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Review Article

# Literature Review on IMRT and VMAT for Prostate Cancer

Bhoj Gautam, PhD

Department of Radiation Oncology, Sacred Heart Hospital, Allentown, Pennsylvania 18102, USA

**Abstract**

Volumetric intensity-modulated arc therapy (VMAT) is gaining popularity to treat the prostate cancer. The main aim of this article is to review the current literature on VMAT and intensity modulated radiation therapy (IMRT) planning for prostate cancer, and highlights several factors which can influence the dosimetric results.

**Keywords**: Prostate Cancer; VMAT; IMRT; Treatment planning

**Peer Reviewers**: Ho Lin, PhD, Department of Life Sciences, National Chung Hsing University, Taiwan;Sharad S. Singhal, PhD, Department of Diabetes and Metabolic Disease Research, Beckman Research Institute, United States

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***Correspondence to**: Bhoj Gautam, Department of Radiation Oncology, Sacred Heart Hospital, Allentown, Pennsylvania 18102, USA

Email: gautam_099@yahoo.com

## Introduction

External beam radiation therapy (EBRT) is considered to be one of the options to treat the prostate cancer. Due to advanced development in EBRT such as volumetric modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT), it is possible to deliver conformal dose to the target while minimizing dose to the organs at risk (OAR). The VMAT can deliver modulated radiation beam with simultaneous adjustment of dose rate, gantry speed, and multi leaf collimator (MLC) field aperture [1]. In IMRT, radiation beam is either divided into smaller segments of differing MLC shape such as in the case of static IMRT or modulated by continuously moving MLC such as in the case of dynamic IMRT [1, 2]. A number of studies have reported the use of VMAT and IMRT for the prostate cancer. The purpose of this study is to review the current literature on VMAT and IMRT for prostate cancer. A literature search was conducted using PubMed and Google Scholar with keywords "prostate cancer", "IMRT", and "VMAT".

## Literature Review

Several authors have reported planning studies on VMAT

vs. IMRT for prostate cancer. Palma *et al.* [3] compared the IMRT with constant dose rate (cdr)-VMAT and variable-dose rate (vdr)-VMAT for 10 prostate cancer patients. It was reported that, in comparison to the IMRT, the vdr-VMAT technique produced more favorable dose distributions and reduced number of monitor units (MUs). Zhang *et al.* [4] compared the VMAT with IMRT for 11 prostate cancer patients, and reported that the VMAT technique was better at sparing rectal wall, with a reduction of beam on time by up to 55% while maintaining dosimetric results compared to that of IMRT. Kjaer-Kristoffersen *et al.* [5] performed the dosimetric study on 8 prostate cancer patients, and the study showed that the VMAT technique produced better or equal sparing of the critical structure than the IMRT, with higher MUs in the IMRT plans. Similarly, Hardcastle *et al.* [6] reported reductions in rectal doses for all 10 prostate cancer patients using VMAT, with significant reduction in MUs and delivery time when compared to the IMRT. **Table 1** shows the average treatment delivery times found among various prostate cancer treatment planning studies.

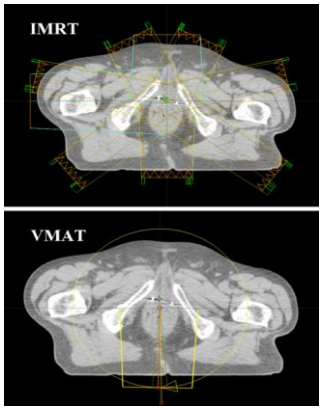


**Figure 1** An example of beam set up for IMRT (top) and VMAT (bottom)

In another planning study by Ost *et al.* [7], dosimetric comparison was done between the VMAT and IMRT plans for 12 prostate cancer patients with an objective of dose escalation to the intraprostatic lesion. Ost *et al.* [7] concluded that the VMAT allowed for dose escalation to the IPL with better sparing of the rectum than the IMRT. Kopp *et al.* [8] compared the VMAT with IMRT for 292 prostate cancer patients, and reported that the VMAT was superior to the IMRT, especially for the critical structures, without compromising coverage to the planning target volume (PTV). However, few other treatment planning studies have shown that the IMRT could result superior dosimetric results than the VMAT, especially for the OARs. For instance, Yoo *et al.* [9] compared the IMRT with VMAT for 10 prostate cancer patients, and reported that the IMRT was better in sparing bladder, rectum, and small bowel than the VMAT when PTV included prostate, seminal vesicles, and lymph nodes. Wolff *et al.* [10] compared the VMAT with IMRT and found lower mean dose to the rectum in the IMRT plans than in the VMAT plans. In contrast, Rao *et al.* [11] showed that the VMAT was better at normal tissue sparing as compared with the IMRT. Tsai *et al.* [12] study on 12 prostate cancer patients showed that VMAT had only slight dosimetric advantage over the IMRT. Shaffer *et al.* [13] investigate the simultaneous integrated boost (SIB) technique in VMAT and IMRT plans for 10 prostate cases, and the study concluded that the VMAT was able to boost more of the clinical target volume (CTV) than IMRT with doses to the OARs within acceptable limit.

