A comparative study of the dosimetric impact on IMRT planning with VMAT plans using a varying number of arcs in prostate cancer

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Abstract.
A study has been carried out to explore the impact by varying the number of arcs and beam arrangement on dose distributions. For this volumetric modulated arc therapy and 7-field, intensity-modulated radiation therapy plans have use for prostate cancer cases. The eclipse treatment planning system version13.6 (Varian California, USA) was used to assess dosimetry data for 20 patients. All patients received intensity-modulated radiation therapy and volumetric modulated arc therapy plans with a varying number of arcs. 6MV X-Ray photon beam energy uses for each patient. Statistical plan assessments have been carried out for various dosimetric parameters to evaluate execution efficiency. There were no statistically significant changes (p>0.05) observed in D98% dose coverage while D2%, conformity index, homogeneity index, monitor unit, and treatment delivery time were showing statistically significant changes (p<0.05). In contrast to six arc volumetric modulated arc therapy and 7 field-intensity-modulated radiation therapy plans, Single arc volumetric modulated arc therapy plans showed 23.28% and 25.96% less monitor unit, 97.52% and 137.53% less treatment delivery time. It concluded that using a higher number of arcs in volumetric modulated arc therapy plans for prostate cancer improves plan efficiency. The four arc volumetric modulated arc therapy plans appeared to provide a reasonable trade-off between enhanced treatment delivery time and high treatment plan quality.

Keywords: Arcs, Intensity-modulated radiation therapy, Prostate cancer, Radiation therapy Volumetric modulated arc therapy.

1. Introduction.
Prostate cancer is the second most frequent cancer in men and one of the important causes of death worldwide [1]. From all the modalities used for treating cancer, radiation therapy seems to be a significant feature for effective treatment for prostatic cancer. With the introduction of modern radiation therapy techniques such as intensity-modulated radiation therapy and volumetric modulated arc therapy, radiation side effects during treatment are reduces [2]. Therefore intensity-modulated radiation therapy and volumetric modulated arc therapy were much more necessary in treatments of prostatic cancer [3]. Intensity-modulated radiation therapy is highly effective for treating target structures with irregular contour lines [4].
Intensity-modulated radiation therapy is useful in treating target structures with abnormal contours while reducing exposures to healthy tissue structures [5]. Compared to static intensity-modulated radiation therapy, volumetric modulated arc therapy (a form of rotational intensity-modulated radiation therapy) required less treatment time and monitor units. Treatment preparation priorities produce strategies that strike the best balance between goal coverage and organ at risk sparing [6, 7].

Many considerations, including the number of beam arcs, may be changed in the quest for better volumetric modulated arc therapy plans. From study shows that volumetric modulated arc therapy with dual arcs is associated with improved plan efficiency over a single arc and increased agreement between predicted and measured doses. Also, beam-on time is less than 3 minutes [8, 9]. Volumetric modulated arc therapy optimization algorithm aims to optimize gantry speed and asserted that using more than two arcs, which could result in longer treatment delivery times and more modulation opportunities, would result in even higher plan quality improvements [10, 11].

As a result, this study aimed to investigate the relationship between the number of arcs, target dose homogeneity, dose conformity, and doses to healthy tissue in prostate cancer treatment. Our investigation was complete as follows:

A) Twenty patients with prostatic cancer and lymph node patients who had been previously treated in our department were chosen, at random. A variable number of arcs volumetric modulated arc therapy and 7 field-intensity-modulated radiation therapy plans were developed for each patient.

B) The arc structure configuration and plan efficiency of volumetric modulated arc therapy (varying number of arcs) and 7 field-intensity-modulated arc therapies were compared [12].

2. Materials and methods
2.1. Patient Characteristics
For this study, data from 20 patients with prostate cancer in various stages (T1, T2a, b, and T3a) (Table – 1) who had previously been treated with traditional, IMRT, and VMAT techniques at our institution were randomly selected. All patients were placed supine on a dedicated flat table couch with a custom thermoplastic immobilization cast. In the supine position, images of 3 mm slice thickness were obtained from the iliac crest to 8 cm below the ischial tuberosity using a computed tomography scan (Siemens Somatom Concept AS+, Siemens Healthcare, USA). Before the CT scan, every patient was advised to clear their urinary bladder and rectum for 1 to 1.5 hours [13].

