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Dosimetric comparison of volumetric modulated arc therapy and intensity modulated radiation therapy for anal cancer

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Technical Note

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Abstract

Aim: Volumetric modulated arc therapy (VMAT), an extension of intensity modulated radiation therapy (IMRT), employs modifications in gantry rotation speed, machine dose rate and multi-leaf collimator motion to deliver a three-dimensional dose distribution. This study compared VMAT to IMRT for patients with anal carcinoma.

Materials and Methods: Sixteen patients previously treated with IMRT were retrospectively selected. Each patient received a total dose of 57·6–63·0 Gy in 1·8 Gy fractions. A single- or double-isocenter multi-arc VMAT treatment plan was generated using Eclipse RapidArc system with the same computed tomography image sets and optimisation constraints used for IMRT. Dose–volume histograms (DVHs) for planning target volumes (PTVs) and organs at risk (OARs), and monitor units (MUs) and beam on times (BOTs) were used for comparison.

Results: IMRT and VMAT plans showed insignificant differences in PTV homogeneity and conformity and sparing hips and bowel. VMAT required fewer mean MU and shorter BOT per plan (1,597 MU, 2·66 min) compared to IMRT (2,571 MU, 4·29 min) with $p < 0·0001$.

Conclusions: Fewer MU and shorter BOT for VMAT may decrease the damage from secondary radiation and treatment delivery uncertainty due to intra-fraction tumour motion, leading to higher machine throughput and improving patient comfort, with less treatment time.

Introduction

Anal cancer, which affects over 8,500 people each year in the United States,[1] is a disease in which the malignant cells are formed in the anal tissues. In general, three standard types of treatment are available for patients with anal cancer. Conventionally, patients with anal cancer are managed surgically via local resection or abdominoperineal resection. Chemotherapy, which uses cytotoxic drugs to stop the growth of cancer cells either by killing the cells or by stopping the cells from dividing, is also used for the treatment of anal cancer. Alternatively, patients wishing for an organ-preserving approach are managed with radiotherapy.[2–4]

The ultimate goal of radiation therapy is to deliver sufficient dose for planning target volume (PTV) coverage while limiting dose to the surrounding normal tissue and organs at risk (OARs). The introduction of intensity modulated radiation therapy (IMRT), which employs multi-leaf collimator motion to modulate the beam intensity, allows for highly conformal three-dimensional (3D) dose distributions. Compared to the conventional 3D conformal radiotherapy technique, the IMRT demonstrated the ability to achieve better PTV coverage while sparing the normal tissues.[5–7] Volumetric modulated arc therapy (VMAT) is an extension of IMRT which employs modifications in both gantry rotation speeds and machine dose rate in addition to multi-leaf collimator motion. VMAT allows delivering a 3D dose distribution in rotational mode with less treatment time than the conventional IMRT, thereby greatly increasing the efficiency of radiation delivery.

Anal cancer is well suited for IMRT or VMAT because OARs such as hips, bladder, and bowel can potentially be spared. However, limited dosimetric comparisons are available in literature with regard to the use of IMRT and VMAT for treating anal cancer. Mok et al.[8] demonstrated superior PTV coverage, dose homogeneity and conformity, lower OAR doses, shorter treatment time with VMAT, in comparison to IMRT. Using the Varian RapidArc system (Varian Medical Systems Inc., Palo Alto, CA, USA), Clivio et al.[9] demonstrated using VMAT improvements in OAR and healthy tissue sparing with PTV coverage similar to IMRT. Vieillot et al.[10] indicated equivalent PTV coverage between IMRT and VMAT, with better OAR sparing while having significant monitor unit (MU) and beam on time (BOT) reductions per fractions with VMAT. Stieler et al.[11] showed improved PTV coverage, similar homogeneity and normal tissue dose and a trend of inferior conformity with VMAT plans compared to IMRT. Having observed some variations in the previously reported results for

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Table 1. Dosimetric comparison of HI and CI for the PTV

