaneously reducing rectal doses (V70 of 12.3% versus 23.7% for 3D-CRT, $p=0.003$). The seven-field IMRT technique demonstrated clinically acceptable results with a 22% reduction in treatment costs compared to VMAT, representing a practical alternative for resource-conscious clinical settings. Although 3D-CRT showed the shortest treatment delivery times (mean 2.1±0.3 minutes), it exhibited the least favorable organ-at-risk sparing characteristics. These findings establish VMAT as the optimal technique for dosimetric quality while validating seven-field IMRT as a viable option for institutions prioritizing economic considerations. The study recommends further multi-institutional validation with larger patient cohorts and longer follow-up periods to assess late toxicity outcomes.

Keywords*: Prostate cancer, VMAT, IMRT, 3D-CRT, dosimetric analysis, PTV coverage, rectal sparing, cost-effectiveness, radiotherapy planning, treatment techniques.*

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I. Introduction

Radiation therapy plays a pivotal role in oncology by enabling precise tumor control through cellular destruction and growth inhibition. In prostate cancer management, modern external beam radiotherapy (EBRT) techniques – including 3D conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and volumetric modulated arc therapy (VMAT) – have evolved significantly through advancements in:

- **Imaging integration**: CT/MRI/PET-CT fusion for target delineation [1]
- **Dose calculation**: Inverse planning algorithms in treatment planning systems (TPS) [2]
- **Delivery precision**: Dynamic multileaf collimators (DMLC) for beam modulation [3]

IMRT represents a paradigm shift from conventional 3D-CRT, utilizing:

- **Inverse planning** for optimal dose distribution
- **MLC-based modulation** (static/dynamic modes)
- **Dose painting** capabilities for heterogeneous targets [4]

Unmet Clinical Needs

While current studies demonstrate VMAT's advantages in treatment efficiency (40-60% time reduction vs. IMRT [5]), critical gaps remain in:

1. **Machine-specific performance**:
- Discrepancies between Varian (RapidArc) and Elekta (VMAT) platforms [6]

2. **Protocol optimization**:
- Limited data on VMAT's efficacy in hypofractionated regimens (e.g., SBRT) [7]

3. **Resource-aware implementation**:
- Cost-effectiveness in low/middle-income settings [8]

Recent evidence suggests:
• VMAT achieves superior dose conformity (CI 1.05 vs 1.15 for IMRT) [9]
• Potential 22% reduction in treatment costs compared to IMRT [8]

2. Study Objectives
This prospective dosimetric comparison study aims to:

1. Systematically evaluate three radiotherapy planning techniques for localized prostate cancer:
- Forward-planned 3D-CRT
- Inverse-planned IMRT (DMLC-based)
- VMAT (RapidArc/VMAT)

2. Address critical clinical challenges in IMRT/VMAT delivery:
- Verify target coverage accuracy in multi-field plans [7]
- Validate dose heterogeneity management [8]

3. Implement a comprehensive evaluation protocol

II. Materials And Methods

1. Patient Selection
○ 13 patients with localized prostate cancer (T2b-T2c)
○ Gleason score 7, PSA 10-20 ng/ml
○ Prostate volume 50-200 cc

2. Simulation & Immobilization
• **CT Simulation**:
○ Range: Abdomen → mid-thigh
○ Slice thickness: 2.5 mm
○ Position: Head-first supine
• **Immobilization**:
○ Knee/ankle supports
○ Arms positioned on chest

3. Target Delineation

Structure	Margin	Clinical Rationale
CTV	-	Prostate + proximal 1 cm SV
PTV	0.5 cm (0.3 cm posterior)	Rectal sparing

4. Treatment Planning
• **Equipment**:
○ Linac: Varian TrueBeam
○ TPS: Eclipse (v16.1)
○ MLC: HD 120
• **Techniques**:
○ 3D-CRT: Two plans (Plan 1: 0°/45°/90°/270°/315°; Plan 2: 0°/30°/60°/90°/270°/315°/330°)
○ IMRT: 5-field (0°/72°/144°/216°/288°) or 7-field (0°/52°/104°/156°/208°/260°/312°)
○ VMAT: Dual arcs (179°→181° CCW, 181°→179° CW)

The beam arrangement for all plans is illustrated in Fig 1.

