Received:
05 February 2018

Revised:
08 May 2018

Accepted:
06 June 2018

<https://doi.org/10.1259/bjr.20180146>

Cite this article as:

Iqbal MS, Richmond N, Ogilvie A, Pilling K, Willis N, Byrne J, et al. Dosimetric evaluation of VMAT for palliative radiotherapy for non-small cell lung carcinoma. *Br J Radiol* 2018; **91**: 20180146.

SHORT COMMUNICATION

Dosimetric evaluation of VMAT for palliative radiotherapy for non-small cell lung carcinoma

¹MUHAMMAD SHAHID IQBAL, FRCR, ²NEIL RICHMOND, MSc., ³AUDREY OGILVIE, DCR(T), ³KAREN PILLING, DCR(T), ⁴NICHOLAS WILLIS, DCR(T), ²JOHN BYRNE, PhD, ²CHRISTOPHER WALKER, BSc. and ²NICHOLAS WEST, MSc.

¹Department of Clinical Oncology, Northern Centre for Cancer Care, The Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

²Department of Radiotherapy Physics, Northern Centre for Cancer Care, The Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

³Department of Therapeutic Radiography, Northern Centre for Cancer Care, The Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

⁴Department of Radiotherapy Dosimetry, Northern Centre for Cancer Care, The Newcastle upon Tyne Hospitals NHS Foundation Trust, Newcastle upon Tyne, UK

Address correspondence to: Muhammad Shahid Iqbal
E-mail: shahid.iqbal@nhs.net

Objective: To compare the dosimetric consequences of volumetric modulated arc therapy (VMAT) for high-dose palliative thoracic radiotherapy through comparison with conventionally used isocentric parallel opposed pair (POP) of fields.

Methods: 20 consecutive patients with non-small cell lung cancer who received 36 Gy in 12 fractions using a POP technique were re-planned using a single VMAT arc. Salient dosimetric parameters were compared between the plans using a paired *t*-test.

Results: VMAT demonstrated dosimetric superiority; all PTV dose parameters were significantly improved and importantly the volume of normal lung receiving a high

dose was also significantly reduced (mean volume of normal lung receiving 36 Gy was 12.9% in POP vs 1.8% in VMAT, $p < 0.005$).

Conclusion: The standard POP technique does not take into account tissue densities which results in higher doses to the normal tissue outside the target volume and reduced conformity to the PTV.

Advances in knowledge: With the help of modern VMAT techniques, it is possible to effectively achieve highly conformal dose delivery which may provide an opportunity to escalate the dose to the tumour in this group of patients.

INTRODUCTION

Lung cancer remains the leading cause of cancer-related mortality.¹ The vast majority of patients with non-small cell lung cancer (NSCLC) present at advanced stage. High dose palliative radiotherapy is frequently used in non-metastatic locally advanced NSCLC patients who are deemed unfit for radical management. The aim of palliative radiotherapy is to obtain symptom relief, preserve quality of life and it also provides a modest survival benefit if given in higher dosage.² The optimal dose fractionation to palliate thoracic symptoms is unknown; however a radiotherapy dose of ≥ 30 Gy (in 10 fractions) is considered "high-dose" and was found to be associated with a modest survival benefit and symptom palliation especially in patients with a good performance status.³

The radiotherapy regime for patients with non-metastatic locally advanced NSCLC, deemed unfit for radical

treatment, is 36 Gy in 12 fractions (5 fractions per week). This regimen is based on the Medical Research Council (UK) Lung Cancer Working Party's clinical trial results published in 1996⁴ and is commonly delivered via a simple parallel opposed pair field technique. Now with the availability of the newer radiotherapy techniques such as volumetric modulated arc therapy (VMAT) which have an ever-increasing applicability to different treatment sites,^{5,6} the possibility exists to improve target dose coverage and homogeneity while better sparing the organs at risk (OARs).⁷

The aim of this study was to compare the dose distribution received when patients were treated with simple parallel opposed pair (POP) fields and using factor-based monitor units (MUs) assuming the patient is equivalent to water, with the actual received dose estimated using a sophisticated dose calculation algorithm and CT measured patient

Figure 1. Simple parallel opposed pair's two field planning technique (a) fields are placed at the mid-point of the patient's separation and geometrically opposed and (b) adjustments made to of the multileaf collimators to spare normal tissues.

densities. We then explored what dose distributions could be achieved by creating a simple (VMAT) plan.