	HI		CI	
	IMRT	VMAT	IMRT	VMAT
1	4·63%	3·55%	1·16	1·19
2	4·53%	4·66%	1·30	1·47
3	13·88%	11·14%	1·18	0·98
4	3·55%	5·43%	1·08	1·08
5	4·33%	6·27%	2·30	1·56
6	5·40%	6·77%	1·22	0·97
7	3·84%	6·47%	1·13	1·17
8	4·57%	5·45%	1·30	1·30
9	9·87%	7·21%	1·12	1·18
10	5·14%	6·01%	1·12	1·06
11	5·21%	7·39%	1·21	1·23
12	7·17%	9·62%	1·20	1·19
13	6·90%	7·00%	1·14	1·05
14	6·96%	6·07%	1·21	1·14
15	5·22%	4·90%	1·09	1·04
16	4·51%	4·39%	1·07	1·00
Mean Std.	5·98%	6·40%	1·24	1·16
	2·64%	1·91%	0·29	0·17
p Value	0·34		0·14	

Abbreviations: PTV, planning target volume; HI, homogeneity index; CI, conformity index; IMRT, intensity modulated radiation therapy; VMAT, volumetric modulated arc therapy.

Table 2. Dosimetric comparison of OAR doses for each plan

	Bladder (Gy)		Hips (Gy)		Bowel (Gy)	
	IMRT	VMAT	IMRT	VMAT	IMRT	VMAT
1	49·60	56·23	38·05	47·87	21·22	22·84
2	35·34	36·18	34·91	32·38	20·83	19·99
3	41·58	35·85	46·40	30·99	5·78	4·98
4	38·64	45·01	28·68	27·45	30·90	33·63
5	38·68	38·84	47·51	39·01	21·89	23·01
6	30·05	31·20	24·91	31·11	11·81	11·30
7	29·54	30·27	17·15	18·61	30·88	30·30
8	19·94	24·94	19·87	32·50	1·20	2·18
9	27·63	33·70	26·90	34·11	0·89	1·34
10	28·47	27·83	21·11	24·45	4·96	4·98
11	56·10	58·62	40·08	45·88	43·62	45·95
12	53·50	53·30	55·85	51·40	26·58	24·46
13	48·19	50·60	36·89	44·59	30·49	31·91
14	34·21	34·40	28·87	31·13	23·21	21·31
15	34·35	37·91	27·06	31·08	5·17	4·01
16	28·04	42·56	20·10	21·96	27·76	37·96
Mean Std.	37·12	39·84	32·15	34·22	19·20	20·01
	10·33	10·28	11·26	9·18	12·78	13·94
p Value	0·03		0·26		0·28	

Abbreviations: OAR, organ at risk; IMRT, intensity modulated radiation therapy; VMAT, volumetric modulated arc therapy.

dosimetric comparisons between VMAT and IMRT, the objective of the present study has been to dosimetrically compare VMAT and IMRT treatment plans among patients with anal carcinoma.

Materials and Methods

Sixteen patients with anal carcinoma previously treated with step-and-shoot IMRT were randomly and retrospectively selected for this study and the study was approved by the institutional review board. Each patient received a total dose of 57·6–63·0 Gy in 1·8 Gy fractions (1 patient received 57·6 Gy, 2 patients received 59·4 Gy, 1 patient received 61·2 Gy and 12 patients received 63·0 Gy). Patient computed tomography scans used for structure contouring were acquired using 2·5 mm slice thickness. For each patient, PTV and OAR were contoured by radiation oncologists. All IMRT plans used 6–9 treatment fields.

For each patient administered the IMRT plan, a corresponding single-isocenter double-arc or double-isocenter double-arc VMAT treatment plan was generated using Varian's Eclipse RapidArc treatment planning system. The same optimisation constraints used for the clinical IMRT treatment plans were used for the corresponding VMAT plans. All plans were normalised, so that 95% of the PTV received 100% of the prescribed dose. Cumulative dose–volume histograms (DVHs) for PTV and OAR (hips, bladder and bowel) were generated for dosimetric evaluations and comparisons. For efficiency comparison, the total MU and BOT per fraction were evaluated.

Results and Discussion

Dosimetric analyses of 16 IMRT and VMAT plans were performed and listed. All parameters were listed as mean values, standard deviations and *p* values determining statistical significance test. Both IMRT and VMAT plans were able to achieve similar PTV coverage and normal tissue sparing.

