

Comparative dosimetric analysis of IMRT and VMAT (RapidArc) in brain, head and neck, breast and prostate malignancies

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Original Article

Abstract

Purpose: Intensity modulated radiotherapy (IMRT) in the recent past has established itself as a gold standard for organs at risk (OAR) sparing, target coverage and dose conformity. With the advent of a rotational treatment technology such as volumetric modulated arc therapy (VMAT), an inter-comparison is warranted to address the advantages and disadvantages of each technique. **Methods:** Twenty patients were selected retrospectively from our patient database. Sites included were brain, head and neck, chest wall, and prostate, with five patients for each site. For all the selected patients, both the IMRT and VMAT treatment plans were generated. Plan comparison was done in terms of OAR dose, dose homogeneity index (HI), dose conformity index (CI), target coverage, low isodose volumes, monitor units (MUs), and treatment time. **Results:** The VMAT showed better sparing of “parotids minus planning target volume (PTV)”, spinal cord and head of femur as compared to the IMRT. The lung V₄₀ for VMAT was lower, whereas the lung V₁₀, contralateral lung mean dose, contralateral breast mean dose and mean body dose were lower with IMRT for chest wall cases. Both the VMAT and IMRT achieved comparable HI except for the brain site, where IMRT scored over VMAT. The CI achieved by the IMRT and VMAT were similar except for chest wall cases, whereas the VMAT achieved better dose conformity. The target coverage was comparable with both the plans. The VMAT clearly scored over IMRT in terms of average MUs (486 versus 812 respectively) and average treatment time (2.54 minutes versus 5.54 minutes) per treatment session. **Conclusion:** The VMAT (RapidArc) has a potential to generate treatment plans for various anatomical sites which are comparable with the corresponding IMRT plans in terms of OAR sparing and plan quality parameters. The VMAT significantly reduces treatment time as compared to the IMRT, thus VMAT can increase the throughput of a busy radiotherapy department.

Keywords: VMAT; RapidArc; IMRT; Plan Comparison

Introduction

The very basic aim of radiotherapy is to deliver a tumoricidal dose to the target and at the same time spare the normal structures in the vicinity. To achieve this goal, technology is driving radiotherapy in future and that is how we have moved from three dimensional conformal radiotherapy (3D-CRT) to intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT). IMRT in the recent past has established itself as a gold standard for organs at risk (OAR) sparing, target coverage and dose conformity. With the advent of VMAT (Rapid Arc), an inter-comparison is needed to address the advantages and disadvantages of each technique.

IMRT uses multi-leaf collimator (MLC) modulated beam delivery planned with inverse treatment planning system (TPS). IMRT treatments can be delivered by two methods. The first technique is called “Step and Shoot IMRT” in which, gantry is static at a specific angle and MLCs are static in a specific position when the beam is turned on. The second technique is called “Dynamic IMRT” in which the gantry is static at a specific angle and MLCs continuously change their positions when the beam is turned on. The classical approach to IMRT planning involves optimization of fluence maps followed by an MLC leaf sequencing step. Several investigators have proposed directly optimizing leaf positions and segment weights.^{1,2} In the recent past, a new technology in

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radiotherapy called Rapid Arc - a type of VMAT technique has emerged. VMAT dose optimization employs aperture based method that incorporates MLC leaf positions and MU weights as optimization parameters. VMAT is a rotational radiotherapy modality with dynamic MLC and varying dose rate. VMAT planning process optimises gantry rotation speed, dose rate, and MLC positions to create a plan. It delivers radiation with multiple superimposing coplanar or non-coplanar arcs. Hence, during the delivery of a VMAT plan, gantry continuously rotates, dose rate keeps changing and MLCs continuously move when the beam is on.

We performed a comparison of VMAT (RapidArc) treatment plans with IMRT plans in terms of OAR doses and various dose parameters which reflect the quality and delivery efficiency of a plan. Various studies have shown that VMAT may provide plan improvements for cervix and intracranial tumors.^{3, 4, 5, 6} Several authors have also compared VMAT with tomotherapy.^{7, 8, 9} Alvarez-Moret *et al.*¹⁰ evaluated VMAT with Oncentra Master Plan and compared with IMRT for the treatment of head and neck cancer.

A multi-institutional comparison of VMAT vs. IMRT for head-and-neck cancer showed superior VMAT plan quality parameters.¹¹ Stieler *et al.*¹² compared IMRT with VMAT in head and neck cancers and validated the dosimetric accuracy of VMAT. Johnston *et al.*¹³ compared simultaneous integrated boost plans generated with IMRT and VMAT for head and neck cancers and concluded that VMAT achieves comparable plans to IMRT and uses two-thirds less monitor units. Palma *et al.*¹⁴ compared VMAT with IMRT for prostate cancer and found more favourable dose distributions with VMAT. Quan *et al.*¹⁵ reported superior plan quality as well as delivery efficiency of VMAT in prostate cancer. Zhang *et al.*¹⁶ showed that VMAT reduces beam on time by up to 55% as compared to five-field IMRT for prostate cancer. Rao *et al.*¹⁷ compared VMAT with IMRT for prostate, head-neck, and lung cancer cases. They reported 40% reduction in treatment time with VMAT while maintaining the plan quality for all the sites studied. Ali *et al.*¹⁸ have compared VMAT with IMRT for pancreatic cancer and Rana *et al.*¹⁹ have compared proton therapy with VMAT and IMRT for lung cancer. Oliver *et al.*²⁰ have studied Rapid Arc and IMRT on virtual phantoms.

