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Case Study

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Dosimetric case study of 3-D FiF vs. VMAT techniques in the treatment of H/N tumour

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Abstract

A case study comparing three-dimensional conformal radiation therapy with field-in-field (FiF) technique and volumetric-modulated arc therapy (VMAT) for head/neck (H/N) irradiation, evaluating the differences in the treatment techniques and low doses to critical structures. Compared to VMAT plan, 3D FIF plan offers similar planning target volume coverage and acceptable organs at risk dose. Therefore, 3D FIF is still a feasible alternative for some centres unqualified for IMRT/VMAT worldwide.

Introduction

Advances in computer technology have enabled the possibility of transitioning from basic 2-dimensional treatment planning and delivery (2-D RT) to a more sophisticated approach with 3-D CRT, and advanced IMRT/ volumetric-modulated arc therapy (VMAT) as well. IMRT/VMAT approach demands even more sophisticated equipment and seamless teamwork, and consequentially more resources, advanced training and more time for treatment planning and verification of dose delivery than 3-D CRT.[1] On the other hand, some cancer centres worldwide are currently in the early stages of implementing radiotherapy and are only enabled to offer 2D and 3D radiotherapy plans due to kinds of issues, such as the limitations of advanced imaging and physics quality assurance (QA), a lack of adequately trained dosimetrists and health insurance clearance.[1–3] There is another essential global issue that may have been frequently overlooked clinics with limited equipment can still be able to treat certain patients even if their linear accelerator only has MLC and no physical/dynamic wedges due to commission issues.

Due to the complex anatomy and large extension of the treated region, H/N treatment is one of the most challenging plans to design. A study reported that after taking into account both PTV coverage and parotid sparing, the best global performance was achieved by the FIF technique with results comparable to that of IMRT plans. This technique can be proposed as a valid alternative when IMRT equipment is not available or patient is not suitable for IMRT treatment.[4]

The purpose of this case study is to compare VMAT with alternative plans obtained by 3D-CRT. Learning the skills of 3D plans more will contribute to improving the cancer treatment capabilities in some centres worldwide with limited equipment and qualified personnel.

Methods and Materials

This case was from the H/N VMAT lab of John Patrick University of Health and Applied Sciences (no demographics). PTV is big and irregular in shape, 238·25 cm^3 and it overlaps with many critical structures which can limit radiation dose, like left parotid, larynx, mandible, maxilla and retropharyngeal and in close proximity to brainstem and spinal cord.

According to ICRU Report 62, the dose–volume histogram (DVH) and evaluation parameters: conformity index (CI) and heterogeneity index (HI).[5] For the PTV, doses D2%, D95% and D_{mean} were evaluated, and the determination of the number of MU per fraction was considered for each plan and technique for the comparisons between the modes of delivery analysed.

$$\mathrm{CI} = \mathrm{Treated\ Volume}/\mathrm{PTV\ Volume}$$

Treated volume corresponds to the part of PTV covered by 95% isodose, both volumes in cubic centimeters (cc).

$$\mathrm{HI} = D_{5\%}/D_{95\%}$$

$D_{5\%}$ and $D_{95\%}$ are the minimum doses received by the PTV at 5% and 95%, respectively (Fig. 1).

