Evaluation of target autocrop function in nasopharyngeal carcinoma SIB IMRT plan

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Abstract
A new target autocrop function was introduced in the Varian Eclipse™ treatment planning software (version 15.5 above) (Lohynská in Klin Onkol 33(4):288–294, 2020). The study aimed to evaluate this new target autocrop impact on nasopharyngeal carcinoma (NPC) plan quality and delivery efficiency. Randomly 66 approved NPC simultaneous integrated boost (SIB) intensity-modulated radiation therapy (IMRT) treatment plans were retrospectively studied. The manual cropping-based plans served as reference and were designed using sliding-window IMRT. Reference plans were re-optimized with identical plan parameters following the institutional clinical protocol, except for the redundant optimization objective of the manual cropping targets deleted. Additionally, each target within 5 mm of another had one minimum objective at 100% volume and one maximum objective at 0% volume for the autocrop plans. Plan quality was assessed based on selected parameters, including TCP (tumor control probability), NTCP (normal tissue complication probability), conformality index (CI), homogeneity index (HI), and dose-volume characteristics. Additionally, the delivery efficiency, the total plan treatment time defined as a sum of monitor units (MUs) for each treated field, and delivery accuracy, γ passing rate of treatment plan quality assurance (QA) also were compared. Both the manual cropping plans and the autocrop plans could be approved by an experienced oncologist. Overall, the autocrop plans could provide approximately a 13% reduction in linac MU while maintaining comparable plan quality, radiobiological ranking, and accuracy to the manual cropping plans. The new target autocrop tip facilitated the SIB IMRT plans for nasopharyngeal cancer patients. The autocrop could guarantee the quality and delivery accuracy of the radiotherapy plan and improved the planning efficiency, treatment efficiency, and reduced machine wear and tear. It was a promising tool for optimal plan selection for NPC SIB IMRT.

Keywords Target autocrop · Plan quality · Dosimetric and radiobiological parameters · Delivery accuracy · Planning and treatment efficiency

Introduction
NPC is particularly prevalent in east and southeast Asia [1]. Treatment options include radiotherapy or chemotherapy, or a combination of both. NPC is highly sensitive to ionizing radiation, and radiotherapy is the mainstay treatment modality for non-metastatic disease. The widespread application of individualized IMRT strategy and advanced imaging-guided techniques have contributed to the improved survival with reduced toxicities [2–4].

Radiotherapy techniques have been progressed from conventional two-dimensional radiotherapy (2DRT) to three-dimensional conformal radiotherapy (3DCRT) and then to IMRT in the last two decades. Considered the complexity of the shape and configuration of tumor and lymph nodes in the target volume and the proximity of OARs, surgery is usually not feasible for the primary treatment of NPC. IMRT is the current preferred method [5, 6] and has better clinical outcomes in treatment plans for NPC patients, such as achieving more accurate target dose distribution and better protection of normal tissues [7–9].

At present, IMRT is mainly simultaneous integrated boost (SIB) IMRT, which allows for concurrent dose escalation to the primary tumor with multiple prescription doses during the optimization process, could conform to the tumor shape better and protect the normal tissue physically [10, 11]. The
planning target volume (PTV) includes several layering structures in the SIB-IMRT for NPC. Monaco® treatment planning systems (TPS) identifies the ownership of organ overlap region by ordering organs from top to bottom, using the parameter “optimize over all voxels in volume” and the optional physical parameters “shrink margin.” Conventionally, Pinnacle® and Eclipse TPS before version 15.5 handle the overlap organ region by the manual cropping and add the optimization objectives during the optimization phase by professionally trained medical dosimetrists and physicists by time and effort consuming steps.

Several variables affect the quality of the radiotherapy plan: patient anatomy, dosimetrist’s experience, plan objectives, TPS optimization algorithm, etc. [12]. The new target autocrop function had been introduced in the Varian Eclipse TPS (version 15.6.06). The purpose of the study was to understand the impact to plan quality and delivery efficiency using the function target autocrop in Eclipse TPS.