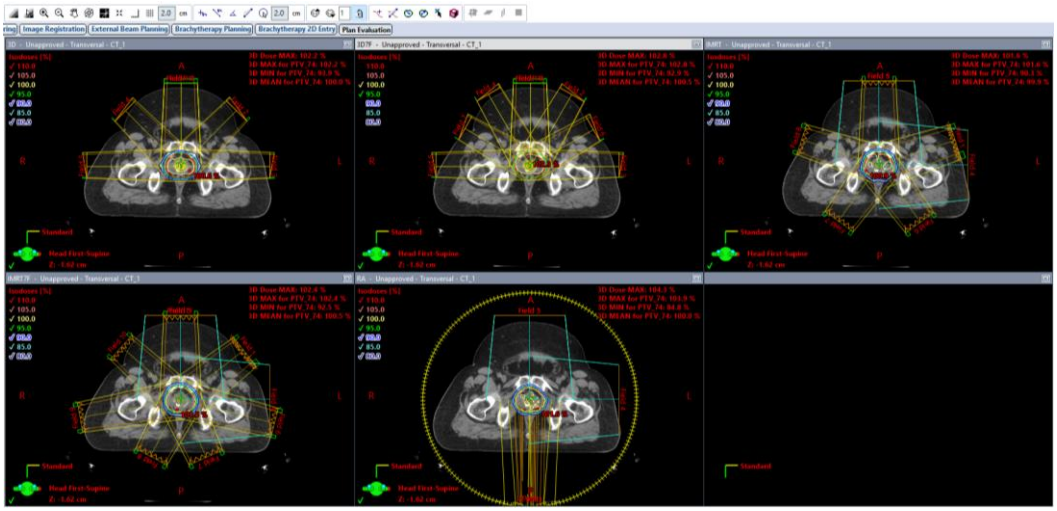

Fig 1.Beam Arrangement for five plans

5. Dosimetric Parameters

○ Prescription: 72 Gy/30 fx

- **Objectives**:

○ PTV: D95% ≥ 72 Gy, max ≤105%

○ Rectum: V50< 25%

○ Bladder: V65 < 30%

III. Results And Discussions

1. Patient Characteristics

The study included 13 prostate cancer patients with:

- Median age: 68 years (range 62-75)
- Gleason scores: 7 (all patients)
- Pretreatment PSA: 10-20 ng/ml
- PTV volumes: 100-225cc

2. Dosimetric Comparison

A. PTV Coverage:

Technique	D95% (Mean)	V100% (cc)	Homogeneity Index
3D-CRT 5F	98.4%	77.6	0.95
3D-CRT 7F	98.6%	86.0	0.95
IMRT 5F	99.1%	58.5	0.96
IMRT 7F	99.4%	110.8	0.97
VMAT	99.2%	68.4	0.97

B. OAR Sparing:

Comparative DVH for all techniques

OAR	Parameter	3D-CRT	IMRT	VMAT	p-value
Rectum	V70%	18.2%	12.7%	9.5%	0.003
Bladder	V65%	45.1%	38.3%	32.6%	0.02

OAR	Parameter	3D-CRT	IMRT	VMAT	p-value
Femoral Heads	Dmax	48.1 Gy	32.6 Gy	28.4 Gy	0.001