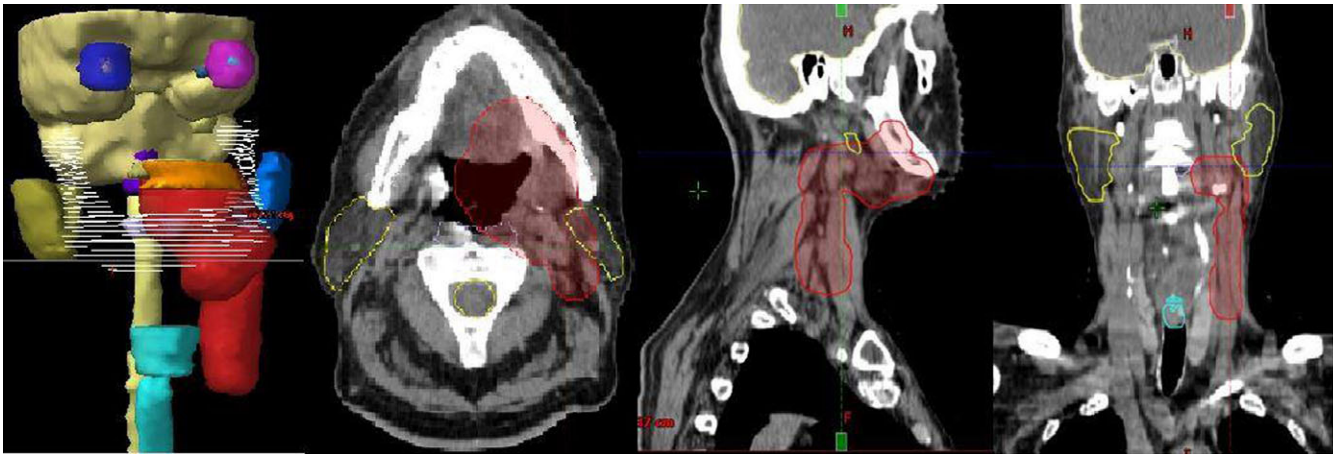
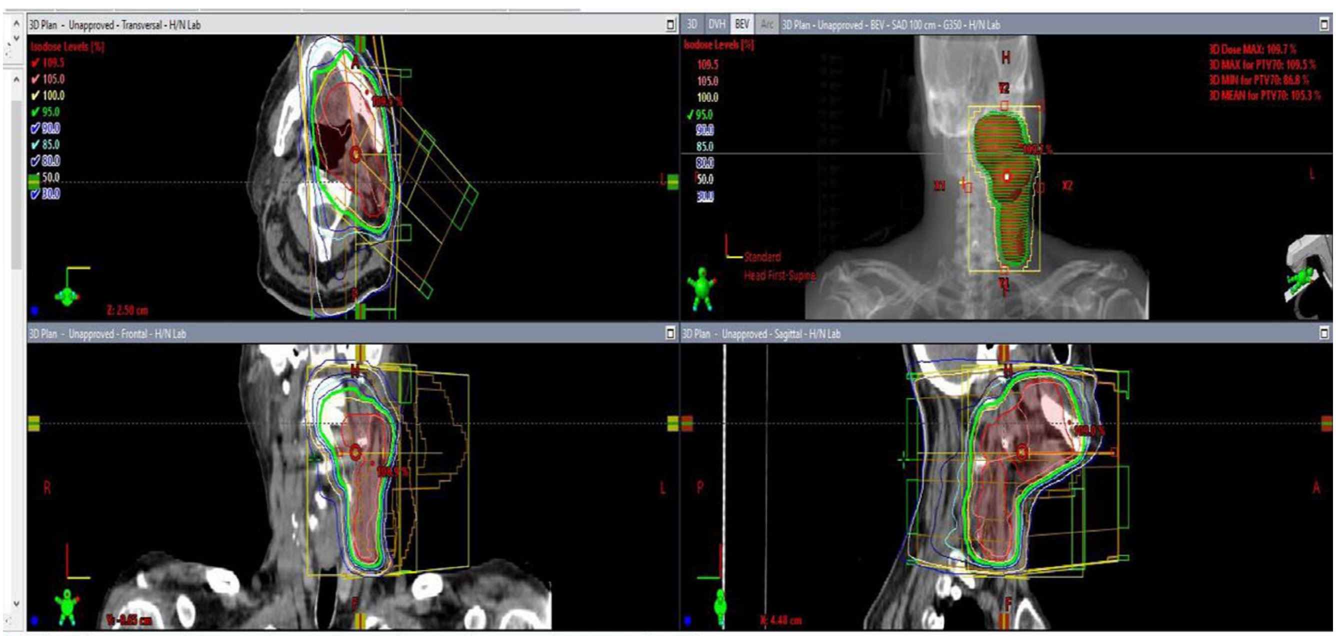