For the present study, sites which were considered for plan comparison include brain, head and neck, chest wall, and prostate malignancies. These cases were selected to represent a large range of clinical and anatomical complexity. The primary aim of this study is to compare the plan quality and treatment efficiency parameters of IMRT and VMAT (Rapid Arc) for different anatomical sites in order to weigh the benefits and drawbacks of each of these two high precision radiotherapy techniques.

Methods and Materials

A total of 20 patients including brain, head and neck, chest wall and prostate malignancies were selected with five patients of each anatomical site. Both VMAT and IMRT plans were generated for each patient based on identical anatomic contours, dose prescriptions and planning objectives.

Anatomical site brain included World Health Organization (WHO) grade III and IV glioma (post-surgery). Head and neck site included base of tongue and hypo-pharyngeal malignancies. Chest wall site included post-mastectomy patients requiring adjuvant radiation therapy. Pelvis site included high risk prostate cancer patients requiring radiation therapy to prostate, seminal vesicles and pelvic nodes. **Table 1** demonstrates the dose prescription used for treatment planning.

All the patients were immobilized in orfit thermoplastic cast (orfit with vacloc for chest wall and prostate cases). Planning CT scan was done using Siemens dual source 64 slice computed tomography (CT) simulator (Siemens Medical Solutions, Malvern, PA, United States) and 3.0 mm CT slices were obtained. CT images were imported in DICOM format to Eclipse TPS, version 8.9 (Varian Medical Systems, Palo Alto, CA, United States). Target volumes and OARs were contoured. For each patient, both the IMRT and VMAT treatment planning was done using Eclipse TPS (version 8.9) and plans were computed using Anisotropic Analytic Algorithm (AAA) dose calculation algorithm. The grid size utilized for dose calculation was 0.25 cm.

TABLE 1: Radiation dose prescription for four different anatomical sites.

| S. No | Site | Target | Dose prescribed (cGy) | Dose per fraction (cGy) | Number of fractions |
|-------|--|-----------------|-----------------------|-------------------------|---------------------|
| 1 | Brain (Sequential boost) | PTV 1 (Phase 1) | 4500 | 180 | 25 |
| | | PTV 2 (Phase 2) | 1440 | 180 | 8 |
| 2 | Head and Neck(simultaneous integrated boost) | PTV-66 | 6600 | 200 | 33 |
| | | PTV-59.4 | 5940 | 180 | |
| | | PTV-54 | 5400 | 163.6 | |
| 3 | Chest wall | PTV-50 | 5000 | 200 | 25 |
| 4 | Prostate (Sequential boost) | PTV 1 (Phase 1) | 5000 | 200 | 25 |
| | | PTV 2 (Phase 2) | 600 | 200 | 3 |
| | | PTV 3 (Phase 3) | 2200 | 200 | 11 |

Abbreviation: PTV = planning target volume

Multiple planners were involved in plan generation. During the process of plan optimization, planners adjusted the dose volume constraints in order to respect the OAR dose tolerance. **Table 2** shows the dose volume constraints of OAR utilised for treatment planning. **Table 3** shows beam geometry of IMRT and VMAT (Rapid Arc) plans for the four sites. All the VMAT (Rapid Arc) plans were performed with 2 coplanar arcs. Vieillot *et al.*²¹ compared double arc with single arc VMAT (Rapid Arc) in anal canal cancer and found that double arc plans resulted in superior target coverage, dose homogeneity and conformity. Similar comparison study between single and double arc Rapid Arc plans was done by Kumar *et al.*²² for head and neck cancers.

TABLE 2: Dose volume constraints utilised for radiotherapy planning.

| S. No. | Organ at Risk (OAR) | Dose maximum (cGy) | Volume | Dose (cGy) |
|--------|----------------------------|--------------------|---------|------------|
| 1 | Bain Stem ²³ | <5400 | 1-10 cc | <5900 |
| 2 | Lens ²⁴ | <700 | - | - |
| 3 | Retina ²⁴ | <4500 | - | - |
| 4 | Optic nerve ²³ | <5500 | - | - |
| 5 | Optic chiasm ²³ | <5500 | - | - |
| 6 | Parotid ²³ | - | Mean | <2500 |
| 7 | Spinal cord ²⁴ | <4500 | - | - |
| 8 | Cochlea ²³ | - | Mean | <4500 |
| 9 | Ipsilateral lung | - | <20% | 2000 |
| 10 | Heart ²³ | - | Mean | <2600 |
| 11 | Contralateral breast | - | Mean | <300 |
| 12 | Rectum ^{23, 24} | - | <20% | 7000 |
| | | | <35% | 6500 |
| 13 | Bladder ²³ | - | <35% | 7000 |
| | | | <50% | 6500 |
| 14 | Femoral head ²⁴ | - | <5% | 5000 |
| 15 | Bowel ²⁴ | - | <100 cc | 4000 |