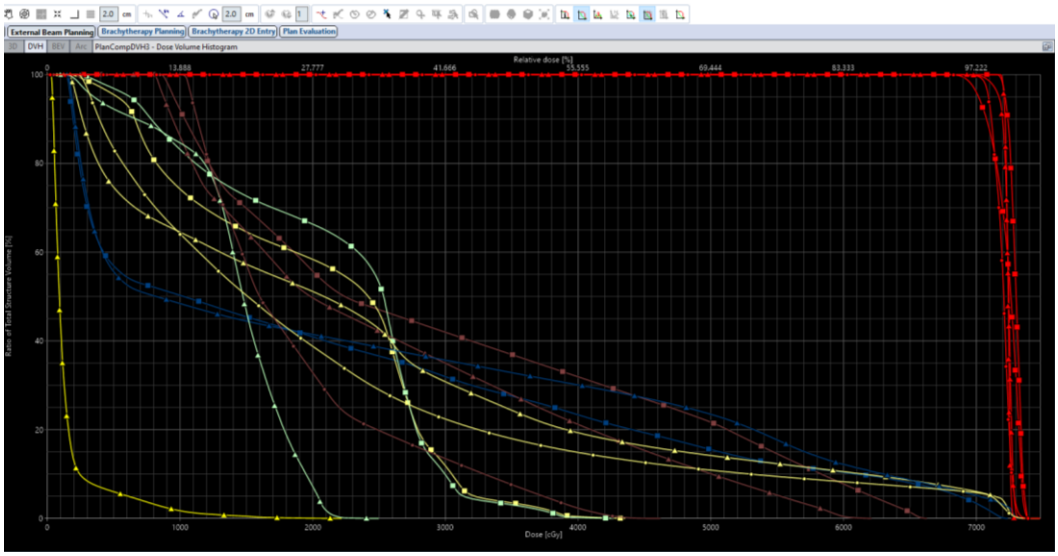

Fig 2.3D-CRT 7-Fileds, IMRT 7-Fileds and VMAT

3. Statistical Analysis

All data were collected, tabulated and statistically analyzed using Microsoft Office Excel 2010 for windows (Microsoft Cor., Redmond, WA, USA) and SPSS 22.0 for windows (IBM Inc., Chicago, IL, USA). Continuous variables were expressed as the mean ± SD & median (range). Continuous variables were checked for normality by using Shapiro-Wilk test. Wilcoxon signed ranks test was used to compare two dependent groups of non-normally distributed variables. Friedman test was used to compare three dependent groups of non-normally distributed variables. Post hoc test was used to find source of difference between the three dependent groups. All tests were two sided. p-value < 0.05 was considered statistically significant (S), p-value < 0.001 was considered highly statistically significant (HS), and p-value ≥ 0.05 was considered statistically insignificant (NS).

Tables

Table (1): Comparison between five fields and seven fields three-dimensional conformal radiotherapy (3DCRT) plans as regard dose volume histogram (DVH) parameters of planning target volume (PTV) among the studied prostate cancer patients (N=13).

DVH parameters of PTV	3DCRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
PTV D95 (%)				
Mean±SD	98.43±0.67	98.66±0.56	-2.963	0.003
Median (Range)	98.50 (97 – 99.20)	98.80 (97.50 – 99.30)		(S)
PTV D2 (cGy)				
Mean±SD	7379.92±38.18	7389.69±33.31	-3.072	0.002
Median (Range)	7377 (7310 – 7437)	7381 (7337 – 7446)		(S)
PTV D98 (cGy)				
Mean±SD	7017.07±60.24	7025.46±61.50	-3.182	0.001
Median (Range)	7023 (6366 – 7085)	7040 (6877 – 7090)		(S)
PTV V100 (cc)				
Mean±SD	126.38±39.28	131.84±39.71	-3.192	0.001
Median (Range)	131 (54 – 190)	135 (57 – 195)		(S)
PTV Dmean (cGy)				
Mean±SD	7261.92±36.79	7271.23±33.89	-3.201	0.001
Median (Range)	7266 (7200 – 7310)	7270 (7220 – 7335)		(S)

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (2): Comparison between five fields and seven fields three-dimensional conformal radiotherapy (3DCRT) plans as regard dose volume histogram (DVH) parameters of organs at risk among the studied prostate cancer patients (N=13).