MATERIALS AND METHODS

The datasets from 20 consecutive patients treated with 36 Gy in 12 fractions radiotherapy to a NSCLC target at this radiotherapy centre were included in this retrospective planning study.

At the time of treatment, as part of the initial planning preparation, all patients underwent a planning CT scan in the supine position, scanned from the spinal vertebrae C6 to L2 ensuring coverage of the whole lungs. Based on staging investigations the gross tumour volume (GTV) was defined to include the macroscopic lung disease and regional lymph nodes. Two parallel opposed 6 MV fields were defined in ProSoma® (MedCom GmbH, Darmstadt, Germany) and multileaf collimators (MLCs) adjusted to conform the field to the GTV using an approximate margin (Figure 1) accounting for the standard intra- and inter-fraction uncertainties. Treatments were prescribed at mid-plane on the central axis (CAX) and MUs were calculated assuming a uniform patient density of 1.00 kgm^{-3} .

In this retrospective study, for the purpose of evaluating the POP plan, the CT datasets were contoured with relevant organ at risk volumes (Table 1), GTVs were grown to a clinical target volume (CTV) using 5 mm isotropically and then on to a planning target volume (PTV) using a further 10 mm isotropic margin. The delivered POP plan was calculated using the Collapsed Cone dose calculation algorithm⁸ on RayStation® Treatment Planning System (RaySearch AB, Stockholm, Sweden) to generate a dose distribution that accounts for tissue heterogeneities based on CT Hounsfield Units.

In addition to recalculating the delivered POP plan, a VMAT plan was also created on the same dataset. This plan was generated using automated functionality adding the planning volumes, beams, optimisation objectives and performing the final dose calculation in a single step. The VMAT plans were prescribed to the median dose of the PTV and accepted using simple dose-volume metrics for PTV and OARs (Table 2).

Statistical analysis

Differences between the recalculated POP plan accounting for anatomical heterogeneities and the VMAT plan were evaluated using mean dose parameters using a paired *t*-test, with statistical significance assigned at $p < 0.005$.

Results

Superior target coverage was observed with the VMAT plan as compared to the POP plan; importantly high dose was more conformal (Conformity Index [equation 1]: POP 0.3 vs VMAT 0.9, $p < 0.0005$) and more homogeneous in the target region (Homogeneity Index [equation 2]: POP 0.8 vs VMAT 0.9).

Equation 1: Conformity Index

$$CI = \frac{\text{PTV volume covered by 95\% isodose}}{\text{Volume of 95\% isodose}}$$

Equation 2: Homogeneity Index

Table 1. The extra organs at risk retrospective added for the purposes of analysing the study

Organ at risk	Mode and nature of creation
Normal lung tissue	Both lungs including inflated and collapsed lungs were contoured automatically using RayStation's MBS functionality, excluding the GTV to be more representative of normal lung tissue.
Spinal cord	Automatically contoured using MBS and based on the bony limits of the spinal canal. The structure included at least 5 cm superior and inferior to the extent of the PTV.
Oesophagus	Contoured using mediastinal windowing on CT scan, 5 cm superior and inferior to the extent of the PTV (gastroesophageal junction determined as the inferior limit if <5 cm).
Heart	Defined including the pericardial sac. The superior aspect was at the level where the pulmonary trunk and pulmonary arteries first seen as separate structures. The inferior aspect was the inferior wall of the left ventricle.

GTV, gross tumour volume; MBS, model-based segmentation; PTV, planning target volume.

Table 2. Clinical goals used to evaluate the VMAT plans

Volume of interest	Dosimetric goal
PTV	D95% $\geq$ 34.2 Gy
PTV	D50% = 36 Gy $\pm$ 1%
PTV	D1% $\leq$ 38.52 Gy
Lungs-GTV	V20 Gy $\leq$ 30%

GTV, gross tumour volume; PTV, planning target volume; VMAT, volumetric modulated arc therapy.

$$HI = \frac{\text{Dose covering 95\% of PTV volume}}{\text{Dose covering 5\% of PTV volume}}$$

The comparison between the full calculated dose distributions for the VMAT and conventional POP plans, also demonstrated significant improvements in minimum and maximum target dose statistics; mean D98% and mean D2% were both significantly improved ($p < 0.005$). In POP, the mean maximum plan dose was 43.9 Gy compared to 38.1 Gy in VMAT ($p < 0.005$). The POP plans were also found to have delivered a significantly higher dose to the target than the VMAT plans; mean D50% dose to PTV was 37.7 Gy with POP whereas VMAT planning ensures the target received the prescribed 36 Gy in all cases.

