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Designing the best treatment plan for patients with nasopharyngeal carcinoma treated with SIB-VMAT using the MONACO treatment planning system

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ABSTRACT

To select the best treatment plan in terms of quality, delivery time, and monitor units resulting from different planning scenarios with different arcs and segment widths for patients with nasopharyngeal carcinoma treated with the Simultaneous Integrated Boost-Volumetric Modulated Arc Therapy (SIB-VMAT) technique using the MONACO treatment planning system. A dosimetric comparison of eight VMAT phantom planning techniques was performed on 30 patients by changing the number of arcs and the minimum segment width, where the eight techniques were abbreviated as A (maximum number of arcs, minimum segment width in cm). Thus, the eight techniques were A1(1, 0.5), A2(1, 1), A3(1, 1.5), A4(1,2), A5(2, 0.5), A6(2, 1), A7(2, 1.5), and A8(2, 2). There was a significant difference in the dose delivered to the organs at risk among the eight plans. The best target coverage was for the A1 and A5 plans, and the rest did not meet the planning requirements in terms of target coverage. The treatment delivery time was significantly shorter for the A1 plan, and the monitor units were comparable between the A1 and A5 plans. The best target coverage was for the A1 plan followed by that for A5. The conformity, homogeneity, and dose gradient indices had the best values for the A5 plan. For the treatment of nasopharyngeal carcinoma with the VMAT technique, the optimized plan should be with a minimum segment width of 0.5 cm and a single or double arc. The treatment planning is infeasible for a minimum segment width bigger than 1 cm.

Key words: treatment planning, VMAT, nasopharyngeal carcinoma

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INTRODUCTION

Intensity-Modulated Radiotherapy (IMRT) is the primary treatment modality used concurrently with chemotherapy to treat locally advanced nasopharyngeal carcinoma. IMRT is used because it can conform to the dose around the target and spare surrounding healthy organs. The dose-sparing ability of organs and dose escalation around the target is based on intensity modulation, which is achieved by dividing the main field into several subfields (segments) [1].

The main drawbacks of IMRT are its long treatment delivery time and the number of monitor units generated from a large number of segments per field [2]. Subsequently, Volumetric-Modulated Arc Therapy (VMAT) was introduced, which can deliver the dose in one rotated gentry; the desired dose distribution with VMAT is delivered through variable gantry speed, continuous MLC movement, and variable dose rate [3, 4].

VMAT delivery technique is superior to IMRT in terms of reduction in treatment delivery time for different cancer types [5, 6]. In addition, total Monitor Units (MU) delivery with the VMAT technique was significantly reduced compared to that with IMRT [7, 8], which leads to smaller volumes of healthy tissues receiving high doses [9].

In this study, we evaluated different VMAT planning techniques for head and neck cancers to determine the optimum dosimetric outcomes, total delivery time, and total monitor units.

METHOD & MATERIAL

Dose prescription

All patients were treated with a simultaneous integrated boost with a dose of 70 Gy for the Primary PTV (PTVP), 60 Gy for high-risk lymph nodes (PTV60), and 54 Gy for low-risk lymph nodes (PTV54) in 33 treatment sessions. This study included eight phantoms VMAT plans for 30 patients with locally advanced head and neck cancers. In the eight phantom plans, the segment width was 0.5 cm, 1 cm, 1.5 cm, and 2 cm, with a minimum number of arcs being 1 and 2 for each segment, where the eight plan techniques were abbreviated as A (max number

of arcs, minimum segment width in cm). Therefore, the eight techniques used were A1(1, 0.5), A2(1, 1), A3(1, 1.5), A4(1,2), A5(2, 0.5), A6(2, 1), A7(2, 1.5), and A8(2, 2), with all plans having the same IMRT constraints. Plans were created using the MONACO treatment planning system.

The total delivery time and number of MUs for each plan were calculated, and the conformity index (CI), homogeneity index (HI), and dose gradient index (DGI) for the PTVP were calculated. Finally, the doses received by different organs were calculated and compared for different plans.