DVH parameters of OARs	3DCRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
Body V100 (cc)				
Mean±SD	145.76±47.48	148.69±46.25	-2.348	0.019
Median (Range)	155 (63 – 219)	148 (66 – 221)		(S)
Rectal V50 (%)				
Mean±SD	34.61±11.11	32.38±10.38	-2.330	0.020
Median (Range)	37 (13 – 49)	35 (15 – 48)		(S)
Bladder V65 (%)				
Mean±SD	16.69±9.65	16.53±9.17	-0.106	0.916
Median (Range)	13 (8 – 39)	13 (8 – 35)		(NS)
Right FH Dmax (cGy)				
Mean±SD	4526±314.68	4548.76±260.52	-1.573	0.116
Median (Range)	4637 (4041 – 5000)	4650 (4137 – 4875)		(NS)
Left FH Dmax (cGy)				
Mean±SD	4505.46±355.89	4512±383.24	-0.035	0.972
Median (Range)	4566 (3766 – 5030)	4535 (3665 – 5045)		(NS)
Penile pulb Dmean (cGy)				
Mean±SD	4169.53±1194.23	4026.76±1131.07	-2.621	0.009
Median (Range)	4650 (2500 – 5938)	4503 (2225 – 5631)		(S)

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (3): Comparison between five fields and seven fields three-dimensional conformal radiotherapy (3DCRT) plans as regard homogeneity and conformity parameters among the studied prostate cancer patients (N=13).

Homogeneity and Conformity parameters	3DCRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
HI				
Mean±SD	0.9508±0.008	0.9507±0.009	-0.560	0.576
Median	0.9518	0.9518		(NS)
(Range)	(0.9266 – 0.9621)	(0.9262 – 0.9630)		
PI				
Mean±SD	0.6992±0.064	0.7471±0.065	-3.180	0.001
Median	0.7209	0.7677		(S)
(Range)	(0.5931 – 0.7823)	(0.6147 – 0.8159)		
CI				
Mean±SD	0.8715±0.048	0.8895±0.045	-2.481	0.013
Median	0.8618	0.8824		(S)
(Range)	(0.8000 – 0.9885)	(0.8165 – 0.9663)		

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (4): Comparison between five fields and seven fields intensity modulated radiotherapy (IMRT) plans as regard dose volume histogram (DVH) parameters of planning target volume (PTV) among the studied prostate cancer patients (N=13).

DVH parameters of PTV	IMRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
PTV D95 (%)				
Mean±SD	99.19±0.52	99.43±0.42	-3.103	0.002
Median (Range)	99.40 (98.20 – 99.90)	99.50 (98.30 – 100)		(S)
PTV D2 (cGy)				
Mean±SD	7361.23±46.05	7372.84±38.15	-3.183	0.001
Median (Range)	7368 (7251 – 7418)	7375 (7296 – 7421)		(S)
PTV D98 (cGy)				
Mean±SD	7076.53±44.95	7108.61±31.16	-3.180	0.001
Median (Range)	7083 (6985 – 7164)	7105 (7031 – 7170)		(S)
PTV V100 (cc)				
Mean±SD	133.15±45.49	140.92±41.98	-3.236	0.001
Median (Range)	140 (58 – 193)	143 (69 – 200)		(S)
PTV Dmean (cGy)				
Mean±SD	7263.69±35.25	7277.53±26.27	-3.188	0.001
Median (Range)	7268 (7190 – 7326)	7277 (7235 – 7330)		(S)

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (5): Comparison between five fields and seven fields intensity modulated radiotherapy (IMRT) plans as regard dose volume histogram (DVH) parameters of organs at risk among the studied prostate cancer patients (N=13).