TABLE 3: Geometry of treatment fields/arcs.

| Site | IMRT field geometry | VMAT (Rapid Arc) trajectory |
|---------------|--|---|
| Brain | 5 fields, coplanar. | 2 coplanar arcs with 360 degree arc trajectory. |
| Head and Neck | 7 fields, coplanar. | 2 coplanar arcs with 360 degree arc trajectory. |
| Breast | 2 Tangents with multiple sub-fields (field in field) | 2 coplanar partial arcs with arc trajectory: a) 225 degree to 45 degree clock wise and 45 degree to 225 degree counter clock wise for right chest wall. b) 315 degree to 135 degree clock wise and 135 degree to 315 degree counter clock wise for left chest wall. |
| | | 2 coplanar arcs with 360 degree arc trajectory. |
| Prostate | 7 fields, coplanar. | 2 coplanar arcs with 360 degree arc trajectory. |

For chest wall patients, forward IMRT (field in field technique) planning was done. For cases with multiple targets, either sequential boost or simultaneous integrated boost (SIB) scheme of dose prescription was utilised. VMAT planning optimization algorithm is based on Progressive Resolution Optimizer (PRO) which uses direct aperture optimization. Because of physical limitations, upper limits were imposed on MLC leaf motion (2.5 cm/sec), dose rate (600 MU/min) and gantry speed (5.5 degree/sec) to ensure deliverability. The linear accelerator used to deliver IMRT and VMAT plans was Varian Clinac 2100 iX (Varian Medical Systems, Palo Alto, CA, United States). Both the IMRT and VMAT plans were normalized such that at least 95% of target volume received at least 95% of prescription dose. Site specific plan comparison was performed between IMRT and VMAT plans.

Plan comparison parameters

- OAR Dose:** Mean doses were used for parallel structures and maximum doses were used for serial structures. Additional dose parameters used for plan comparison were: V₁₀, V₂₀ and V₄₀ (percentage volume of organ receiving respective dose in Gy) for lung and heart, V₇₀, V₆₅ and V₄₀ for rectum and urinary bladder, V₅₀ for head of femur and V₄₀ for bowel.
- Dose Homogeneity Index:** I_{MAX}/I_R, where I_{MAX} is the maximum isodose inside the target volume and I_R is the reference isodose (95% isodose line). Ideally, it should be less than 2. Lower homogeneity index value indicates a more homogeneous target dose.^{25,26}
- Dose Conformity Index:** V_R/V_T, where V_R is the reference isodose volume (volume of 95% isodose line in cubic centimetres) and V_T is the volume of the target (in cubic centimetres). Ideally it should lie between 0.9 and 2.0.²⁷
- Target Coverage:** It is defined in terms of percentage volume of target covered by prescription isodose line (95%).
- Low Isodose Volumes:** 10%, 20%, 50% and 70% isodose volumes (in cubic centimetres) were studied to compare low dose volumes in IMRT and VMAT.
- Monitor Units:** Number of monitor units required to deliver daily prescription dose.
- Treatment Time (beam on to beam off):** Time in minutes (measured by a timer) required to deliver daily prescription dose including mode up time between fields (IMRT) and arcs (VMAT).

Results

- For brain site (**Table 4**), the OAR dose sparing was better with IMRT whereas, mean whole brain dose was lower for VMAT. **Figure 1(A and B)** shows Dose Volume Histogram (DVH) showing comparison of OAR doses and PTV coverage, respectively.

TABLE 4: Brain OAR doses (cGy) and plan quality parameters [Mean and standard deviation (SD)].

| | OAR | IMRT (cGy) | | VMAT (cGy) | | |
|------------------------|--------------------------|---------------|--------|------------|--------|-----|
| | | Mean | SD | Mean | SD | |
| | Lens (max dose) | 327 | 194 | 327.2 | 158 | |
| | Retina (max dose) | 1397 | 1268 | 1395.3 | 958 | |
| | Optic nerve (max dose) | 2096.5 | 1808 | 2189.5 | 1527 | |
| | Optic chiasma (max dose) | 4396 | 1278 | 4570.8 | 908 | |
| | Brain stem (max dose) | 5530.8 | 372 | 5618.6 | 289 | |
| | Whole brain (mean dose) | 3741.8 | 738 | 3720.5 | 731 | |
| DOSE PARAMETERS | | | | | | |
| Brain | Mean body dose | 1265.98 | 205 | 1258.52 | 185 | |
| | PTV max isodose | 103.3% | 1.14 | 105.22% | 0.56 | |
| | Homogeneity index | 1.052 | 0.01 | 1.07 | 0.007 | |
| | Conformity index | 1.22 | 0.29 | 1.034 | 0.26 | |
| | Target coverage | 99.74% | 0.47 | 99.10% | 1.7 | |
| | Low isodose Volume(cc) | 10% | 2012.4 | 224.9 | 2123.2 | 254 |
| | | 20% | 1616.4 | 229.9 | 1712.4 | 204 |
| | | 50% | 974.4 | 242 | 902 | 249 |
| | | 70% | 666.2 | 204 | 623.4 | 180 |
| | | Monitor units | 458 | 88 | 354 | 113 |
| | Treatment time (minutes) | 2.478 | 0.11 | 2.286 | 0.37 | |