The CI was calculated using the following formula: CI=(TVRI)2/(TV × VRI), which was introduced. [10], where TVRI is the target volume covered by the reference isodose (the reference isodose in our study was 95% of the prescribed dose), TV is the target volume, and VRI is the volume of the reference isodose.

The HI was calculated using the formula by Semerenko et al., which is given as HI=D5/D95, where D5 and D95 are the minimum doses of 5% and 95% of the target volume, respectively [11].

The DGI for the PTVP was calculated using the formula described by Paddick et al.[12]; DGI= V50%.RI / VRI, where V50%RI is 50% of the volume of reference isodose.

The target coverage and organs at risk (OARs) for each plan were evaluated using a dose-volume histogram (DVH), and the dose constraints for each organ are listed in Table 1.

Statistical analysis

The Friedman test was used to find the significant changes between the eight plans, and the change was considered insignificant if the p-value ≥ 0.5.

RESULTS

Figure 1(A) shows the changes in delivery time for the eight plans. The delivery time per fraction was significantly changed, with a shorter delivery time for the A3 plan and a longer one for the A5 plan, with median delivery times of 119(116-130) seconds and 181(173-187) seconds, respectively.

The total number of monitor units per fraction changed significantly (p<0.001), as shown in Figure 1(B). The lowest and highest MUs were observed for A4 and A1, with median MUs of 473(429-486) and 833(782-873), respectively.

Table 2 summarizes the changes in delivery times and MUs for the eight plan scenarios.

On the diametric side, all organs showed significant changes in dose delivery. The lowest maximum dose to the optic chiasm was for the A8 plan, and the highest was for the A1 plan, with median maximum doses of 3990(3743-4210) cGy and 4665(3846-4798) cGy for the A8 and A1 plans, respectively. Figure 1 (C) shows the changes in the maximum dose delivered to the optic chiasm for the eight VMAT plans.

In addition, the spinal cord showed a significant change in maximum dose delivery, where the lowest maximum dose was for the A6 plan and the highest maximum dose was for the A8 plan, with median maximum doses of 3977(3895-4074) cGy and 4124(4014-4178) cGy, respectively. Figure 1(D) shows the changes in the maximum dose to the spinal cord for the eight VMAT plans.

In contrast, the lenses and right eye showed insignificant changes in the maximum dose delivery for the eight plans. Table 2 summarizes the dose-delivery changes for organs at risk and PTVP.

The PTVP dose coverage was significantly changed (p<0.001), with the highest D98 being for the A1 plan, with a median dose of 6490(6130-6600) cGy, followed by the A5 plan, with a median dose of 6470(6320-6620) cGy.

In contrast, the value of D2 was better for A5 than for A1, with median doses of 7380(7360-7400) cGy and (7350-7300-7360) cGy, respectively. Figure 1 (E and F) shows the changes in PTVP D2 and D98 for the eight plans, and Table 3 summarizes the dose-delivery changes for organs at risk and PTVP.

The CI significantly changed (p<0.001) for PTVP, where the best results among the eight plans were rendered by the A5 plan (Figure 1 (G)) with a median CI value of 0.73(0.71-0.75).

Further, HI changed significantly (p<0.001) for the PTVP, where the best results among the eight plans were for the A5 plan (Figure 1 (H)) with a median HI value equal to 1.09(1.07-1.11).

Also, DGI changed significantly, with the best result for the A5 plan with a median DGI value of 13.2 (7.3-19.9). Table 4 summarizes the changes in CI, HI, and DGI for the eight VMAT plans.

