Organ at risk dose verification in nasopharyngeal cancer VMAT planning with collimator comparison between single arc and double arc

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Abstract. Volumetric modulated arc therapy (VMAT) is an irradiation technique that enables the improvement of the flexibility of dose delivery from a full range of angles with continuous modulation of beam aperture and dose rate. We compared the homogeneity index (HI), conformity index (CI), dose volume histogram (DVH) and dose differentiation of single arc and double arc VMAT delivered for nasopharyngeal cancer (NPC). Planning for gantry rotation angles of 360° counter clockwise and clockwise (double arc) with collimator (0° and 10°) and 360° clockwise (single arc) were created for ten nasopharyngeal cancer cases applied in RANDO phantom with the Eclipse treatment planning system and delivered using Trilogy linear accelerator. The verification was performed by using gafchromic film EBT3 and placed on the RANDO phantom according to the location of the organs at risk. In this study, we evaluated right parotid, left parotid, right eye, left eye and trachea. The measurement of mean dose using gafchromic film and TPS shows that the resulting values were close to TPS results with the difference being -1.51%. From the result of dose measurement using gafchromic film based on the data from RANDO CT phantom use, it can be concluded that double arc VMAT technique with collimator can reduce the dose in the organ at risk.

1. Introduction
Radiotherapy is one of cancer therapy techniques that uses radiation to kill cancer cell. It is very common combined with surgery and chemotherapy. Radiotherapy normally takes at least 1 week and up to 7 weeks depending on types and stages of the cancer. The goal of radiotherapy is providing the maximum dose in the cancer target volume and the minimal dose in the organs at risk surrounding the cancer target volume. If the dose of organs at risk exceeds the tolerance dose then it can cause diseases. For example the lens has a tolerance dose of 25 Gy during irradiation, if lens received dose exceeds the maximum dose then it can cause cataract disease. Radiotherapy for nasopharyngeal cancer has been technically challenging, requiring delivery of high doses to the target while constraining the dose organs at risk (OARs) around the target. Volumetric modulated arc therapy (VMAT) is a form of intensity-modulated arc radiotherapy which enables increased flexibility of dose delivery from a full range of angles (gantry rotation) with continuous modulation of beam aperture and dose rate [1]. VMAT can improve the dose distribution, reduce the dose to normal tissues and shorten the delivery time [2]. Quick delivery reduces the inconvenience to the patients and also increases the throughput of the linear accelerator. VMAT technique is designed so that optimized plans may be delivered.
efficiently in a single gantry arc, with high dose conformality using a full 360 deg range of gantry directions and accurately with high resolution sampling of beam directions during planning [3]. The VMAT technique allows for large reductions in the number of MUs and treatment delivery times. Since the VMAT technique is equally effective in producing clinically acceptable plans, but it has the advantage of sparing OARs and normal tissues, the VMAT technique may be more beneficial for NPC treatments than IMRT [4]. Dual arc VMAT for the treatment of NPC produced superior results in terms of planning target volume (PTV) coverage and organs at risk (OARs) sparing, but was slightly less efficient than single arc VMAT [5]. In this study, we would like to evaluate organ at risk verification in nasopharyngeal cancer using VMAT planning single arc and double arc with collimator comparison.

2. Experimental method

2.1. Patient selection
A total of ten simulated treatment planning of nasopharyngeal cancer cases were selected to be registered with treatment planning with RANDO phantom. The clinical stage distribution was five patients each for stage 3 and stage 4, respectively. All simulated planning have employed 3 different of VMAT techniques such as single arc, double arc and double arc with collimator.

2.2. Delineation of target volumes and organ at risk structures
In the Eclipse treatment planning system, the images based on Computerized Tomography of phantom and patient were registered. The target volumes and organ at risk structures were delineated by the radiation oncologists on the transversal slices based on registered images of phantom and patients. According to Radiation Therapy Oncology Group (RTOG) 0225 and 0615A Phase II, the criteria of Locally or Regionally Advanced Nasopharyngeal Cancer, PTV 50 (PTV 60 + Bilateral Nodule) were set up with PTV 60 (Nasopharynx + Nodule), PTV 70 (CTV Primer (CTV-P) + CTV Nodule (CTV-N) with margin 5 mm). For OARs as parotid glands, trachea and eyes, the mean dose of parotid glands < 26 Gy at least 50% of one gland will receive < 30 Gy, the maximum dose of eyes 50 Gy and mean dose of trachea < 40 Gy.