Figure 1. The H/N anatomical region. Red = PTV



Group	Field ID	Technique	Machine/Energy	MLC	Field Weight	Scale	Gantry Rtn [deg]	Coll Rtn [deg]	Couch Rtn [deg]	Wedge	Field X [cm]	X1 [cm]	X2 [cm]	Field Y [cm]	Y1 [cm]	Y2 [cm]	X [cm]	Y [cm]	Z [cm]	Calculated SSD [cm]	MU	Ref. D [cGy]
I	G350	Static-I	Varian IX-3402 - 18X	Static	0.381	Varian IEC	350.0	0.0	0.0	None	8.8	+4.7	+4.1	13.7	+7.8	+5.9	4.00	-11.50	0.50	90.5	86	101.2
I	G35	Static-I	Varian IX-3402 - 6X	Static	0.082	Varian IEC	35.0	0.0	0.0	None	11.4	+5.4	+6.0	13.9	+8.0	+5.9	4.00	-11.50	0.50	95.5	18	19.4
I	G90	Static-I	Varian IX-3402 - 6X	Static	0.096	Varian IEC	90.0	0.0	0.0	None	11.8	+5.9	+5.9	14.0	+8.2	+5.8	4.00	-11.50	0.50	96.6	20	21.4
I	G125	Static-I	Varian IX-3402 - 6X	Static	0.081	Varian IEC	125.0	0.0	0.0	None	9.5	+5.3	+4.2	14.0	+8.3	+5.7	4.00	-11.50	0.50	95.1	18	19.5
I	G180	Static-I	Varian IX-3402 - 18X	Static	0.253	Varian IEC	180.0	0.0	0.0	None	9.1	+4.3	+4.8	14.0	+8.2	+5.8	4.00	-11.50	0.50	90.1	57	69.3
I	G350.0	Static-I	Varian IX-3402 - 18X	Static	0.047	Varian IEC	350.0	0.0	0.0	None	8.8	+4.7	+4.1	13.7	+7.8	+5.9	4.00	-11.50	0.50	90.5	11	12.5
I	G180.0	Static-I	Varian IX-3402 - 18X	Static	0.019	Varian IEC	180.0	0.0	0.0	None	9.1	+4.3	+4.8	14.0	+8.2	+5.8	4.00	-11.50	0.50	90.1	7	5.3
I	G125.0	Static-I	Varian IX-3402 - 6X	Static	0.020	Varian IEC	125.0	0.0	0.0	None	9.5	+5.3	+4.2	14.0	+8.3	+5.7	4.00	-11.50	0.50	95.1	5	4.9
I	G35.1	Static-I	Varian IX-3402 - 6X	Static	0.021	Varian IEC	35.0	0.0	0.0	None	11.4	+5.4	+6.0	13.9	+8.0	+5.9	4.00	-11.50	0.50	95.5	5	5.1

Figure 2. 3D-CRT fields properties

The prescription is a total dose of 70 Gy/35 fractions. The planning objective was to ensure that ≥95% of the target volume was covered by at least 95% of the prescribed dose while restricting doses to spinal cord (maximum dose <45 Gy) and the contralateral parotid gland (mean dose ≤26 Gy) because one of the most common toxicities of H/N irradiation is xerostomia.[6] 3D-CRT was planned with 6 MV (in some cases mixed with 18 MV) photon beams, using 5 MLC-shaped beams with the FiF technique (Fig. 2). FIF segments use multileaf collimators to generate a homogeneous and conformal dose distribution via segmental subfields, and the number of segments also plays a part in the optimisation process. The treatment planning process can be considered in two steps: determination of treatment field apertures, then the use of subfields to give a homogeneous dose distribution. The beam weights for both primary and subfields need to be readjusted with the goal of increasing homogeneity of planning target volume (PTV) while decreasing the hotspot volumes, and this entire process is iterative.[7] According to a study report, 3D-CRT in H/N cancers permits good coverage of the planning target volume with about 10–11 segments.[8] The FiF technique uses 5 gantry angles

Table 1. The main characteristics of each delivery mode

Delivery Method	Gantry Motion	Gantry Speed	MLC Motion	Dose Rate	Beam Intensity
3D-CRT	Static	Constant	Static	Constant	Uniform
VMAT	Dynamic	Variable	Dynamic	Variable	Modulated