Table 1 – Characteristics of the patients

| No. of Patient | Gleason Score | PSA (ng/ml) | Stage | Age |
|----------------|---------------|-------------|-------|-----|
| 1              | 3+4= 7        | 25.0        | T2b   | 60  |
| 2              | 4+4=8         | 67.0        | T2b   | 56  |
| 3              | 4+5=9         | 45.0        | T2b   | 67  |
| 4              | 4+4=8         | 34.0        | T1a   | 65  |
| 5              | 3+4=7         | 26.0        | T2b   | 65  |
| 6              | 4+5=9         | 13.0        | T2b   | 68  |
| 7              | 4+4=8         | 5.46        | T1    | 70  |
| 8              | 4+4=8         | 22.5        | T2b   | 65  |
| 9              | 4+5=9         | 15.34       | T2b   | 54  |
| 10             | 4+4=8         | 24.8        | T2a   | 56  |
| 11             | 3+4= 7        | 5.67        | T2b   | 68  |
| 12             | 4+4=8         | 6.86        | T2b   | 65  |
| 13             | 4+5=9         | 14.67       | T2b   | 65  |
| 14             | 4+4=8         | 12.56       | T2b   | 56  |
| 15             | 3+4=7         | 16.78       | T1    | 69  |
| 16             | 4+5=9         | 52.34       | T2b   | 70  |
| 17             | 4+4=8         | 24.67       | T2b   | 67  |
| 18             | 4+4=8         | 12.34       | T2a   | 65  |
| 19             | 4+5=9         | 16.45       | T2a   | 64  |
| 20             | 4+4=8         | 15.67       | T2b   | 61  |
2.2. Contouring target and Organ at Risk structures

According to the international commission on radiation units and measurements studies no. 50 and 62 [14,15], a radiation oncologist contoured all target structures such as gross tumor volume (GTV), clinical target volume (CTV), planning target volume (PTV), and organ at risk structures (OARs). The prostate was contoured as CTV1 and the pelvic lymph node as CTV2. To ensure that the recommended dosage is administered to CTV and to reduce the risk of treatment failure due to variability in the positioning setup and movement of the organ during actual treatment delivery, a 7mm margin is provided to CTV2 and an 8mm margin is given to CTV1 in all directions except posterior, where the margin was 5mm. The entire amount, including CTV and margin, is deducted. PTV refers to the total volume, which includes CTV and margin. As organs at risk, the entire rectum, urinary bladder, penile bulb, and bilateral femoral heads were contoured [16, 17].

2.3. Dose prescription

The prescribed dose to the pelvic lymph node was 50.4 Gy in 28 fractions and an additional plan of 19.6 Gy in 11 fractions was given to the prostate cancer.

2.4. Treatment planning

The medical accelerator True Beam STx (Varian Medical Systems, Palo Alto, CA, USA) was used in this study. VMAT plans were produced for all 20 patients using co-planar 6MV X-Ray photon beam energy (PBE), with single, dual, four, and six arcs plan optimized using progressive resolution optimizer, eclipse treatment planning station version 13.6. (Varian Medical System, Palo alto, CA, USA). With a 5° angle difference between individual arcs, the collimator angle was chosen. With a grid size of 0.25 cm, the dose distribution was determined using the anisotropic analytical algorithm. In addition to primary optimization and dose computation, a 'continue previous optimization' approach was used to improve the objective and enhance the target dose homogeneity [18, 19]. An additional Co-planar 6MV X-Ray PBE IMRT plan was generated for individual patients. In the IMRT plan, 7fields co-planar beam was used with gantry angle 0°, 51°, 102°, 153°, 204°, 255° and 306° in which collimator angle was kept at 0° for all beam arrangement. The dose-volume location of those objectives was repeatedly modified during the plan optimization process, to keep them at a constant distance from the healthy tissue dose-volume histogram (DVH) line that's posturized during plan optimization. All plans were generated as per our institutional approach. Concisely, the urinary bladder, rectum and femoral heads were each constrained ultimately lower to their particular tolerance levels [20].

2.5. Plan Assessment

The DVH of an individual patient was used to determine the quantitative evaluation of IMRT and VMAT plans. PTV structures were examined for D98%, D2%, conformity index (CI), and homogeneity index (HI). The ratio of the volume of PTV covered with a 98 % isodose line to the total volume of PTV was used to calculate the conformity index.

The ratio of the difference between D2% and D98% percent to dose obtained by 50% of the PTV was used to calculate the homogeneity index (D50 %). A homogeneous plan is defined as an HI value close to zero.

The radiation therapy oncology group 0815 [19] was used to measure the doses to OARs. D15%, D20%, D25%, D35%, and D50% rectum doses, D15%, D25%, D35%, and D50%, bladder doses, D5%, D25%, and D50% femoral head doses, as well as mean penile bulb doses, were studied. For statistical evaluation of the plans, IBM SPSS version 24 was used to see which of the evaluated factors improved significantly by using more arcs, with a p<0.005 considered statistically important. Dosimetric approval was obtained for the one, two, four, and six arcs VMAT, as well as the 7F-IMRT plans. On the True Beam STx, the plan delivery time and monitor unit for single, two, four, and six arc VMAT and 7F-IMRT plans were calculated [21].