2.3. Treatment planning system
Three technique VMAT plans were optimized on the Eclipse version 11 treatment planning system (Varian Medical Systems, USA), using the 6 MV photon beam of Varian Trilogy Linear accelerators. The optimization software using Progressive Resolution Optimizer (Version 11.0.31) allows users to adjust dose constraints and priorities during optimization to achieve an optimal treatment plan which was equipped with 120 multileaf collimators (MLCs). In the upper jaws and backup jaws covering full 40 x 40 cm² and the variable dose rate up to 600 MU/min. CT images from CT simulator machine was transferred to treatment planning system (TPS) via Digital imaging and Communications in Medicine (DICOM) and treatment plan from TPS was transferred to ARIA via DICOM-Radiotherapy (DICOM-RT).

2.4. VMAT planning technique
VMAT plans double arc technique for gantry rotation angles of 360° counter clockwise and clockwise with collimator (0° and 10°) and 360° clockwise or counter clockwise for VMAT plan single arc. All techniques were created for ten nasopharyngeal cancer cases applied in RANDO phantom with the Eclipse treatment planning system and delivered using a Trilogy linear accelerator at Siloam Hospitals Simatupang as shown in Figure 1. Homogeneity index (HI), conformity index (CI), dose volume histogram (DVH) and dose differentiation was compared for double and single arc. The optimization was based on the Progressive Resolution Optimizer (PRO) algorithm. The iterative inverse planning process aimed to optimize simultaneously the instantaneous MLC positions, the dose rates and the gantry rotation speeds to achieve the desired dose distributions.
The dose was calculated using AAA version 11 after optimization. A plan normalization was selected such that 100% of coverage would be delivered to 95% the target volumes.

2.5. Plan comparison
The comparison of three VMAT plans was evaluated using the following terms:

1. Homogeneity Index (HI) : \( \frac{(D_{2\%} - D_{98\%})}{D_{50\%}} \), a ratio evaluating the dose homogeneity in PTV, HI of zero indicates the dose distribution is homogeneous
2. Conformity Index (CI) : \( \frac{V_{\text{pres}}}{PTV_p} \), a ratio evaluating the coverage of the prescription dose in treatment plans, CI of one indicates the good dose conformity
3. Dose Volume Histogram Organ at Risk : The mean dose of parotid glands < 26 Gy at least 50% of one gland will receive < 30 Gy, the maximum dose of eyes 50 Gy and mean dose of trachea < 40 Gy
4. Dose Differentiation between dose volume histogram and absorbed dose in gafchromic film.

3. Measurement
A Gafchromic film EBT3 was calibrated with size 4 × 4 cm² and irradiated using 6 MV photon beams with field size of 10 × 10 cm² in dose variation in range of 0 - 200 cGy. The irradiated gafchromic film EBT3 was scanned using Epson V700 scanner to evaluate the pixel value. Figure 2(a) shows gafchromic film EBT3 inserted horizontally on a slab phantom and irradiated with field size of 10 × 10 cm² at SAD 100 cm. The prescribed dose were setup at 70 Gy for 33 fractions (2.121 Gy per fraction). For dose verification measurements with VMAT, the gafchromic film EBT3 3 × 3 cm² were distributed at 5 points (right parotid, left parotid, right eye, left eye and trachea) and attached at the mask used by the RANDO phantom during the irradiation as shown in Figure 2(b).
4. Result and discussion

The coverage of PTVs of three technique VMAT plans single arc (SA), double arc (DA) and double arc with collimator (DAC) were evaluated by homogeneity index, conformity index, dose volume histogram and dose differentiation. And we irradiated gafchromic film EBT3 and will be compared with dose calculated in TPS. The gafchromic film EBT3 scanning results are obtained in .TIFF format and then read on the red channel using ImageJ software to obtain pixel values. The average pixel value was obtained by making the region of interest (ROI) at the center of the gafchromic film EBT3 images to avoid any impact due to cutting on the edge of the film. In addition, it will get more homogeneous doses value at the center of the radiation beam. The dose value and the netOD value are plotted, a radiation dose calibration curve will be obtained by linear interpolation technique. From the curve, we obtained the relation between netOD and dose as following equation:

\[ Y = -16493X^3 + 7957X^2 + 296.9X + 5.667 \]

where \( Y \) is the dose value (cGy) and \( X \) is the netOD value.