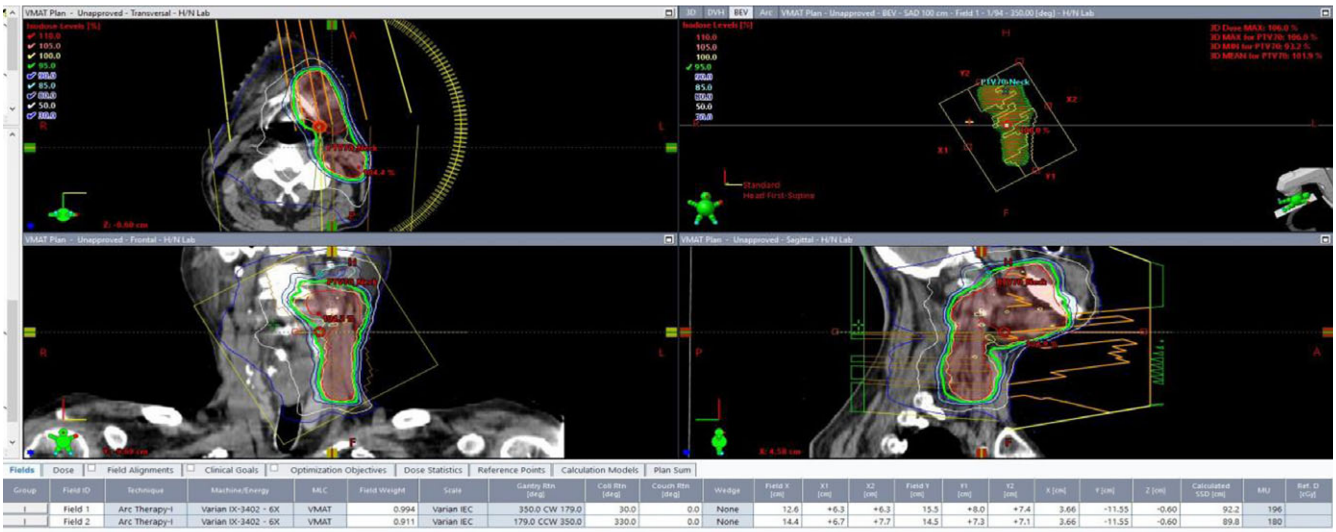


Figure 3. VMAT fields properties

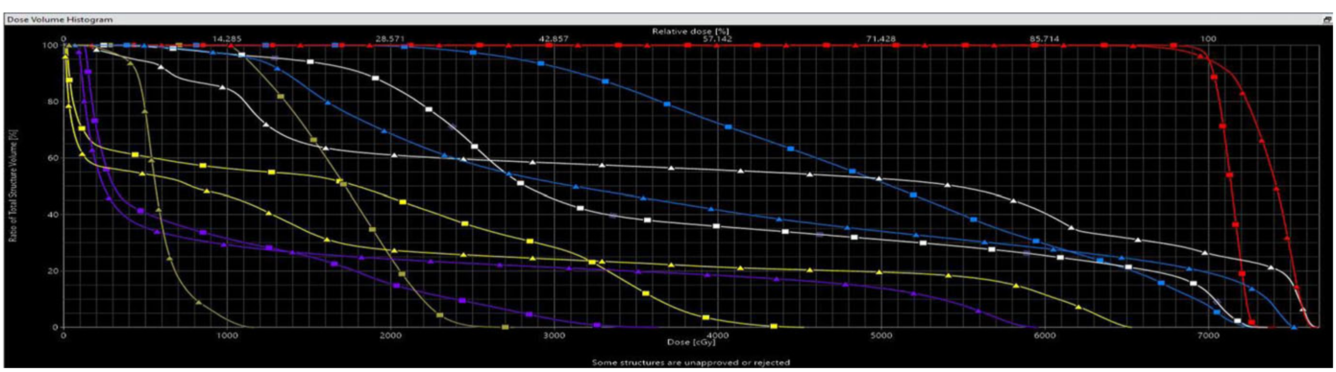


Figure 4. The comparison in the DVH for two plans. Triangle = 3D-CRT; square = MAT

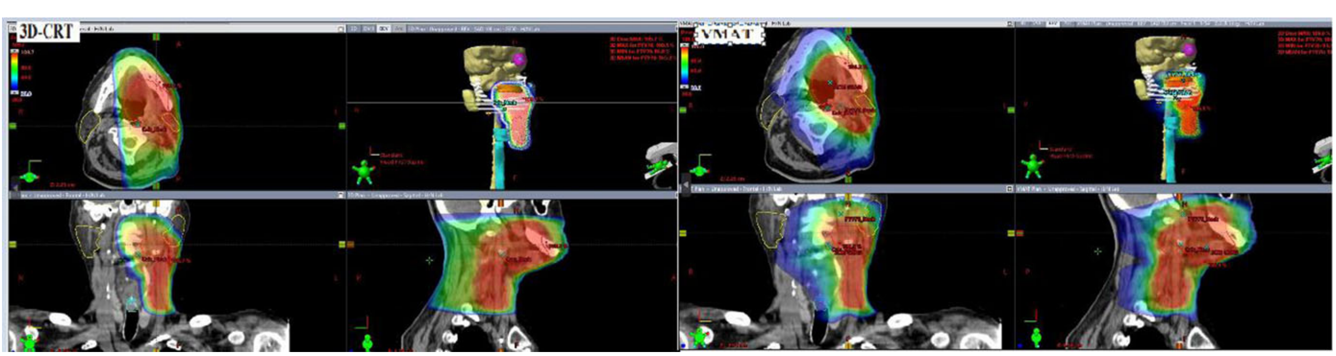


Figure 5. The dose distribution for the two plans in the same slide

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Table 2. The volume of different isodose levels (%). (Unit: cm^3)