3. Results

The description of the quantitative study of the DVH of the aim and OARs structures for the VMAT and IMRT plans is shown in Table 2, Figures 1, 2, 3, and 4. The target dose homogeneity, conformity index, monitor unit, treatment delivery time, and OAR sparing all improved as the number of arcs was
When arcs were raised from fourth to sixth, the importance of the enhancements declined. When arcs were increased from four to six, no statistically significant differences were observed.

### Table 2: Comparison of the doses received by PTV and OARs in dose distribution compared to VMAT with variable arcs and IMRT.

| Techniques          | VMAT Technique | IMRT Technique | P-value |
|---------------------|----------------|----------------|---------|
|                     | Number of arcs |                |         |
|                     | One            | Two            | Four    | Six    |
| **Target (PTV)**    |                |                |         |        |
| $D_{98\%}$ (Gy)     | 68.53±1.05     | 68.88±1.11     | 69.23±1.02 | 69.25±1.15 | 68.39±1.14 | 0.068       |
| $D_{2\%}$ (Gy)      | 76.3±1.15      | 76.09±1.09     | 75.67±1.12 | 75.6±1.03  | 76.23±1.05  | <0.05**     |
| Conformity index (CI) | 1.08±0.03      | 1.07±0.05      | 1.05±0.08 | 1.01±0.09 | 1.10±0.05   | <0.05**     |
| Homogeneity Index (HI) | 0.161±0.07    | 0.19±0.05      | 0.22±0.05 | 0.24±0.09 | 0.157±0.05  | <0.05**     |
| Monitor Unit (MU)   | 516±34         | 576±40         | 628±48  | 652±39  | 670±42      | <0.05**     |
| **Treatment Delivery** |              |                |         |        |
| Time (minute)       | 2.59±0.32      | 3.59±0.5       | 5.38±1.19 | 7.52±1.83 | 14±2.35     | <0.05**     |
| **Organ at risk (OAR)** |             |                |         |        |
| Rectum              |                |                |         |        |
| $D_{15}$            | 58.17±3.9      | 54.25±5.7      | 52.31±4.5 | 51.61±7.5 | 59.21±6.1   | 0.078       |
| $D_{20}$            | 50.25±5.3      | 46.54±4.8      | 44.88±5.2 | 44.26±4.5 | 49.13±5.8   | 0.036**     |
| $D_{25}$            | 44.32±7.8      | 41.02±5.7      | 39.57±5.9 | 39.03±5.5 | 43.85±6.8   | 0.028**     |
| $D_{35}$            | 40.85±5.8      | 37.85±5.3      | 36.50±7.1 | 35.99±6.7 | 40.01±7.2   | 0.021***    |
| $D_{50}$            | 34.1±6.3       | 31.58±3.8      | 30.46±5.3 | 30.04±4.9 | 35.89±5.5   | 0.018***    |
| Bladder             |                |                |         |        |
| $D_{15}$            | 58.59±6.7      | 54.27±6.2      | 51.55±5.6 | 50.72±5.6 | 63.59±7.8   | 0.028**     |
| $D_{25}$            | 47.24±5.4      | 43.74±6.8      | 41.55±5.1 | 40.93±3.8 | 50.32±7.6   | 0.04**      |
| $D_{35}$            | 41.57±5.7      | 38.49±5.8      | 36.59±7.8 | 36.04±4.5 | 46.89±7.1   | 0.024***    |
| $D_{50}$            | 34.86±6.3      | 32.28±3.9      | 30.71±7.2 | 30.24±4.2 | 35.31±7.6   | 0.022***    |
| Femur (right side)  |                |                |         |        |
| $D_{3}$             | 37.59±3.8      | 34.58±4.5      | 33.19±4.8 | 30.52±4.7 | 39.54±2.7   | <0.05**     |
| $D_{25}$            | 26.66±3.5      | 24.52±4.1      | 23.53±4.8 | 23.05±4.6 | 31.58±2.1   | <0.05**     |
| $D_{50}$            | 22.69±3.9      | 20.87±4.9      | 20.03±4.2 | 19.62±4.7 | 28.98±2.9   | <0.05**     |
| Femur (left side)   |                |                |         |        |
| $D_{3}$             | 37.66±3.5      | 34.67±4.9      | 33.62±4.5 | 32.94±4.5 | 39.51±2.7   | <0.05**     |
| $D_{25}$            | 27.40±3.3      | 25.21±4.5      | 24.45±4.7 | 23.96±4.7 | 32.61±2.3   | <0.05**     |
| $D_{50}$            | 20.79±3.5      | 19.12±4.7      | 18.54±4.7 | 18.17±4.5 | 28.15±2.8   | <0.05**     |
| Penile bulb         |                |                |         |        |
| Mean                | 33.83±5.2      | 34.75±5.8      | 33.52±5.1 | 32.98±5.4 | 39.7±5.5    | 0.075       |