4.1. Homogeneity index and conformity index

Homogeneity index and conformity index of three VMAT plans for each PTV are shown in Table 1. Based on the evaluation of PTV54, PTV59.4 and PTV70, VMAT plans double arc with collimator achieved better homogeneity index and conformity index than VMAT plans using single arc and double arc. Homogeneity index for PTV 54 (0.33 ± 0.09), PTV 59.4 (0.23 ± 0.03) and PTV 70 (0.06 ± 0.01) indicates the dose distribution is homogenous with reference value of 0. On the other hand, the conformity index (0.98 ± 0.08) is close to one indicates the good dose conformity. From the data, we found the optimum value of the homogeneity index and conformity index for VMAT plans double arc with collimator.

4.2. Organ at risk dose volume histogram

The Dose Volume Histogram (DVH) comparison of organ at risk for VMAT plans, double arc with collimator, double arc and single arc. The average coverage of 95% of the PTV70 was 100% of the prescribed dose for all techniques VMAT plans. Dose volume histograms for the organ at risk are presented in Table 2. The Table 2 indicated the double arc with collimator VMAT received the lowest dose at all organ at risk. This result supported Ning et al., study that in the single arc technique, all of organ at risk receive a higher dose than another techniques. When single arc VMAT was used in the treatment of NPC, smaller and faster MLCs were sometimes needed to meet the plan optimization.
The advantages of using double arc were an increase in the modulation factor during optimization and the provision of more MLC control points than single arc, achieving better dose distribution [7]. The previous results on the maximum dose reported by Verbakel et al. [8] showed that parotid dose lower with double arc VMAT (by average 2 Gy) compared with single arc VMAT. Parotid sparing was better with the double arc collimator VMAT plans, with the (average) mean dose of 22.11 Gy (range 20.76-23.65 Gy) for left parotid and 21.49 Gy (range 20.59-22.10 Gy) for right parotid. Trachea doses for double arc and single arc VMAT plans were higher and not acceptable because the trachea received >40 Gy compared with double arc collimator VMAT plan, with a mean dose of (40.61 Gy and 43.87 Gy) versus 39.63 Gy. The left and right eyes received <50 Gy in all techniques VMAT plans. Double arc with collimator VMAT plan led to superior results of dose coverage and spared OARs when compared with single arc and double arc VMAT, without sacrificing the delivery efficiency. The collimator was rotated 10° to cover the entire tumour and to reduce the tongue and groove effect.

Table 1. Homogeneity index dan conformity index based on CT RANDO.

|                | Homogeneity Index | Conformity Index |
|----------------|-------------------|------------------|
|                | DA COL | DA | SA   | DA COL | DA | SA   |
| PTV 54         | 0.33 ± 0.09 | 0.34 ± 0.10 | 0.37 ± 0.10 |
| PTV 59.4       | 0.23 ± 0.03 | 0.25 ± 0.02 | 0.29 ± 00.4 |
| PTV 70         | 0.06 ± 0.01 | 0.07 ± 0.02 | 0.08 ± 0.02 | 0.98 ± 0.08 | 0.96 ± 0.14 | 0.89 ± 0.10 |

Table 2. DVH organ at risk based on CT RANDO in TPS.

|                | VMAT Double Arc (Gy) | VMAT Double Arc (Gy) | VMAT Single Arc (Gy) |
|----------------|----------------------|----------------------|----------------------|
| Left Eye       | 28.35 ± 1.06         | 29.15 ± 0.99         | 30.55 ± 0.64         |
| Right Eye      | 38.20 ± 8.49         | 39.80 ± 8.75         | 40.16 ± 9.55         |
| Trachea        | 39.63 ± 0.92         | 40.61 ± 2.26         | 43.87 ± 4.05 |
| Left Parotid   | 20.76 ± 1.77         | 21.92 ± 5.52         | 23.65 ± 0.21         |
| Right Parotid  | 20.59 ± 4.24         | 21.77 ± 1.41         | 22.10 ± 2.40         |