Tab. 1. Dose constraints for some organs at risk in the head and neck

Organs at risk	Dose constraints in (Gy)	Reference
Brainstem	D_{max}≤54 Gy	13, 14, 15
Spinal cord	D_{max}≤45 Gy	16
Optic chiasm	D_{max}≤54 Gy	17
Optic nerve	D_{max}≤54 Gy	17
Eye	D_{max}≤45 Gy	18
Mandible	D_{max}≤72 Gy	19
Parotid	D_{mean}≤20 Gy (contralateral)	20
Lens	D_{max}<10 Gy	21

Tab. 2. Median monitor units and delivery time per fraction for the eight VMAT plans

Endpoint median[25th,75th]	A1	A2	A3	A4	A5	A6	A7	A8	P value
Monitor units (MU)	833 [782-873]	584 [541-616]	482 [432-512]	473 [429-486]	809 [658-883]	615 [549-657]	502 [460-562]	479[446-504]	<0.001
Delivery time (sec)	126 [118-132]	125 [120-133]	119 [116-130]	124 [116-129]	181 [173-187]	157 [145-180]	155 [138-166]	152 [147-159]	<0.001

Tab. 3. Dosimetric changes for OARs and target for the eight VMAT plans

Endpoint median [25th,75th] in Gy	A1	A2	A3	A4	A5	A6	A7	A8	P value
Spinal cord maximum dose	41[40-42]	41[40-43]	40[39.5-42]	41[40-43]	40[39.9-42]	39.7[39-41]	41[40-42]	41[40-42]	>0.001
Brainstem maximum dose	49.8[47.6-51.8]	50.3[49.6-51.4]	50.9[50-51.3]	50[49.8-51.3]	50.3[48.7-50.4]	50.2[48.6-50.3]	51.5 [49.352.3]	51.5[49.9-51.7]	>0.001
Optic chiasm maximum dose	46.7[38.5-48]	42.9[41.3-45.2]	41[39.6-41.9]	40.6[37.9-43.6]	41.3[39.9-43.3]	44[39.5-47.9]	44.2[38.9-47.3]	39.9[34.7-42.1]	>0.001
Left optic nerve maximum dose	52[47.9-52.6]	45[43-51.3]	44.3[42.8-49.2]	44[42.7-50.9]	52.4[46-53]	51.9[47.1-52.2]	47.8[43.5-52]	43[37.9-47.1]	>0.001
Right optic nerve maximum dose	51.6[47.4-52.4]	45.5[43-51.4]	43.8[43-49.2]	44.4[42.4-50.8]	49.8[46.6-53]	49.8[46.4-52.1]	46.7[40.7-52]	42.3[39-47.2]	>0.001
Left eye maximum dose	27.2[25.2-36]	26[25-33.5]	32.2[26.2-33.3]	32.6[26.6-37.5]	35.7[29.2-37.8]	35.1[22.4-38.5]	36.7[22.3-40.2]	33.8[22.5-36.5]	0.02
Right eye maximum dose	30.7[15.9-33.7]	30[13.9-33.2]	26.9[14.2-34.9]	29.3[15-32.1]	27.9[12.1-38.1]	30.7[15.7-38.8]	25.9[13-36.3]	30.1[12.6-37.2	0.1
Left lens maximum dose	6.2[3.4-8]	6.5[4.3-8.3]	6[4.8-8.8]	6.1[4.2-8.2]	6.2[3.9-8.9]	6[4.8-9.6]	6.2[4.6-9.7]	6.1[4.2-8.6]	0.25
Right lens maximum dose	6.6[4.5-9.6]	6.5[4.4-9.9]	6.2[5.1-10]	6.6[4.2-9]	6.6[4.1-9.4]	6.7[5.2-9.5]	6.2[5.2-9.6]	6.1[3.9-10.3]	0.2
Mandible maximum dose	67.5[66-68.6]	66.7[65.1-67.3]	66.6[64.5-67.2]	65.2[63-67.1]	67.7[66.8-69.3]	67.2[66-67.9]	66.1[65.4-67]	65.2[64-66.1]	>0.001
Left parotid mean dose	25.1[23.4-27.2]	25.9[23.4-30.5]	25.3[22.7-30.3]	25.1[22.5-30.2]	25.7[23.2-30.5]	26[22.6-30.6]	25.1[21.7-30.5]	25[21.8-29.8]	>0.001
Right parotid mean dose	29[26-34.1]	27.2[25.9-5]	27.2[25.5-31.9]	26.7[25.4-30]	26.8[24.8-28.9]	27.5[25-33]	27.3[25-33]	26.5[24.8-29.1]	0.01
PTVp D2	73.8[73.6-74]	74[73.3-74]	73.5[73.2-73.6]	73[73.2-73.6]	73.5 [73.48-74]	73.8[73.6-74]	73.8[73.1-74.1]	73.6[73-74]	0.07
PTVp D98	64.9[61.3-66]	62.9[58.7-65.4]	61.7[56.6-61.7]	59.4[54.2-64]	64.7[63.2-66.2]	62.8[61.1-66.6]	61.6[59.6-65.5]	59.8[56.7-64.8]	<0.001