## Materials and methods

### Patients and treatment planning

Approved 66 NPC patients with SIB IMRT plans were analyzed retrospectively, 16 of whom had high-risk lymph nodes. This study was approved by the medical ethics committee of second affiliated hospital of army medical university, PLA. (2021-Research No. 038-01).

Computer tomography (CT) images were acquired on a Philips Brilliance Big Bore CT scanner (Philips, Cleveland, OH, USA), the slice thickness was 3 mm. Nasopharynx gross tumor volume (GTVnx), lymph node gross tumor volume (GTVnd), clinical target volume (CTV1, CTV2) were delineated. CTVnd was obtained by GTVnd expansion when the lymph nodes were the high-risk region. CTV1 referred to the outward expansion of GTVnx by 0.5–1.0 cm in the anterior, the superior, the inferior, and the sides, and 0.3–0.5 cm in the posterior (the appropriate distance of outward expansion was determined by the tumor involvement and the distance between the tumor and the spinal cord, brainstem, and other tissue structures). CTV2 consisted of two parts. One was CTV1 enlarged by 0.5–1.0 cm in the anterior, the superior, the inferior, and the sides, and then enlarged by 0.3–0.5 cm in the posterior (the appropriate distance is determined according to the tumor involvement and the distance between the tumor and the spinal cord, brain stem, and other tissue structures). The other was GTVnd, its lymphatic drainage area, and the negative lymphatic drainage area requiring prophylactic irradiation. The planning target volumes were created based on target volume with an additional 3 mm margin, considering setup inaccuracy.

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The prescription dose to GTVnx, GTVnd, CTV1, CTV2 were 69–72 Gy, 60–70 Gy, 60–64 Gy, 50–56 Gy in 30–33 fractions, respectively. When the lymph nodes were the high-risk region, the prescription dose to GTVnx, GTVnd, CTV1, CTV2 were 70 Gy, 66–70 Gy, 60 Gy, 60 Gy, 54 Gy in 33 fractions, respectively. Critical organs at risk were also contoured by the certified oncologist, including the brain stem, spinal cord, lens, optic nerve, optic chiasma, parotid gland, and so on.

All IMRT plans were generated using the Eclipse planning system (Varian Medical System, Palo Alto, CA) with 120 MLC. The Anisotropic Analytical Algorithm (AAA, version 15.6.06) dose calculation algorithm was chosen for dose calculation using the dose calculation grid resolution of $0.25 \times 0.25 \times 0.25 \text{ cm}^3$. The treatment couch was not considered in the dose calculation. All cases used nine equally spaced beams for IMRT sliding window plans. The collimator rotation and jaw positions were optimized and fixed by the dosimetrists.

A new target autocrop function was introduced in the Varian Eclipse TPS, which was in the optimization interface like a black box to handle the overlapping targets volumes. The principle diagram was shown in Fig. 1. After activating the target autocrop function, TPS automatically identified the target volumes with contradictory doses objectives and overlapping areas, such as GTV and CTV in Fig. 1a, which required different prescription doses. Then, a 5 mm buffer ring between the GTV and CTV would be formed, and the optimization and calculation for the CTV would be carried out automatically according to the shaded area in Fig. 1b.

The manual cropping plans, which radiation oncologists had been accepted and approved, served as reference. The procedure for the manual cropping used in the reference plans corresponds with the autocrop. However, there were minor differences in the width of the buffer ring due to the physicists’ different experiences and preferences. Reference plans were re-optimized with identical planning optimization parameters and OAR constraints following the institutional clinical protocol except for the optimization objective of the manual cropping targets deleted. Additionally, each
target had one minimum objective at 100% volume and one maximum objective at 0% volume for the autocrop plans. Compared to the manual plans (original plan), the objectives of target volumes only retain one minimum objective at 100% volume and one maximum objective at 0% volume.

The difference between the reference (manual) plans and the autocrop plans included: (a) the width of the buffer ring. The manual plans may use different widths from the different physicists, while the autocrop used fixed 5 mm. (b) the optimization objective to target volume: the manual plans may have one minimum objective at 100% volume and one minimum objective at 95% volume, or had two minimum objectives at 100% volume due to different physicists. However, the autocrop plans only had one minimum objective at 100% volume and one maximum objective at 0% volume.