Organ at risk (OAR) doses did not demonstrate significant improvement with the VMAT plan; this is likely due to OARs not being included in the optimisation. There was also the expected

increase in low dose to the normal tissues demonstrated by a significantly worse V5 Gy dose parameter for the VMAT plans. Although importantly the mean volume normal lung receiving the prescription dose being significant less with VMAT (Lung-GTV D36 Gy: POP 12.9% vs VMAT 1.8%, $p < 0.005$) and the mean maximum doses in the patient being significantly lower (Body D0.5 cc: 38.1 Gy and 43.9 Gy for VMAT and POP respectively; $p < 0.005$).

Reduced treatment times were also observed with the VMAT plans compared to parallel opposed plan; from beam on to beam off there was a mean 37% reduction in estimated delivery time (POP: 78.2 s, VMAT: 49.0 s, $p < 0.005$). All results are summarised in Table 3.

DISCUSSION

VMAT is a modern radiotherapy technique which can provide highly conformal dose distributions and better sparing of normal tissues. It has also another potential advantage of reduced treatment delivery time which may be of great importance in thoracic radiotherapy as it may help in reducing the degree of intrafraction motion.⁵ Due to its dosimetric superiority over 3D conformal radiotherapy or static intensity modulated radiotherapy (IMRT), VMAT is gaining popularity and is being increasingly used in many tumour sites including thoracic radiotherapy to treat both early stage lung cancers with stereotactic radiotherapy and locally advanced disease with conventional dose fractionation.^{5,6}

Table 3. Mean dose parameters across the 20 patients for both the POP and VMAT planning techniques

		Parallel opposed		VMAT			
		Gy/%		Gy/%			
	Dose parameter	Mean	SD	Mean	SD	<i>p</i> value	
PTV	D98%	27.7	8.8	33.7	0.7	<0.005	Significantly better
	D50%	37.7	1.2	36.0	0.0	<0.005	Significantly better
	D2%	40.9	2.0	37.3	0.5	<0.005	Significantly better
	CI	0.3	0.1	0.9	0.1	<0.005	Significantly better
	HI	0.8	0.1	0.9	0.0	<0.005	Significantly better
Lungs-GTV	V5 Gy	27.1	11.4	50.0	16.6	<0.005	Significantly worse
	V20 Gy	19.4	8.2	16.4	6.6	0.206	No difference
	V36 Gy	12.9	6.0	1.8	0.9	<0.005	Significantly better
	Mean dose	8.7	3.4	9.4	3.3	0.513	No difference
Spinal cord	D0.1 cc	33.5	11.7	29.0	7.8	0.156	No difference
	D1.2 cc	32.5	12.7	27.2	7.7	0.123	No difference
Oesophagus	D0.5 cc	33.9	9.2	35.6	3.3	0.443	No difference
	Mean dose	18.2	6.7	19.5	5.0	0.500	No difference
Heart	D0.5 cc	36.8	8.3	34.3	8.7	0.348	No difference
	Mean dose	12.5	8.7	9.6	5.3	0.212	No difference
Body	D0.5 cc	43.9	2.1	38.1	0.9	<0.005	Significantly better

GTV, gross tumour volume; POP, parallel opposed pair; PTV, planning target volume; SD, standard deviation; VMAT, volumetric modulated arc therapy.

Figure 2. (a) Delivered POP plan using manually calculated MUs recalculated with the Collapsed Cone dose algorithm showing overdosing in normal tissues and underdosing in the target. (b) The VMAT plan conforming high dose to the PTV. (c, d) The position and value of the line doses for POP (dotted) and VMAT (solid). (e) The PTV DVH plots for the POP (dotted) and VMAT (solid) plans. DVH, dose-volume histogram; MUs, monitor units; POP, parallel opposed pair; PTV, planning target volume; VMAT, volumetric modulated arc therapy.

To the best of the authors' knowledge, this is the first comparison of these two techniques for this cohort of patients. The commonly used simple POP technique ignores the limitations associated with different tissue densities; most notably the high doses outside the target region (Figure 2) and the uncertainty in the delivered dose. Prescribing the POP dose to the mid-point without tissue heterogeneity corrections results in an inhomogeneous dose distribution, with high dose outside the target volume, poor conformity and the dose delivered significantly more than expected (maximum D50% was 39.7 Gy). The POP planning process is also resource-intensive with manual placement of individual beams and a factor-based MU calculation.