Tab. 4. CI, HI, and DGI changes for the eight VMAT plans

Endpoint median [25th,75th]	A1	A2	A3	A4	A5	A6	A7	A8	P value
Conformity index CI	0.69[0.61-0.71]	0.62[0.51-0.68]	0.49[0.36-0.53]	0.26[0.23-0.46]	0.73[0.71-0.75]	0.69[0.63-0.71]	0.53[0.49-0.63]	0.41[0.29-0.56]	<0.001
Homogeneity index HI	1.1[1.07-1.12]	1.12[1.09-1.16]	1.14[1.11-1.19]	1.16[1.12-1.22]	1.09[1.07-1.11]	1.11[1.08-1.14]	1.14[1.1-1.15]	1.17[1.11-1.21]	<0.001
Dose gradient index DGI	13.7[7.6-21.5]	14.2[10.1-24.6]	15.3[12.2-27.7]	17.3[16.3-28.7]	13.2[7.3-19.9]	14.3[7.7-22.8]	15.6[9.2-23.1]	18.4[15.3-28.8	<0.001

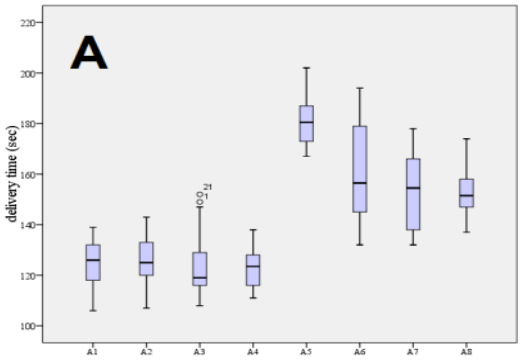

Fig. 1 (A). Delivery time per fraction for the eight VMAT plan techniques

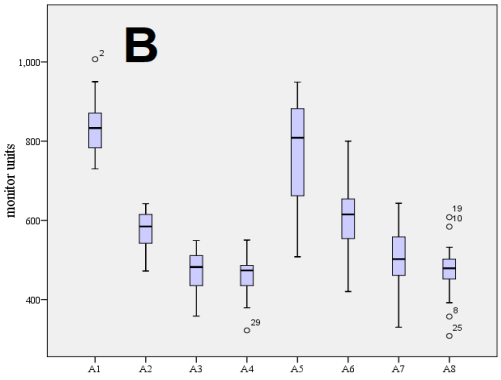

Fig. 1 (B). Monitor units per fraction for the eight VMAT plan techniques

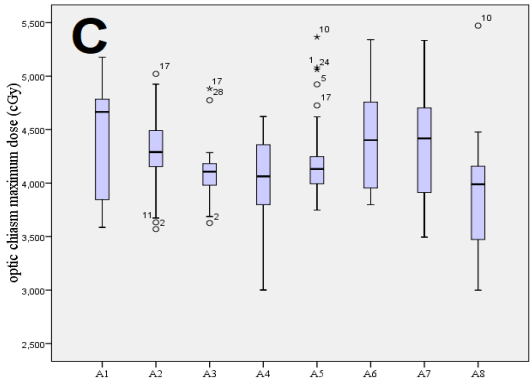

Fig. 1 (C). Maximum dose changes for the optic chiasm for the eight plans

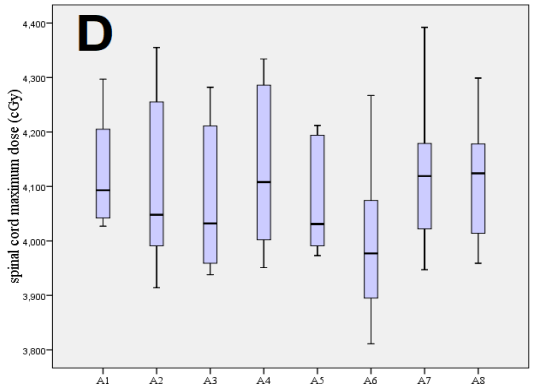

Fig. 1 (D). Maximum dose changes for the spinal cord for the eight plans

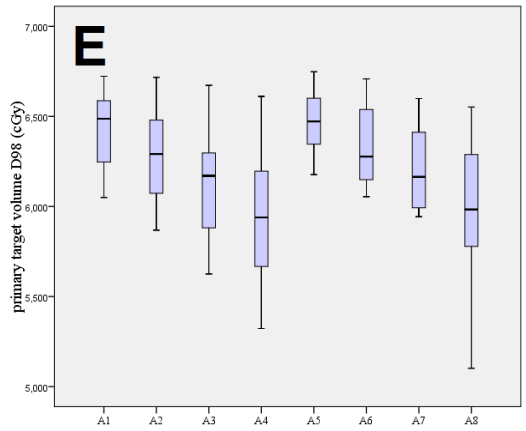

Fig. 1 (E). PTVP D98 dose changes for the eight plans

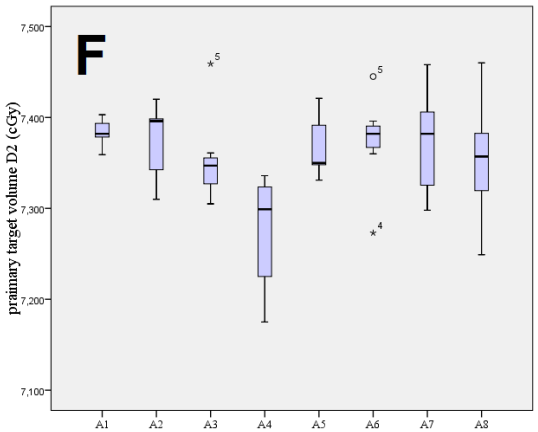

Fig. 1 (F). PTVP D2 dose changes for the eight plans

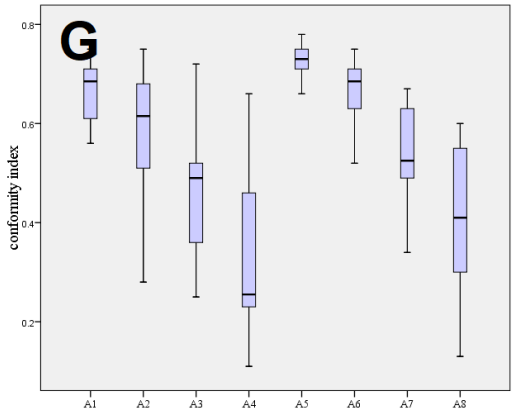

Fig. 1 (G). Changes in the conformity index (CI) for the eight VMAT plans

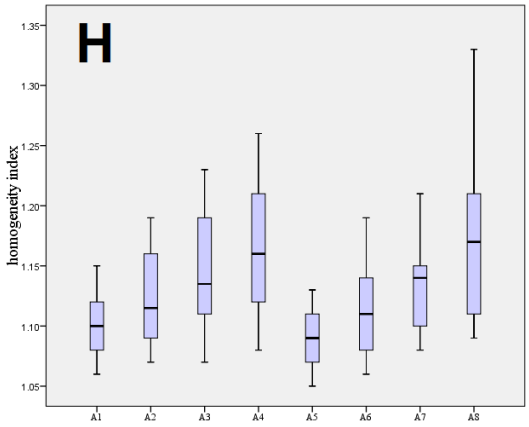

Fig. 1 (H). Changes in the homogeneity index (HI) for the eight VMAT plans

DISCUSSION

Radiotherapy, with or without chemotherapy, is the major treatment modality for patients with nasopharyngeal carcinoma. VMAT is one of the most effective treatment techniques for this type of cancer because of the complex shape of the target and the large number of small critical structures surrounding it [13-20].

Therefore, it is complex to optimize the plan regarding the best dose coverage of the target and accurate dose sparing to the organs and may require high and tight constraints, which can be achieved by selecting a proper segment width and the number of arcs [21].