All plans were delivered on a Varian Trilogy linear accelerator, which adopted 6 MV photon and a sliding-window technique. The accelerator is equipped with a multi-leaf collimator containing 120 leaves, 80 5.0 mm central leaves, and 40 10.0 mm peripheral leaves.

**Plan quality evaluation**

The treatment plan was evaluated by multiple parameters, including target coverage criteria, normal tissue sparing criteria, biological parameters TCP and NTCP, treatment efficiency, and delivery accuracy. The paired t-tests were performed to assess statistically significant differences (p < 0.05).

In terms of target coverage criteria, PTV dose-volume histogram (DVH) parameters, including $D_{2\%}$, $D_{98\%}$, $D_{\text{mean}}$, HI (homogeneity index), CI (conformal index), were computed and recorded with the ICRU83 report [13], defined as follows:

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{\text{mean}}}$$

$$CI = \frac{TV_{RI}}{TV} \times \frac{TV_{RI}}{V_{RI}}$$

where $RI$ represents the prescribed dose, $TV_{RI}$ is the volume of target covered by prescribed dose, $TV$ is the target volume, and $V_{RI}$ is the volume of the body covered by the prescribed dose. Variables were assessed for organs at risk (OARs), including mean dose ($D_{\text{mean}}$), maximum dose (or point in a significant volume, $D_{\text{max}}$ or $D_{p}$), volume receiving a fixed-dose level, and dose levels delivered to a certain volume.

Radiation biological parameters tumor control probability (TCP) and normal tissue complication probability (NTCP) was calculated from the extracted differential dose volume histogram (DVH) data based on the Niemierko model [14, 15].

The equivalent uniform dose (EUD) was calculated by [16]:

$$EUD = \left( \sum_{i=1}^{N} n_i D_i \right)^{\frac{1}{\alpha}}$$

where $V_i$ is fractional volume, $D_i$ is dose bin, and $\alpha$ value is the tumor normal tissue-specific parameter that describes the dose-volume effect. For NPC cases, the “$\alpha$” value is -13 [11, 17]. The TCP could be calculated based on the equivalent uniform dose [15]:

$$TCP = \frac{1}{1 + \left( \frac{TCD_{50}}{EUD} \right)^4 r_{50}}$$

where $TCD_{50}$ is the tumor dose required for producing 50% TCP and $r_{50}$ is the slope of the dose response at 50% TCP. Okunieff et al. [18] reported that tumor-specific parameters for head and neck squamous cells (macroscopic) were $TCD_{50} = 51.77$ Gy, $r_{50} = 2.28$. Also, the NTCP is determined below:

$$NTCP = \frac{1}{1 + \left( \frac{TD_{50}}{EUD} \right)^4 r_{50}}$$

where $TD_{50}$ is the dose at which probability of complication becomes 50% in 5 years and $r_{50}$ is the slope of the sigmoidal dose response curve of normal tissue at 50% complication probability. These specific parameters given for normal tissue were based on the reports of Emami et al. [19] and Burman et al. [20] (Table 1).

The dose delivery efficiency of each plan was evaluated based on the total number of MU, which were compared between the autocrop plan and the manual cropping plan. Additionally, the agreement of the planning and delivered doses was assessed by studying the patient-specific QA results. The QA of the auto-crop plan and the manual cropping plan was performed with the two-dimensional dose

| Structure | Endpoint | $\alpha$ | $r_{50}$ | $TD_{50}$ (Gy) |
|-----------|----------|---------|---------|----------------|
| Brainstem | Necrosis | 7       | 3       | 65             |
| Spinal cord | Myelitis/necrosis | 7.4 | 4 | 66.5 |
| Optic chiasm | Blindness | 25 | 3 | 65 |
| Optic nerve | Blindness | 25 | 3 | 65 |
| Lens | Cataract | 3 | 1 | 18 |
| Parotid | Xerostomia | 5 | 6 | 46 |
verification equipment PTW seven29 [21], and the gamma passing rates were compared. The criteria for gamma analysis was 3%/3 mm, with a 10% dose threshold.