The homogeneity index (HI) = $(D_{5\%} - D_{95\%})/ D_{prescribed}$, and conformity index (CI) = $V_{D99\%}/ V_{PTV}$, were calculated for all plans. For IMRT, the mean HI was found to be 5·98%; whereas for VMAT, it was found to be 6·40%. The mean CI was found to be 1·24 and 1·16 for IMRT and VMAT, respectively. The differences in values for both HI and CI are statistically insignificant with *p* values of 0·34 and 0·14, respectively. The dosimetric comparisons of HI and CI for the PTV using IMRT and VMAT for all 16 plans are shown in Table 1.

Doses to normal tissue volumes showed similar mean values for VMAT compared to IMRT. The average mean bladder, hip and bowel doses were 37·12, 32·15 and 19·20 Gy for IMRT and 39·84, 34·22 and 20·01 Gy for VMAT, respectively, with *p* values of 0·03, 0·26 and 0·28, respectively. The dosimetric comparisons of IMRT and VMAT for all three OARs for all 16 plans are shown in Table 2. The VMAT required fewer mean total MU and shorter mean BOT per fraction (1597 MU, 2·66 min) when compared to IMRT (2571 MU, 4·29 min), with $p < 0·0001$ as shown in Table 3.

Our findings of similar PTV coverage for IMRT and VMAT are in agreement with Clivio et al.[9] and Vieillot et al.[10] but disagreed with Stieler et al.[11] and Mok et al.[8] who advocated superior PTV

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Table 3. Comparison of MU and treatment delivery times for each plan

	MU		Delivery times (min)	
	IMRT	VMAT	IMRT	VMAT
1	3,337	1,810	5·56	3·02
2	2,978	2,075	4·96	3·46
3	1,430	1,798	2·38	3·00
4	3,465	1,684	5·78	2·81
5	1,603	1,380	2·67	2·30
6	2,781	1,856	4·64	3·09
7	2,429	1,044	4·05	1·74
8	2,440	940	4·07	1·57
9	1,777	986	2·96	1·64
10	1,998	1,021	3·33	1·70
11	1,626	1,279	2·71	2·13
12	2,768	1,687	4·61	2·81
13	2,225	830	3·71	1·38
14	2,214	1,483	3·69	2·47
15	4,124	3,776	6·87	6·29
16	3,947	1,901	6·58	3·17
Mean Std.	2,571·38	1,596·88	4·29	2·66
	829·25	703·78	1·38	1·17
p Value	0·000018		0·000018	

Abbreviations: MU, monitor unit; IMRT, intensity modulated radiation therapy; VMAT, volumetric modulated arc therapy.

coverage for VMAT. Superior homogeneity and conformity observed by Mok et al.[8] for VMAT disagreed with our results, thereby indicating similar homogeneity and conformity. Stieler et al.[11] observed superior homogeneity and inferior conformity for VMAT, which in turn disagreed with our findings. Similar normal tissue doses were found for VMAT and IMRT in the present study as well as in the study by Stieler et al.[11] However, lower OAR doses were found in VMAT compared to IMRT for all other studies.[8–10] Shorter BOT was found for VMAT compared to IMRT in the present study as well as in other studies.[8,10] Arc control points in RapidArc planning during optimisation uses variable length of time which is subject to treatment planner's judgement and may vary from plan to plan and thus may not necessarily use the same optimisation steps, which might be a possible study limitation.

Conclusion

For radiation therapy for anal carcinoma, VMAT is considered the favourable technique. Both IMRT and VMAT plans were able to achieve similar conformity and homogeneity and normal tissue sparing, except in bladder where the IMRT was found better than VMAT. We found that the VMAT plans require approximately 40% less MUs and 40% less beam delivery times compared to IMRT. The benefits of having fewer MU and shorter BOT in VMAT may decrease the damage from secondary radiation and reduce the treatment delivery uncertainty due to intra-fraction tumour motion. This will also lead to higher machine throughput as well as improved patient comfort, with less time on the treatment table that makes the patient immobile during treatment.

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