Simultaneously, choosing a small segment width and increasing the number of arcs to reach the optimum plan will increase the number of MUs and the treatment time [20].

In our study, the best target coverage was observed for plans A1 and A2, with A1 being the best, which is in disagreement with a previous study that showed that the use of the dual arc technique in nasopharyngeal cancers increased the target coverage [22].

Evidently, the recommended plans for head and neck cancers are those with a minimum segment width of 0.5 cm. This is due to the small critical organs surrounding the target, which can be protected by obtaining a sculpted dose around the target and simultaneously producing a high dose gradient between the target and organs at risk, which can be achieved by creating small segments.

Although small segments are advantageous in treating nasopharyngeal cancers, they may affect the plan delivery accuracy [23], thus, a stringent verification of the dose should be performed before treatment.

The delivery time may affect the treatment delivery accuracy. Li et al. showed that the average leaf speed significantly affects dose delivery accuracy [24]. For the A1 and A2 plans, the delivery time per fraction was significantly shorter for the A1 plan because the time needed to deliver a single arc was shorter than that of a dual arc. By contrast, the MUs were greater for A1 than for A2.

CCI and HI are essential for evaluating any plan that may affect clinical outcomes. An undesirable overdose can be generated outside the target (PTVP), causing the dose to exceed the tolerated dose for healthy organs [25].

In our study, the CI for PTVP was improved for A1, and A2 plans, with more efficiency for the A2 plan, with a median CI value equal to 0.73(0.71-0.75). Notably, the value of CI is not ideal because the plan was done using the simultaneous integrated boost (SIB) technique with three different doses for three targets at the same time.