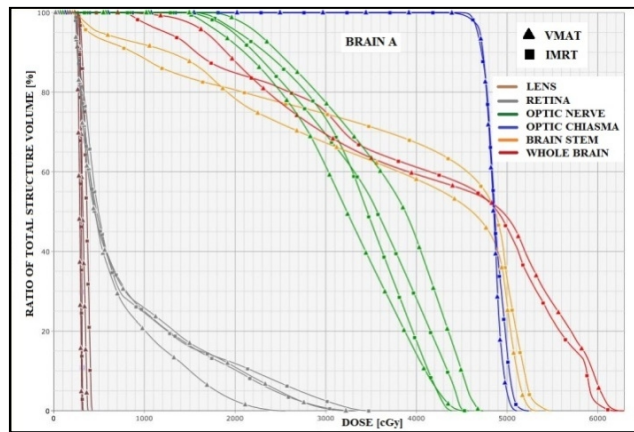


FIG. 1(A): Dose volume histogram of a brain case showing comparison of OAR doses for VMAT and IMRT.

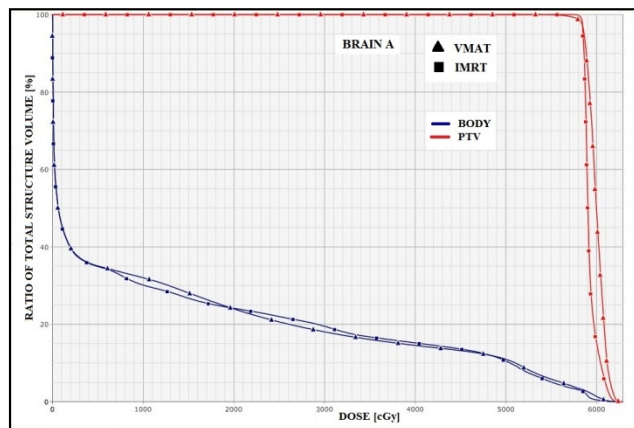


FIG. 1(B): Dose volume histogram of a brain case showing comparison of Body dose and PTV coverage for VMAT and IMRT.

b) For head and neck site (Table 5), OAR dose sparing was better with VMAT. Figure 2(B and C) shows DVH showing comparison of OAR doses and PTV coverage respectively.

TABLE 5: Head and neck OAR doses (cGy) and plan quality parameters [Mean and standard deviation (SD)].

| | OAR | IMRT (cGy) | | VMAT (cGy) | |
|-------------------------|--------------------------------|------------|-------|------------|-------|
| | | Mean | SD | Mean | SD |
| | Parotids (mean dose) | 2561.3 | 385 | 2178.9 | 591 |
| | Parotids minus PTV (mean dose) | 2187 | 180 | 1776.2 | 143 |
| | Spinal cord (max dose) | 4449.2 | 125 | 4185.6 | 50 |
| | Cochlea (mean dose) | 1790.6 | 1527 | 1670.5 | 937 |
| | Brain stem (max dose) | 4944.8 | 403 | 4932.8 | 236 |
| DOSE PARAMETERS | | | | | |
| Head and Neck | Mean body dose | 1477.7 | 529 | 1405.34 | 443 |
| | PTV max isodose | 106.5% | 1.35 | 105.48% | 0.71 |
| | Homogeneity index | 1.082 | 0.014 | 1.072 | 0.008 |
| | Conformity index | 1.237 | 0.37 | 1.11 | 0.2 |
| Target coverage | PTV 1 | 98.24 | 2.49 | 97.74 | 2.72 |
| | PTV 2 | 98.24 | 2.42 | 97.06 | 2.27 |
| | PTV 3 | 97.64 | 2.46 | 96.14 | 3.53 |
| Low isodose volume (cc) | 10% | 9065.6 | 5329 | 8889 | 5038 |
| | 20% | 7925.4 | 5624 | 7409.4 | 5439 |
| | 50% | 5093.2 | 5981 | 4725.8 | 5726 |
| | 70% | 3877.8 | 5805 | 3834.8 | 5563 |
| | Monitor units | 1228 | 143 | 465 | 46 |
| | Treatment time (minutes) | 7.132 | 0.79 | 2.89 | 0.07 |