	V105%	100%	97%	95%	90%	85%	80%	50%	30%	10%
3D-CRT	192·2	364·6	419·6	451·3	529·9	616·8	724·7	1167·3	1443·6	2355·0
VMAT	0	255·3	310·5	335·9	385·9	434·2	482·4	905·4	1640·2	3120·6

Table 3. The PTV dose parameters for two techniques

Parameters	D2 (Gy)	D5 (Gy)	D50 (Gy)	D95 (Gy)	D98 (Gy)	Min Dose	Mean Dose	Max Dose	CI	HI	Total MU/Fx
3D-CRT	76·1	75·8	74·1	70·0	68·5	60·8	73·7	76·6	1·41	1·08	227
VMAT	72·6	72·3	71·4	70·0	69·5	65·2	71·3	74·2	1·89	1·03	376

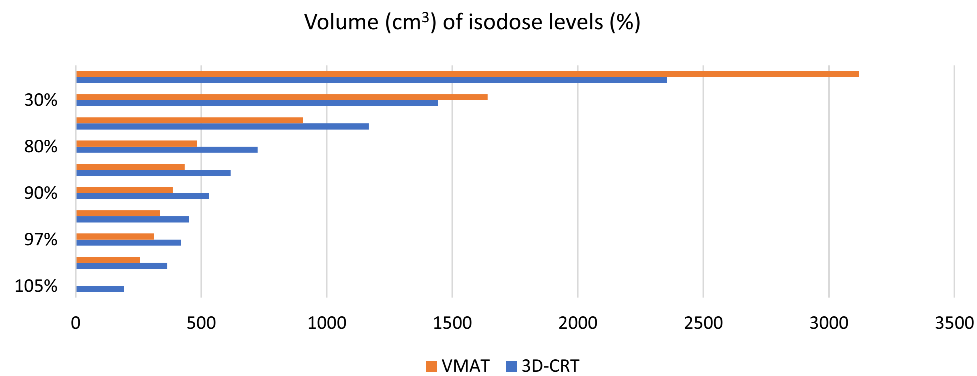

Figure 6. Volume of isodose levels

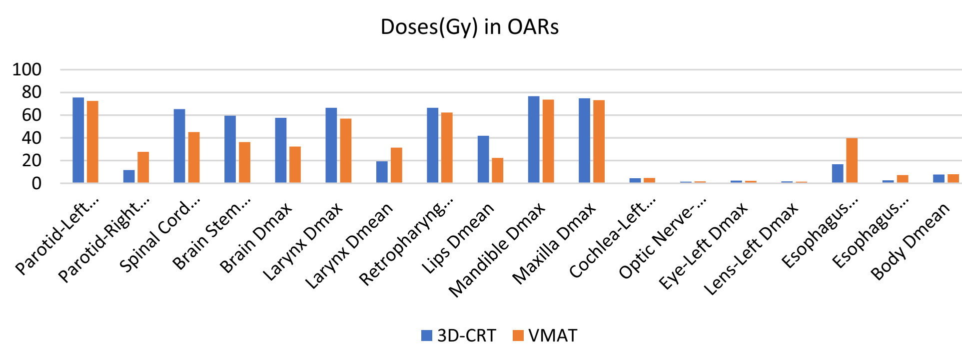

Figure 7. Doses (Gy) in OARs

(350°, 35°, 90°, 125° and 180°), and the dosimetric calculation is performed using a forward-planning treatment system. VMAT was done with 6 MV photons with two partial arcs range selected to avoid as much of the contralateral organs as possible (Fig. 3, Table 1).

Results

The data were collected from DVH's generated for each treatment technique. The results of statistical analysis of PTV coverage and OAR's doses are presented in Tables (Figs. 4–6, Tables 2 and 3).

The target coverage was achieved 95% of prescribed dose to 100% of PTV in 3D CRT and VMAT methods. Comparing the max hot spot of 3D plan <110%, VMAT's hot spot <105%. Both CI and HI for VMAT showed better than 3D. This case study report improved conformity with VMAT at the above 50% isodose levels; however, the volume of healthy tissue receiving low-dose radiation (10% and 30% isodose line coverages) was lower in 3D-CRT plans. The value of MU was statistically low for 3D-CRT at 39·6% less than VMAT which used more time (Table 4).