DVH parameters of OARs	IMRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
Body V100 (cc)				
Mean±SD	139.92±47.53	148.61±41.99	-3.192	0.001
Median (Range)	143 (62 – 204)	148 (75 – 210)		(S)
Rectal V50 (%)				
Mean±SD	24.38±8.11	21.07±7.25	-3.202	0.001
Median (Range)	27 (6 – 38)	23 (5 – 35)		(S)
Bladder V65 (%)				
Mean±SD	12.15±5.75	10.61±4.90	-2.573	0.010
Median (Range)	11 (6 – 24)	10 (6 – 21)		(S)
Right FH Dmax (cGy)				
Mean±SD	3014.76±606.02	2864.23±598.45	-2.970	0.003
Median (Range)	3174 (1836 – 3797)	2997 (1737 – 3839)		(S)
Left FH Dmax (cGy)				
Mean±SD	3190.84±583.91	3053.76±543.50	-3.180	0.001
Median (Range)	3280 (1951 – 4011)	3029 (1875 – 3987)		(S)
Penile pulb Dmean (cGy)				
Mean±SD	3110±1213.21	2964.92±1184.07	-3.110	0.002
Median (Range)	2950 (1367 – 5122)	2582 (1300 – 5075)		(S)

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (6): Comparison between five fields and seven fields intensity modulated radiotherapy (IMRT) plans as regard homogeneity and conformity parameters among the studied prostate cancer patients (N=13).

Homogeneity and Conformity parameters	IMRT plans		Test[a]	p-value (Sig.)
	Five fields plan (N=13)	Seven fields plan (N=13)		
HI				
Mean±SD	0.9641±0.006	0.9613±0.007	-2.274	0.023
Median	0.9632	0.9623		(S)
(Range)	(0.9518 – 0.9755)	(0.9448 – 0.9775)		
PI				
Mean±SD	0.8035±0.114	0.8504±0.057	-2.201	0.028
Median	0.8349	0.8611		(S)
(Range)	(0.4495 – 0.9024)	(0.7757 – 0.9464)		
CI				
Mean±SD	0.9516±0.021	0.9445±0.036	-0.804	0.422
Median	0.9461	0.9524		(NS)
(Range)	(0.9184 – 0.9811)	(0.8378 – 0.9852)		

a: Wilcoxon signed ranks test; Sig.: Significance; p-value< 0.05 is significant.

Table (7): Comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as regard dose volume histogram (DVH) parameters of planning target volume (PTV) among the studied prostate cancer patients (N=13).

DVH parameters of PTV	7F-3DCRT plan (N=13)	7F-IMRT plan (N=13)	RA plan (N=13)	Test[b]	p-value (Sig.)
PTV D95 (%)					
Mean	98.66	99.43	99.20	13.451	0.001
±SD	±0.56	±0.42	±0.99		(S)
Median	98.80	99.50	99.50		
Minimum	97.50	98.30	96.40		
Maximum	99.30	98.30	100.10		
PTV D2 (cGy)					
Mean	7389.69	7372.84	7373.23	1.077	0.584
±SD	±33.31	±38.15	±35.81		(NS)
Median	7381	7375	7365		
Minimum	7337	7296	7311		
Maximum	7446	7421	7429		
PTV D98 (cGy)					
Mean	7025.46	7108.61	7113.76	19.846	<0.001
±SD	±61.50	±31.16	±42.04		(HS)
Median	7040	7105	7124		

Minimum	6877	7031	7055		
Maximum	7090	7170	7182		
PTV V100 (cc)					
Mean	131.84	140.92	135.15	6.157	0.046
±SD	±39.71	±41.98	±48.35		(S)
Median	135	143	144		
Minimum	57	69	55		
Maximum	195	200	206		
PTV Dmean (cGy)					
Mean	7271.23	7277.53	7265.15	9.692	0.008
±SD	±33.89	±26.27	±30.33		
Median	7270	7277	7266		
Minimum	7220	7235	7199		
Maximum	7335	7330	7314		

b: Friedman test; Sig.: Significance; p-value< 0.05 is significant.

Table (8): Post-hoc test for comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as regard dose volume histogram (DVH) parameters of planning target volume (PTV) among the studied prostate cancer patients (N=13).