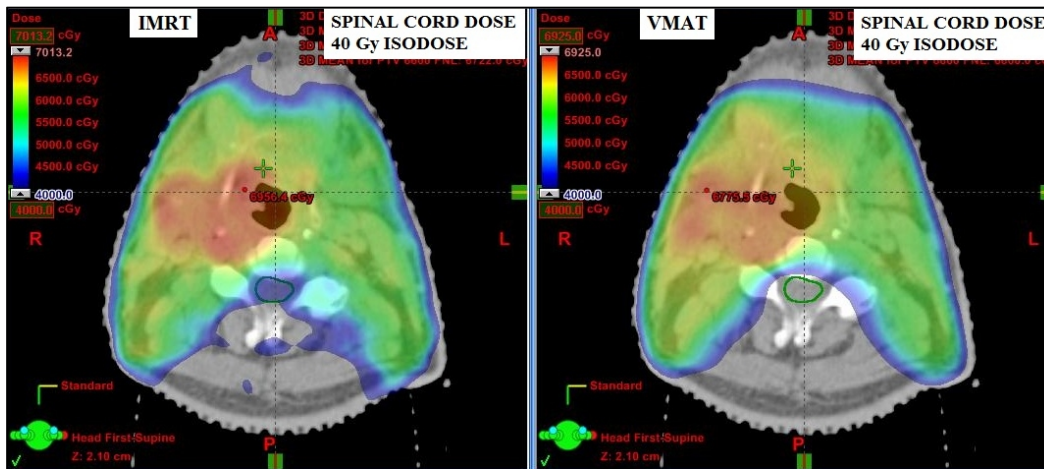


FIG. 2(A): Head and neck plan comparison: IMRT vs VMAT, axial planning CT image with dose in colour wash showing 40 Gy isodose volume.

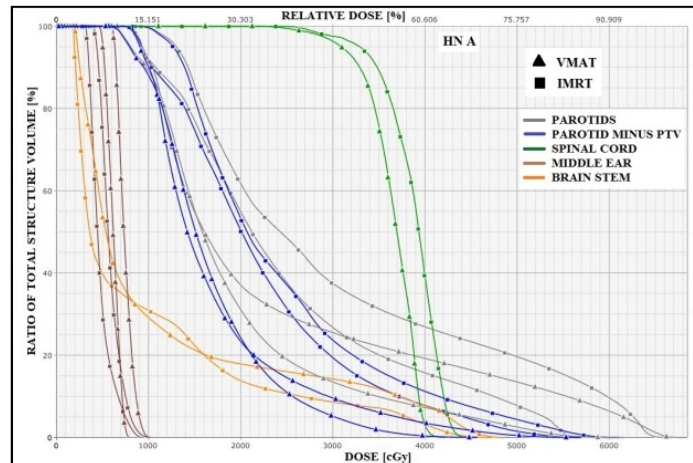


FIG. 2(B): Dose volume histogram of a head and neck case showing comparison of OAR doses for VMAT and IMRT.

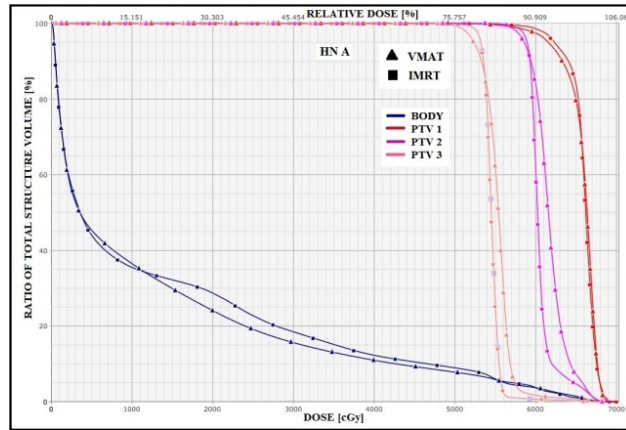


FIG. 2(C): Dose volume histogram of a head and neck case showing comparison of Body dose and PTV [PTV 1 (high risk), PTV 2 (intermediate risk) and PTV 3 (low risk)] coverage for VMAT and IMRT.

- c) For chest wall site (Table 6), mean ipsilateral lung dose and V_{10} (Figure 3A) were lower for IMRT whereas, V_{20} and V_{40} were lower for VMAT. Mean heart dose and V_{10} was lower with IMRT whereas, V_{20} and V_{40} (Figure 3B) were lower for VMAT. Opposite breast sparing was better with IMRT. Figure 3C shows DVH showing comparison of OAR doses.

TABLE 6: Chest wall OAR doses (cGy) and plan quality parameters [Mean and standard deviation (SD)].

| OAR (cGy) | | IMRT (cGy) | | VMAT (cGy) | |
|----------------------------------|----------|------------|-------|------------|-------|
| | | Mean | SD | Mean | SD |
| Ipsilateral lung | Mean | 1416 | 151 | 1433 | 166 |
| | V_{10} | 33.60% | 3.97 | 47% | 8.18 |
| | V_{20} | 26.60% | 3.84 | 22.80% | 3.76 |
| | V_{40} | 18.20% | 3.7 | 5.80% | 2.48 |
| Contralateral lung (mean dose) | | 41.6 | 14.4 | 443.2 | 53.5 |
| Heart | Mean | 854 | 455 | 1119.3 | 277 |
| | V_{10} | 18% | 10 | 37.60% | 15 |
| | V_{20} | 15% | 9.8 | 12.60% | 7.5 |
| | V_{40} | 11% | 8.7 | 1.38% | 1.4 |
| Contralateral breast (mean dose) | | 92.8 | 22 | 456.6 | 96 |
| DOSE PARAMETERS | | | | | |
| Mean body dose | | 593.12 | 61 | 724.52 | 39.9 |
| PTV max isodose | | 108.9% | 1.1 | 108.66% | 0.6 |
| Homogeneity index | | 1.144 | 0.008 | 1.14 | 0.007 |
| Conformity index | | 1.628 | 0.2 | 1.06 | 0.1 |
| Monitor units | | 452 | 23 | 592 | 55 |
| Treatment time (minutes) | | 4.44 | 0.5 | 2.146 | 0.07 |