It is significant to maximize sparing of the right parotid gland when the left parotid is involved in the irradiation area, and the mean dose of left parotid was 75·4 Gy and 72·6 Gy for 3D and VMAT plans. For right parotid gland, the mean dose was 11·6 Gy for 3D and 27·6 Gy for VMAT. As a result, 3D-CRT improved sparing of the contralateral parotid gland in this case. The integral dose to the body was also lower in the 3D plans by 2% compared with the VMAT plan. A reason for this is that this VMAT plan was optimized by taking into consideration dose constraints to the spinal cord and brainstem. Compared to 3D-CRT, the absorbed doses of VMAT in the spinal cord and brainstem are reduced by 31% and 39%. As a result, the doses to the spinal cord and brainstem in this study were significantly

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Table 4. shows Doses in OARs. (Unit: Gy)

	3D-CRT	VMAT
Parotid-Left D_{mean}	75·4	72·6
Parotid-Right D_{mean}	11·6	27·6
Spinal Cord D_{max}	65·3	45·2
Brain Stem D_{max}	59·6	36·3
Brain D_{max}	57·7	32·4
Larynx D_{max}	66·4	56·9
Larynx D_{mean}	19·3	31·3
Retropharyngeal D_{mean}	66·4	62·3
Lips D_{mean}	41·9	22·3
Mandible D_{max}	76·7	73·6
Maxilla D_{max}	74·8	73·3
Cochlea-Left D_{mean}	4·4	4·7
Optic Nerve-Left D_{max}	1·5	1·7
Eye-Left D_{max}	2·3	2·1
Lens-Left D_{am}	1·7	1·4
Esophagus D_{max}	16·8	39·8
Esophagus D_{mean}	2·6	7·2
Body D_{mean}	7·7	8·0

lower in the VMAT plans, but at the cost of increased dose to the contralateral parotid gland.

Discussion

The 3D plan generated with a mix of 6 and 18 MV energy gave the best ratio of coverage and dose to OAR as well as high dose because the 6 MV energy produces plans that are too hot to be used. As the energy increases, the dose to the OAR and the size of the hotspot decreases.[9] FIF technique can be added to a 3D forward-planning method to minimise hotspots and improve dose homogeneity in the target volume, producing high-quality clinical plans. Compared with physical/dynamic wedges, FIF provides more nuanced hotspot reduction and can achieve a better dose distribution, and its ability to operate in two dimensions instead of one.[10] Also, FiF is better than wedges in terms of maximum dose, D2, and V > 107% for most of the sites, and its MU is 30% lower than in the wedge method. A reduction in MU minimizes the chance of developing secondary cancers in radiotherapy.[11]

Surveys show that most radiation oncologists in the USA use IMRT/VMAT for H/N cases.[12] However, as a time-intensive, labor-intensive process, IMRT/VMAT is not fully covered by the public health system in middle- and low-income countries because it requires considerable investments in both software and hardware.[13] It also has a more stringent machine QA and quality control to check the performance of its delivery system. Achieving a widespread IMRT/VMAT technology in most cancer centres in the world will require a long time given the economic costs, quality and safety problems. Currently, the use of 3D-CRT technique still be useful to improve the quality of treatments in various anatomical sites like H/N even for centres in low- and middle-income countries. The dose distribution within the target was more homogenous, and the doses for healthy tissue were less in the FIF plan compared to the tangential wedge plans.[14] Therefore, 3D-CRT with FiF could be useful to assess and improve clinical validation of the feasibility and reproducibility of this technique in different RT centres.

Conclusion

The present case aimed to assess the potential benefits and limitations of 3D-CRT techniques in treating advanced H/N tumours, and it showed that both 3D-CRT and VMAT are dosimetrically feasible techniques in the treatments for H/N tumours. The advantages of VMAT are improved target volume conformity, particularly in volumes with complex concave shapes, and improved sparing of OARs; however, it cannot be considered the universal solution for all clinical scenarios. Each case must be evaluated on an individual basis to select the most appropriate radiation technique that will give optimal results.[15]

In summary, in some centres where VMAT equipment is not available, optimisation of treatment may be feasible with such a 3DCRT technique. FiF technique is easier to implement and requires less planning time. It is feasible to replace wedge filters with FIF because some centres worldwide do not have physical/dynamic wedges for some reasons, such as no commissioning and QA limitation. The dynamic MLC can be used to implement dynamic wedges in the clinics due to this method can be applied to any machine equipped with a MLC.[16]

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