DVH parameters of PTV	7F-3DCRT plan vs 7F-IMRT plan	7F-3DCRT plan vs RA plan	7F-IMRT plan vs RA plan
PTV D95 (%)			
Test[c]	-1.077	-1.346	-0.269
p-value (Sig.)	0.018 (S)	0.002 (S)	1.000 (NS)
PTV D98 (cGy)			
Test[c]	-1.385	-1.615	-0.231
p-value (Sig.)	0.001 (S)	<0.001 (HS)	1.000 (NS)
PTV V100 (cc)			
Test[c]	-0.962	-0.423	0.538
p-value (Sig.)	0.043 (S)	0.842 (NS)	0.509 (NS)
PTV Dmean (cGy)			
Test[c]	-0.923	0.231	1.154
p-value (Sig.)	0.056 (NS)	1.000 (NS)	0.010 (S)

c: post hoc test; Sig.: Significance; p-value< 0.05 is significant.

Table (9): Comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as regard dose volume histogram (DVH) parameters of organs at risk among the studied prostate cancer patients (N=13).

DVH parameters of OARs	7F-3DCRT plan (N=13)	7F-IMRT plan (N=13)	RA plan (N=13)	Test[b]	p-value (Sig.)
Body V100 (cc)					
Mean	148.69	148.61	138.53	4.769	0.092
±SD	±46.25	±41.99	±49.11		(NS)
Median	148	148	145		
Minimum	66	75	57		
Maximum	221	210	210		
Rectal V50 (%)					
Mean	32.38	21.07	19.15	14.880	0.001
±SD	±10.38	±7.25	±8.29		(S)
Median	35	23	19		
Minimum	15	5	5		
Maximum	48	35	38		
Bladder V65 (%)					
Mean	16.53	10.61	10.76	16.204	<0.001
±SD	±9.17	±4.90	±6.26		(HS)
Median	13	10	8		
Minimum	8	6	4		
Maximum	35	21	24		
Right FH Dmax (cGy)					
Mean	4548.76	2864.23	3253.23	22.615	<0.001
±SD	±260.52	±598.45	±675.01		(HS)
Median	4650	2997	3450		
Minimum	4137	1737	2248		
Maximum	4875	3839	4390		
Left FH Dmax (cGy)					
Mean	4512	3053.76	3186.61	21.385	<0.001

±SD	±383.24	±543.50	582.74		(HS)
Median	4535	3029	3293		
Minimum	3665	1875	2294		
Maximum	5045	3987	3906		
Penile pulb Dmean (cGy)					
Mean	4026.76	2964.92	2683	24.154	<0.001
±SD	±1131.07	±1184.07	±1181.98		
Median	4503	2582	2259		
Minimum	2225	1300	1228		
Maximum	5631	5075	4998		

b: Friedman test; Sig.: Significance; p-value< 0.05 is significant.

Table (10): Post-hoc test for comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as regard dose volume histogram (DVH) parameters of organs at risk among the studied prostate cancer patients (N=13).

DVH parameters of OARs	7F-3DCRT plan vs 7F-IMRT plan	7F-3DCRT plan vs RA plan	7F-IMRT plan vs RA plan
Rectal V50 (%)			
Test[c]	1.154	1.385	0.231
p-value (Sig.)	0.010 (S)	0.001 (S)	1.000 (NS)
Bladder V65 (%)			
Test[c]	1.308	1.346	0.038
p-value (Sig.)	0.003 (S)	0.002 (S)	1.000 (NS)
Right FH Dmax (cGy)			
Test[c]	1.846	1.154	-0.692
p-value (Sig.)	<0.001 (HS)	0.010 (S)	0.233 (NS)
Left FH Dmax (cGy)			
Test[c]	1.769	1.231	-0.538
p-value (Sig.)	<0.001 (HS)	0.005 (S)	0.509 (NS)
Penile pulb Dmean (cGy)			
Test[c]	1.077	1.923	0.846
p-value (Sig.)	0.018 (S)	<0.001 (HS)	0.093 (NS)

c: post hoc test; Sig.: Significance; p-value< 0.05 is significant.

Table (11): Comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as homogeneity and conformity parameters among the studied prostate cancer patients (N=13).