Evidently, the value of CI is affected by the segment width; the smaller the segment width, the better dose conformity around the target. This is in agreement with the study by Hong et al., who showed that a plan with minimum segment width of 0.5 cm for esophageal cancer had the best CI [26].

Also, the HI had the best value for the A2 plan with a median

value equal to 1.09(1.07-1.1), followed by the A2 plan with a median value of HI 1.1(1.07-1.12).

The best value of HI for a segment width of 0.5 cm implies that the dose inside the target is homogenous. This is due to the large number of segments that can help the planning system to make a complex intensity map to distribute the dose homogenously to the target. In contrast, a large segment width will decrease the ability to make the desired dose distribution as was observed with plans A3, A4, A7, and A8, where the minimum segment widths were 1.5 cm and 2 cm.

In addition, changes in the dose gradient index in patients with head and neck cancer reportedly affect the high-dose gradient area at the target border. This leads to a significant increase in the dose delivered to the organs at risk [27].

The dose gradient index value was very low for all plans because, with the SIB technique, there were multiple targets near each other. Therefore, a steep dose gradient could not be achieved. The DGI had the best value for the A5 plan, followed by the A1 plan.

CONCLUSION

For patients with nasopharyngeal carcinoma treated with the SIB-VMAT planning technique, using a minimum segment width > 1 cm is infeasible. The planning system cannot achieve planar constraints regarding the target coverage. Thus, plans with a minimum segment width of 0.5 cm and single or double arcs can achieve the desired target coverage and spare the surrounding healthy organs.

DISCLOSURE

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