The main advantage of using a VMAT plan with full dose calculation incorporating tissue density corrections is that it ensures that the volume of high dose coincides with the target volume; this was demonstrated in our study by the significant improvement in all PTV dose parameters evaluated. Full dose calculation

also allows meaningful follow up; correlating patient outcomes with a more accurate estimate of received dose.

The only potential disadvantage is the expected increase in the volume of low dose with VMAT, normal lung V5 Gy being significantly higher ($p < 0.005$). Considering the palliative nature of treatment, the clinical impact of this is likely to be insignificant.

FUTURE WORK

Based on the findings from this cohort we are currently setting up a prospective study evaluating the feasibility of automated VMAT planning in this context. For this approach to be clinically feasible for the palliative patient pathway, contouring and planning needs to be simple and efficient. We have also changed the prescription for these plans, delivering radiotherapy closer to what this cohort of patients has previously received. Delivering more conformal dose distributions may also allow the future exploration of increasing the therapeutic interval, dose

escalation or hypofractionation possibly without any increase in toxicity.

CONCLUSION

In this small planning study for this cohort of patients, we have demonstrated that VMAT plans are dosimetrically superior to previous techniques. Based on these findings, it can be justified that these patients who have traditionally been poorly served by simple radiotherapy approaches could be treated more appropriately using a sophisticated technique. With the reduced high

doses to OARs afforded by VMAT comes with the opportunity to conduct a prospective dose escalation study to capitalise on this improved therapeutic ratio. It is therefore anticipated that more disease sites requiring palliative radiotherapy will utilise this automated VMAT approach in the future after appropriate evaluation.

DISCLAIMER

Part of this study was presented in British Thoracic Oncology Group (BTORG) meeting 2018 as a poster presentation.

REFERENCES

1. Ridge CA, McErlean AM, Ginsberg MS. Epidemiology of lung cancer. *Semin Intervent Radiol* 2013; **30**: 093–8. doi: <https://doi.org/10.1055/s-0033-1342949>
2. Fairchild A, Harris K, Barnes E, Wong R, Lutz S, Bezjak A, et al. Palliative thoracic radiotherapy for lung cancer: a systematic review. *J Clin Oncol* 2008; **26**: 4001–11. doi: <https://doi.org/10.1200/JCO.2007.15.3312>
3. Rodrigues G, Videtic GM, Sur R, Bezjak A, Bradley J, Hahn CA, et al. Palliative thoracic radiotherapy in lung cancer: An American Society for Radiation Oncology evidence-based clinical practice guideline. *Pract Radiat Oncol* 2011; **1**: 60–71. doi: <https://doi.org/10.1016/j.prro.2011.01.005>
4. Macbeth FR, Bolger JJ, Hopwood P, Bleehen NM, Cartmell J, Girling DJ, et al. Randomized trial of palliative two-fraction versus more intensive 13-fraction radiotherapy for patients with inoperable non-small cell lung cancer and good performance status. Medical Research Council Lung Cancer Working Party. *Clin Oncol* 1996; **8**: 167–75. doi: [https://doi.org/10.1016/S0936-6555\(96\)80041-0](https://doi.org/10.1016/S0936-6555(96)80041-0)
5. Teoh M, Clark CH, Wood K, Whitaker S, Nisbet A. Volumetric modulated arc therapy: a review of current literature and clinical use in practice. *Br J Radiol* 2011; **84**: 967–96. doi: <https://doi.org/10.1259/bjr/22373346>
6. Macchia G, Deodato F, Cilla S, Cammelli S, Guido A, Ferioli M, et al. Volumetric modulated arc therapy for treatment of solid tumors: current insights. *Onco Targets Ther* 2017; **10**: 3755–72. doi: <https://doi.org/10.2147/OTT.S113119>
7. Zhao N, Yang R, Wang J, Zhang X, Li J. An IMRT/VMAT technique for nonsmall cell lung cancer. *Biomed Res Int* 2015; **2015**: 1–7. doi: <https://doi.org/10.1155/2015/613060>
8. Ahnesjö A. Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media. *Med Phys* 1989; **16**: 577–92. doi: <https://doi.org/10.1118/1.596360>