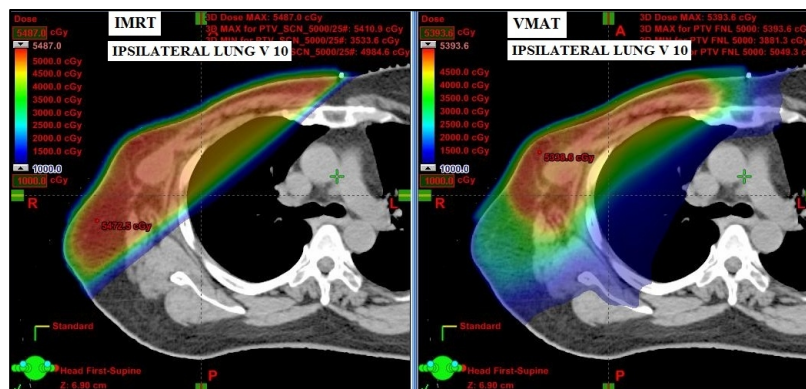


FIG. 3(A): Chest wall plan comparison: IMRT vs VMAT, axial planning CT image with dose in colour wash showing ipsilateral lung V_{10} (volume of lung receiving minimum dose of 10 Gy).

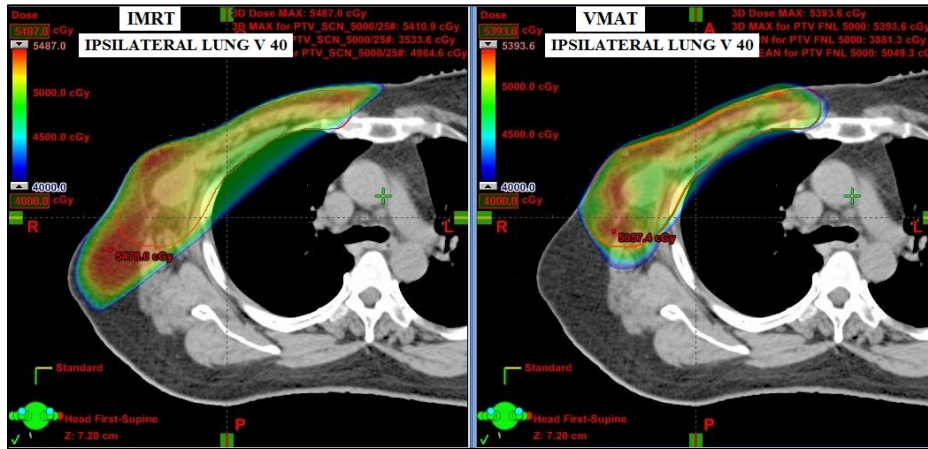


FIG. 3(B): Chest wall plan comparison: IMRT vs VMAT, axial planning CT image with dose in colour wash showing ipsilateral lung V₄₀ (volume of lung receiving minimum dose of 40 Gy).

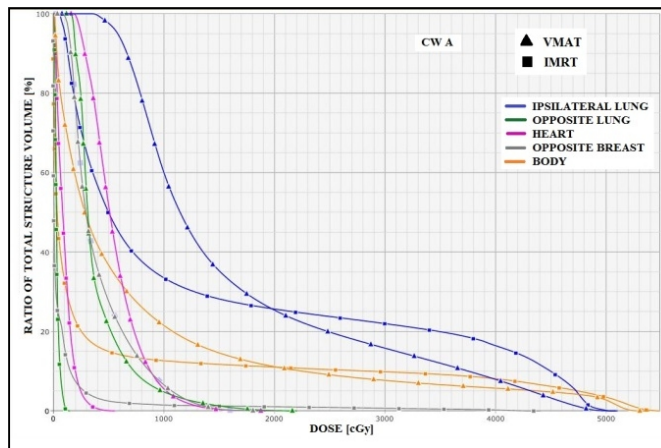


FIG. 3(C): Dose volume histogram of a Chest Wall case showing comparison of OAR doses for VMAT and IMRT.

- (d) For prostate site (Table 7), rectal sparing was better with VMAT whereas, bladder sparing was better with IMRT. Femoral head (Figure 4A) and bowel sparing was better with VMAT. Figure 4(B and C) shows DVH showing comparison of OAR doses and PTV coverage respectively.