4.3. Organ at risk dose at two clinical stage

The dose differences between stage 3 and stage 4 based on registered CT RANDO phantom to patient are tabulated in Table 3. The classification of stage 3 are T_{1,2} N_{2} M_{0} (nasopharynx, oropharynx, nasal cavity, parapharyngeal extension, medial and lateral pterygoid muscles (T_{1,2}), bilateral level Ib, II, III and V_{a} involvement, or the maximum diameter ≤ 3 cm, or with extranodal neoplastic spread (N_{2}) and no distant metastasis (M_{0})), T_{3} N_{0,2} M_{0} (Bone structures and/or paranasal sinuses (T_{3}), unilateral or bilateral retropharyngeal node (s), unilateral level Ib, II, III, and V_{a} involvement and the maximum diameter ≤ 3 cm, bilateral level Ib, II, III and V_{a} involvement, or the maximum diameter >3 cm, or with extranodal neoplastic spread (N_{0,2}) and no distant metastasis (M_{0})). For the classification of stage 4 are T_{1,3} N_{1} M_{0} (nasopharynx, oropharynx, nasal cavity, parapharyngeal extension, medial and lateral pterygoid muscles, bone structures and/or paranasal sinuses (T_{1,3}), level IV and V_{b} involvement (N_{3}) and no distant metastasis (M_{0})), T_{4} N_{0,3} M_{0} (intracranial extension and/or cranial nerves, infratemporal fossa hypopharynx (T_{4}), unilateral or bilateral retropharyngeal node (s), unilateral level Ib, II, III and V_{a} involvement and the maximum diameter ≤ 3 cm, bilateral level Ib, II, III and V_{a} involvement, or the maximum diameter >3 cm, or with extranodal neoplastic spread level IV and V_{b} involvement (N_{0,3}) and no distant metastasis (M_{0})). The doses were within the acceptable limit. Both the parotid glands, eyes and trachea had better sparing in double arc with collimator than double arc and single arc. The
volume of normal tissue dose received in double arc with collimator is less than double arc and single arc, which will reduce late effect of low dose radiation (radiation-induced carcinomas). The measurement of dose differentiation using gafchromic film EBT3 and TPS shows that the gafchromic film detector values around of -1.51% in right eye with VMAT plan double arc with collimator.

Table 3. Average dose comparison with 3 VMAT techniques for each stage based on CT RANDO.

| Measurement (cGy) ± SD | Diff (%) |
|-----------------------|----------|
|                       | Stage 3  | Stage 4  |
|                       | Film | TPS | Film | TPS | Stage 3 | Stage 4 |
| LE                    | 18.34 ± 1.60 | 19.90 | 20.13 ± 0.89 | 21.40 | 7.85 | 5.93 |
| RE                    | 21.42 ± 1.81 | 21.10 | 31.92 ± 0.59 | 33.10 | -1.51 | 3.56 |
| T                     | 31.68 ± 0.46 | 32.50 | 34.79 ± 1.11 | 33.80 | 2.53 | -2.91 |
| LP                    | 26.68 ± 0.70 | 28.20 | 32.50 ± 1.41 | 30.70 | 5.38 | -5.86 |
| RP                    | 22.54 ± 4.48 | 20.50 | 44.67 ± 1.79 | 46.50 | -6.70 | 3.95 |
| LE                    | 22.21 ± 2.75 | 23.30 | 23.52 ± 1.81 | 24.70 | 4.70 | 4.79 |
| RE                    | 23.01 ± 0.78 | 22.40 | 35.90 ± 1.27 | 37.60 | -2.73 | 4.51 |
| T                     | 32.86 ± 1.19 | 34.10 | 35.53 ± 1.36 | 37.30 | 3.62 | -6.87 |
| LP                    | 26.76 ± 1.06 | 26.10 | 33.49 ± 0.94 | 33.90 | -2.53 | -4.82 |
| RP                    | 23.71 ± 1.08 | 24.30 | 45.52 ± 1.98 | 50.30 | 2.42 | 9.51 |
| LE                    | 31.70 ± 6.52 | 32.70 | 29.87 ± 1.26 | 31.80 | 3.06 | 6.07 |
| RE                    | 27.08 ± 0.91 | 28.80 | 40.88 ± 0.76 | 42.30 | 5.97 | 3.36 |
| T                     | 34.71 ± 2.23 | 33.30 | 51.27 ± 2.08 | 53.10 | -4.24 | 3.45 |
| LP                    | 33.26 ± 2.60 | 34.30 | 36.97 ± 1.09 | 34.60 | 3.02 | -6.86 |
| RP                    | 24.95 ± 0.93 | 26.30 | 47.76 ± 0.95 | 49.70 | 5.13 | 3.91 |

5. Conclusion
This study compared VMAT plans double arc with collimator, double arc and single arc for 10 base of nasopharyngeal cases. The measurement ratio of mean dose using gafchromic film EBT3 and TPS shows that the values around of -1.51%. The result of dose measurement using gafchromic film EBT3 based on the registered data of CT RANDO to patient described that double arc VMAT technique with collimator for NPC cases reduced the dose in the organ at risk.

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