Several planning studies have also investigated the planning techniques in VMAT using either single arc (SA), double arc (DA), partial SA (p-SA), or partial-DA (p-DA). Recently, Rana *et al.* [14] showed that both the DA and p-DA techniques produced more conformal and less heterogeneous plans, with better sparing of rectum and bladder when compared with the SA technique. Rana *et al.* [14] also showed that the p- DA technique was better than the standard DA (with full gantry rotation) in terms of sparing of the rectum and bladder, but no clear dosimetric differences was observed between these two techniques for dose conformity and target heterogeneity. In another study by Rana *et al.* [15], it was reported that, for the identical

PTV coverage, p-SA was better than the standard SA (one full gantry rotation) resulting lower doses to the rectum and bladder, but for the higher femoral head dose and integral dose in the p-SA plans. The radiobiological study [16] comparing SA and DA techniques for prostate cancer showed that DA resulted lower normal tissue complication probability (NTCP) whereas the NTCP for other structures (bladder and femoral heads) and tumor control probability (TCP) for prostate tumor were comparable. The current literature on planning studies comparing SA and DA has also shown some inconsistence in terms of dosimetric results. For instance, Sze *et al.* [17] reported that the SA technique resulted smaller volume of bladder exposed at 70Gy and 20Gy, whereas Rana *et al.* [14] showed that SA always produced higher doses to the bladder. Wolff *et al.* [10] reported no significant difference in dosimetric quality between DA and SA techniques. Guckenberger *et al.* [18] showed that SA technique yielded lower dose to the rectum.

The contradictory dosimetric results among treatment planning studies are mainly attributed to variations in terms of treatment planning systems (TPS), beam parameters, treatment delivery, and plan optimization techniques. For instance, commercial TPS from different vendors employ different dose calculation and optimization algorithms, and the prostate treatment plans optimized and/or calculated by different algorithms will typically result different dosimetric results as shown by Rana *et al.* [19]. This is mainly due to difference in beam modeling approach within the dose calculation and plan optimization algorithms. Furthermore, since prostate cancer involves heterogeneities such as femoral heads along the radiation beam path, dosimetric results may vary depending upon the heterogeneity corrections employed within the dose calculation algorithms [19-22]. Thus, planning studies utilizing different dose calculation algorithms may produce different dosimetric results for the prostate cancer.

**Table 1** Summary of average treatment delivery times between IMRT and VMAT in various treatment planning studies of prostate cancer

| | Average treatment delivery times | |
|---|---|---|
| References | VMAT | IMRT |
| Sze *et al.* [17] | 1.30 min (Single Arc); 2.78 min (Double Arc) | 4.80 min (7 field) |
| Zhang *et al.* [4] | 1 min (Single Arc) | 5 min (5 field) |
| Hardcastle *et al.* [6] | 1.3 min (Single Arc) | 4.5 min (5 field) |
| Ost *et al.* [7] | 1.95 min (Single Arc) | 4.82 min (7 field); 3.85 min (5 field) |
| Yoo *et al.* [9] | 1.5 min (Single Arc) 3.1 min (Double Arc) | 8.1 min (9 field); 4.9 min (7 field) |
| Guckenberger *et al.* [18] | 2.08 min (Single Arc); 3.87 min (Double Arc) | 5.82 min (7 field) |
| Shaffer *et al.* [13] | 3.7 min (Single Arc) | 9.6 min (9 field) |
| Tsai *et al.* [12] | 2.6 min (Single Arc) | 3.8 min (5 field) |
| Rao *et al.* [11] | 2.2 min (Single Arc) | 8.1 min (7 field) |
| Wolf *et al.* [10] | 1.8 min (Single Arc); 3.7 min (Double Arc) | 6 min (7 field) |

The number of arcs used in VMAT can also influence in the dosimetric results of prostate cancer. The SA VMAT plan has less control points when compared to the DA VMAT plan, and more control points typically result higher degree of modulation producing better plan quality. However, it is essential to note that highly modulated treatment plans are associated with longer plan optimization, and this could be a hindrance if the limited planning resources are available in the clinic. Additionally, the design of treatment machine head can also affect the OAR dose due to variability in secondary collimator transmission and scatter radiation of the machines from different vendors.

Another factor that can influence on the dosimetric results is the experience of a treatment planner, especially during the plan optimization process. As a part of plan optimization process, a treatment planner has to select the dose constraints and objectives for the target volume and each OAR. The dosimetric results as a result of plan optimization are dependent on the optimization parameters and method of optimization. Hence, it is possible that the difference in plan optimization techniques may have contributed to the inconsistencies in the findings among different planning studies.

Treatment outcome of patients is very important to ensure the safety of treatment technique. For IMRT, it was reported that high radiation dose delivered to small volume of rectum is the primary cause of toxicities or late rectal bleeding. For rectum, studies recommend that relative volume receiving 70 Gy ($V_{70Gy}$) must be less than 20% of total rectal volume [23], whereas the dose constraint for the bladder [24] is $V_{70Gy}$ must be less than 35%. Treatment outcome with long term follow up for patients treated with VMAT is yet to be reported.

# Conclusion

Despite several dosimetric differences among planning studies, the common agreement was that VMAT requires less number of MUs and shorter delivery time when compared to the IMRT. In comparison to the DA, the SA was more efficient in terms of beam delivery and MUs. The partial arc technique could provide dosimetric advantage over standard arc technique (with full gantry rotation) for the prostate cancer.

# Abbreviations

CDR = Constant dose rate
CTV = Clinical target volume
DA = Double Arc
EBRT = External beam radiation therapy
IMRT = Intensity modulated radiation therapy
MLC = Multi leaf collimator
MUs = Monitor Units
NTCP = normal tissue complication probability
OAR = Organs at risk
p-DA = Partial-Double Arc
p-SA = Partial-Single Arc
PTV = Planning target volume
SA = Single Arc
SIB = Simultaneous integrated boost
TCP = Tumor control probability
TPS = Treatment planning systems
$V_{70Gy}$ = Relative volume of the structure receiving 70 Gy
VDR = Variable-dose rate
VMAT = Volumetric Intensity-Modulated Arc Therapy

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