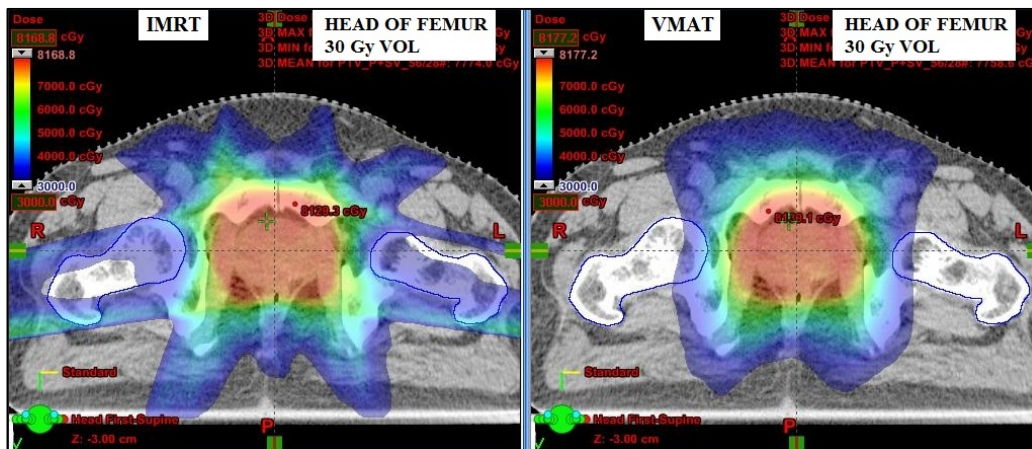


FIG. 4(A): Prostate plan comparison: IMRT vs VMAT, axial planning CT image with dose in colour wash showing 30 Gy volume and sparing of femoral heads.

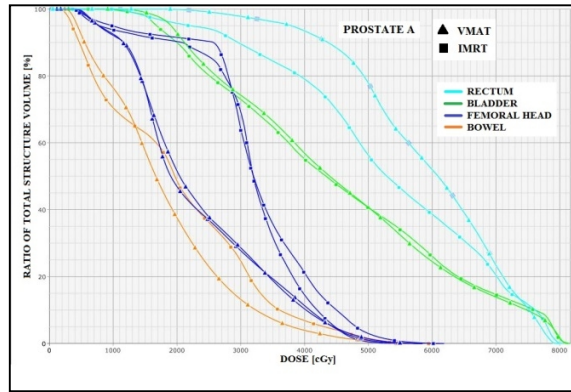


FIG. 4(B): Dose volume histogram of a Prostate case showing comparison of OAR doses for VMAT and IMRT.

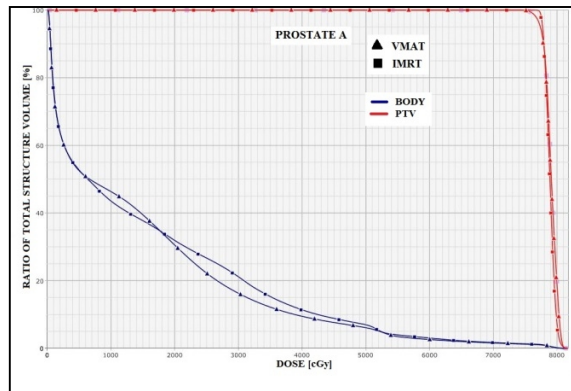


FIG. 4(C): Dose volume histogram of a Prostate case showing comparison of Body dose and PTV coverage for VMAT and IMRT.

TABLE 7: Prostate OAR doses (cGy) and plan quality parameters [Mean and standard deviation (SD)].

| | OAR (cGy) | IMRT (cGy) | | VMAT (cGy) | | |
|------------------------|--------------------------|-----------------|---------------|------------|-------------|------|
| | | Mean | SD | Mean | SD | |
| Prostate | Rectum | Mean | 5392.58 | 397 | 5297.6 | 636 |
| | | V ₇₀ | 26.60% | 7.19 | 24.20% | 4.9 |
| | | V ₆₅ | 34% | 7.3 | 33.20% | 6.6 |
| | | V ₄₀ | 75.20% | 10.3 | 73.80% | 18.4 |
| | Bladder | Mean | 4651.1 | 372 | 4818.2 | 415 |
| | | V ₇₀ | 17.60% | 5.7 | 18% | 6.7 |
| | | V ₆₅ | 21.60% | 6.9 | 22.60% | 8.2 |
| | Femoral head | Mean | 2976.94 | 426 | 2213 | 303 |
| | | V ₅₀ | 1.36% | 0.78 | 0.85% | 0.83 |
| | Bowel | Mean | 2142.18 | 535 | 2037.4 | 546 |
| | | V ₄₀ | 16% (249.4cc) | 125 | 14% (219cc) | 127 |
| | DOSE PARAMETERS | | | | | |
| | Mean body dose | 1286.76 | 268 | 1235.4 | 249 | |
| | PTV max isodose | 104.22% | 0.59 | 104.39% | 0.76 | |
| | Homogeneity index | 1.094 | 0.005 | 1.09 | 0.18 | |
| | Conformity index | 1.49 | 0.18 | 1.414 | 0.23 | |
| | Target coverage | 99.92% | 0.08 | 99.92% | .08 | |
| Low isodose volume(cc) | 10% | 11478.2 | 2559 | 11921.2 | 2652 | |
| | 20% | 8912.8 | 1818 | 8975 | 2000 | |
| | 50% | 2691.8 | 605 | 2373 | 424 | |
| | 70% | 761.8 | 326 | 702.4 | 275 | |
| | Monitor units | 1108 | 135 | 535 | 50 | |
| | Treatment time (minutes) | 8.11 | 0.5 | 2.876 | 0.01 | |