P<0.05, ***- Highly significant; **- Medium significant

### 3.1. Dose to Target

Table 2, Figures 1 and 2, shows that there were no statistically significant changes ($p>0.05$) observed in $D_{98\%}$ dose coverage. $D_{2\%}$, CI, HI, monitor unit and treatment delivery time were showing statistically significant changes ($p<0.05$). The higher number of arcs showing better CI and HI coverage in comparison with less number of arcs. There were statistically significant changes ($p<0.05$) in the homogeneity of the PTV dose. The CI of PTV for the six arcs VMAT plans was significantly higher in comparison with
others. 7F-IMRT was showing a higher number of MUs in comparison with VMAT plans and six arcs VMAT plans were demonstrating a higher number of MUs in comparison with two and four arcs. Single arc VMAT plane was showing 23.28% and 25.96% less MU, 97.52% and 137.53% less treatment delivery time in comparison with six arc VMAT and 7F-IMRT plan respectively.

3.2. Dose to Organ at Risk
Quantitative comparison of OAR doses among the VMAT and 7F-IMRT plans are shown in Table 2, Figures 3 and 4. Dose constraints for healthy tissue structures were all within the tolerance limits. Increasing the number of arcs, leads to an improving dose sparing to healthy tissue structures. There were statistically significant (p<0.05) changes observed for the urinary bladder D15%, D20%, D35%, and D50%. There were statistically significant (p<0.05) changes observed for the rectum D20%, D25%, D35%, and D50%, while there were no statistically significant (p>0.05), changes observed for D15%. There were statistically significant (p<0.05) changes observed for the femur D5%, D25%, and D50%. No statistically significant (p>0.05) changes were observed for the penile bulb. Except for the mean dose of a penile bulb, there were significant statistical changes observed (p<0.05) in the comparison between single arc, dual arc, four arcs, six arcs and 7F-IMRT.
Discussion
This study aimed to see how the number of arcs affected the dose distribution of VMAT and 7F-IMRT plans for prostate cancer. Isodose lines, DVH, CI, and HI for PTV coverage, mean and volume doses to OARs were used to assess the consistency of treatment planning.

It was investigated which VMAT arc configuration provided better plan efficiency in prostatic cancer patients in this systematic research. When the number of arcs in a VMAT plan was increased from one to six, there was a strong trend toward improved safe tissue sparing and more standardized target dose coverage. The greatest benefits were observed when the arcs numbers were increased from two to four, which is commonly used in clinical practice [22].

Even if the improvements were smaller, using more than four arcs allowed for even more improvement. We assume that the dosimetric changes are sufficient to be clinically significant, based on the available literature on OARs toxicity [23]. Increased treatment delivery time and a small increase in monitor unit were needed to achieve the improved plan efficiency, all of which were clinically acceptable. In terms of treatment delivery time, our study found that four arc VMAT plans could be delivered in less than 4.5–5.5 minutes, while Lechner et al. found that single arc smart arc plans could take more than 6 minutes [24]. Due to elemental characteristics within the TPS, statistics concerning the use of multiple arcs from other vendor-based TPS systems cannot be estimated to rapid arc. Multiple arc VMAT, according to Guckenberger et al., improved plan efficiency over single arc VMAT at the cost of longer treatment delivery times, more monitor units, and a wider spread of low doses [25].

When more than two arcs are uses in VMAT plans, Tol et al. have quantitatively shown that plan consistency improves. They concluded that the four arc plans provide a reasonable balance of increased delivery time and enhanced plan efficiency. The use of non-coplanar beam structures is expected to improve plan efficiency even further. As the number of arcs grew, plan efficiency improved at the cost of treatment delivery times and monitor units. Because of the variations in target structures, target complication, prescription dosage, and treatment modality direct comparisons between different investigations are difficult [26].

Conclusion
According to the quantitative study of statistics (Table 2), plan efficiency improved when higher numbers of arcs were used in VMAT plans for prostate cancer. In contrast to VMAT plans, IMRT had a lower response rate. The four arc VMAT plans seemed to be a good compromise between faster delivery and high treatment plan efficiency.

Acknowledgments
The Authors thank Mr. Sulabh Singh (Medical Physicist), Department of Radiotherapy, Capitol cancer hospital, Jalandhar, India for support during the research period.
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