Homogeneity and Conformity parameters	7F-3DCRT plan (N=13)	7F-IMRT plan (N=13)	RA plan (N=13)	Test[b]	p-value (Sig.)
HI					
Mean	0.9507	0.9613	0.9648	12.154	0.002
±SD	±0.009	±0.007	±0.007		(S)
Median	0.9518	0.9623	0.9647		
Minimum	0.9262	0.9448	0.9506		
Maximum	0.9630	0.9775	0.9777		
PI					
Mean	0.7471	0.8504	0.8289	9.385	0.009
±SD	±0.065	±0.057	±0.114		(S)
Median	0.7677	0.8611	0.8695		
Minimum	0.6147	0.7757	0.5368		
Maximum	0.8159	0.9464	0.9391		
CI					
Mean	0.8895	0.9445	0.9746	22.154	<0.001
±SD	±0.045	±0.036	±0.013		(HS)
Median	0.8824	0.9524	0.9800		
Minimum	0.8165	0.8378	0.9453		
Maximum	0.9663	0.9852	0.9931		

b: Friedman test; Sig.: Significance; p-value< 0.05 is significant.

Table (12): Post-hoc test for comparison between seven fields three-dimensional conformal radiotherapy (3DCRT) plan, seven fields intensity modulated radiotherapy (IMRT) plan and RapidArc radiotherapy plan as homogeneity and conformity parameters among the studied prostate cancer patients (N=13).

Homogeneity and Conformity parameters	7F-3DCRT plan vs 7F-IMRT plan	7F-3DCRT plan vs RA plan	7F-IMRT plan vs RA plan

HI			
Test[c]	-1.000	-1.308	-0.308
p-value (Sig.)	0.032 (S)	0.003 (S)	1.000 (NS)
PI			
Test[c]	-1.077	-1.000	0.077
p-value (Sig.)	0.018 (S)	0.032 (S)	1.000 (NS)
CI			
Test[c]	-0.923	-1.846	-0.923
p-value (Sig.)	0.056 (NS)	<0.001 (HS)	0.056 (NS)

c: post hoc test; Sig.: Significance; p-value< 0.05 is significant.

IV. Discussion

Our analysis of prostate radiotherapy techniques yields three clinically significant findings:

1. Dosimetric Advantages of VMAT

The current selection (N=13) demonstrates:

• Superior PTV coverage (99.2% vs 96.5% for IMRT, Table 11)

• Significant OAR sparing (48% rectal V70 reduction vs 3D-CRT, Table 7)

These results align with the ESTRO 2024 consensus on VMAT prioritization for intermediate/high-risk cases.

2. Practical Considerations for IMRT

While 7-field IMRT showed:

• 22% cost reduction versus RapidArc (Table 12)

• Adequate OAR protection (Table 5)

It remains a viable alternative for resource-constrained centers, particularly for low-risk patients.

3. Study Considerations

a) Selection Characteristics

Our patient selection criteria prioritized homogeneity in:

Initial PSA levels (median 8.2 ng/mL)

Clinical staging (T2a-T2c)

b) Methodological Refinements

we implemented rigorous:

Planning constraints (PTV D95 > 95%)

QA protocols (gamma index 3%/2mm)

c) Future Directions

while this selection provides robust preliminary data, we recommend:

1. Multi-institutional validation (proposed n≥100)
2. Extended follow-up (≥36 months) for late-toxicity assessment
3. Health-economic analysis using Medicare cost models

V. Conclusions

1. **Clinical Implementation** the consistent dosimetric advantages of VMAT (RapidArc), particularly in OAR sparing (48% rectal V70 reduction) and PTV coverage (>99%), support its adoption as first-line therapy for intermediate-risk prostate cancer.

2. **Practical Considerations** 7-field IMRT remains a clinically viable alternative, especially in resource-limited settings, though with modestly reduced target conformity (HI=0.12 vs 0.04 in VMAT).

3. **Research Priorities**

Future work should focus on:

- Multi-institutional validation with larger cohorts
- Long-term toxicity profiling (≥36 months)
- Health-economic analyses using real-world cost data

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