In summary, the plan quality and treatment efficiency parameter comparison shows:

- a) Mean body doses for brain, head and neck and prostate were lower with VMAT whereas, for chest wall cases, mean body dose was lower for IMRT.
- b) HI for head and neck, chest wall and prostate was better with VMAT whereas, it was better with IMRT for brain.
- c) CI was better for all the four sites with VMAT.
- d) Target coverage was better with IMRT for brain, head and neck whereas, it was similar to VMAT for prostate.
- e) Low isodose volumes – V_{10} and V_{20} for brain and prostate were lower for IMRT whereas, V_{50} and V_{70} were lower for VMAT. For head and neck, all the four low isodose volumes (V_{10} , V_{20} , V_{50} and V_{70}) were lower for VMAT.
- f) MUs required to deliver daily prescription dose for brain, head and neck and prostate were lower for VMAT whereas, for chest wall cases MUs required were lower for IMRT.
- g) Treatment time with VMAT was less for all the four sites studied as compared to IMRT.

Discussion

VMAT (RapidArc) is an advanced radiation treatment modality. It has a potential to generate treatment plans for various anatomical sites which are comparable with the corresponding IMRT plans in terms of OAR sparing, plan quality with better treatment efficiency. In the present study, VMAT plans were compared with IMRT plans. Various dose-volume parameters to assess OAR sparing were studied. Plan quality was assessed by comparing dose HI, CI, target coverage, low isodose volumes, monitor units and treatment time.

It was observed that for OAR sparing, VMAT is comparable to IMRT for most of the OARs; however VMAT scored over IMRT for “parotid minus PTV”, spinal cord and femoral head sparing. For chest wall cases, IMRT scored over VMAT for ipsilateral lung V_{10} , contralateral lung mean dose, contralateral breast mean dose and mean body dose, however VMAT scored over IMRT for ipsilateral lung V_{40} . The possible explanation for high 10 Gy isodose volume for VMAT is that the chest wall target is treated with a semi arc and the beam is on throughout the sweep of gantry hence increasing the exit dose through lung parenchyma. Whereas, since the IMRT plans for chest wall were all forward IMRT plans with modulation of intensity in the tangential fields (using sub-fields), only a small thickness of lung parenchyma was in the field, hence better V_{10} .

The reason for better V_{40} for VMAT is that since the dose distribution was more conformal for VMAT, 40 Gy isodose line was closer to the target contour, hence minimizing the volume of lung encompassed. VMAT (Rapid Arc) showed

higher 10% and 20% isodose volumes whereas, IMRT showed higher 50% and 70% isodose volumes for Brain and Prostate site. For Head and Neck site, all the isodose levels studied (10%, 20%, 50% and 70%) were higher for IMRT. Ekambaram *et al.*²⁸ analysed low dose level volumes in IMRT and 3D conformal radiotherapy.

For plan quality parameters, it was observed that VMAT and IMRT achieved almost similar dose maximum levels inside the PTV except for brain site, where IMRT scored over VMAT by achieving a lesser PTV dose maximum. Similarly, both the plans achieved comparable H.I except for brain site, where IMRT scored over VMAT because of lesser PTV dose max. C.I achieved by IMRT and VMAT were similar except for chest wall cases, where VMAT achieved better dose conformity. Target coverage was almost equally good with both the plans.

The most significant observation of this study was the difference in MUs and treatment time between the two modalities. VMAT clearly scored over IMRT in terms of MUs required to deliver daily the prescription dose. VMAT delivers significantly less MUs per treatment session as compared to IMRT. Treatment time (including mode up time) was significantly less with VMAT as compared to IMRT thereby increasing the throughput of the department. These results are in good agreement with the published literature.

The AAA calculation algorithm improves the accuracy of dose calculations over pencil beam algorithm and particular progress has been made with respect to the penumbra and low dose regions.²⁹ However, AAA dose calculation algorithm has some limitations when there is presence of tissue heterogeneity. In general, AAA over predicts the dose beyond low density regions and under predicts the dose distal to high density tissue. In the presence of tissue heterogeneity, there can be differences of up to 10.2% in lung with AAA calculation as compared to Monte Carlo calculations.³⁰ More recently, Acuros XB dose calculation algorithm has been introduced the results of which were found to agree better with Monte Carlo calculations as compared to AAA.^{30, 31, 32}

Conclusion

The dosimetric plan quality parameters of VMAT are comparable with IMRT plans. OAR sparing with VMAT is comparable with IMRT except for “parotid minus PTV”, spinal cord and head of femur, where VMAT proved itself better than IMRT. The most significant differences between VMAT and IMRT plans were the daily treatment time and monitor units per treatment session, where VMAT scored over IMRT. Reducing the daily treatment time decreases the chances of geographic miss due to organ motion and increases patient comfort and compliance.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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