**Result**

A total of 132 clinically acceptable IMRT plans were achieved for all 66 cases. For each patient case, two IMRT plans were generated with different target crop methods: manual cropping and autocrop, respectively. The manual cropping and autocrop methods were sufficient to produce highly conformal treatment plans for NPC cases to meet the treatment goals. On average, the two types of plans provided comparable plan quality in terms of target dose coverage, dose homogeneity, and critical structure sparing. Additionally, the radiation biological parameters TCP and NTCP only had subtle differences (p < 0.05).

The average planning target volume of all these patients whose lymph nodes were the low-risk region was shown in Table 2 for PGTVnx, PGTVnd(L), PGTVnd(R), PCTV1, PCTV2, respectively. While the average planning target volume of all these patients whose lymph nodes are the high-risk region was shown in Table 3 for PGTVnx, PGTVnd(L), PGTVnd(R), PCTVnd(L), PCTVnd(R), PCTV1, PCTV2, respectively.

The detailed DVH statistical results on the plan quality index are summarized in Tables 2, 3, 4 and Fig. 2, 3. The mean HI values were within 0.15 and 0.20 for the manual cropping and autocrop plans, respectively (Fig. 4). Figure 5 shows the dose in color wash from the manual cropping and autocrop plans of a randomly selected case. There was no significant difference in the minimum dose, maximum dose, and mean dose for planning targets volume between the manual cropping and autocrop plans (p < 0.05). The mean HI and CI were statistically equivalent concerning the two target crop methods.

In this particular case (Fig. 5), the quality of the autocrop plans was almost equivalent to the manual cropping plan. The maximum dose, minimum dose, and mean dose of PGTVnx in the autocrop plan decreased by 0.38%, 0.71%, and 0.39%, respectively. Additionally, for the lymph nodes PGTVnd(L) and PGTVnd(R) in the autocrop plan, the maximum dose, minimum dose, and mean dose increased by 1.80%, 0.22%, 1.13% and 1.69%, 0.05%, 0.94%, respectively. For the planning clinical target volume PCTV1 and PCTV2, the difference of the maximum dose, minimum dose, and mean dose between the two type plans were 0.31%, −0.55%, −0.24%, and 0.28%, −0.47%, −0.68% respectively. The doses to the OARs were slightly increased but are well below the normal tissue limit. The CI of PCTV2 decreased from 0.92 (the manual cropping plan) to 0.88 (the autocrop plan). Both types of plans had similar dose distributions in the color wash, except the 40 Gy dose color wash of the manual cropping plan was slightly more compact than that of the autocrop plans. However, both dose distributions were considered good results in clinical practice.

The maximum, D1, mean, and Vx values of DVH parameters showing OAR sparing of the manual cropping and autocrop plans for 66 cases are shown in Table 4. The average

### Table 2

| Structures  | Volume [cm³] | Dose volume index | Avg. ± SD | Range D | Avg. ± SD | Range D |
|------------|--------------|-------------------|----------|----------|----------|----------|
|            |              | D_M                 |          | D_A                  |          |
| PGTVnx     | 65.61 ± 36.77| D90% [Gy]          | 71.00 ± 1.55 | 71.07 ± 1.24 | 63.49–73.47 | 66.05–74.58 |
|            |              | D2% [Gy]           | 75.32 ± 0.98 | 74.83 ± 0.97 | 72.22–78.02 | 72.29–78.15 |
|            |              | Dmean [Gy]         | 73.63 ± 0.82 | 73.26 ± 0.74 | 70.77–75.75 | 70.80–74.83 |
| PGTVnd(L)  | 16.30 ± 17.73| D90% [Gy]          | 65.36 ± 3.06 | 66.74 ± 3.40 | 59.23–70.90 | 59.16–71.17 |
|            |              | D2% [Gy]           | 68.23 ± 3.31 | 69.92 ± 3.82 | 62.25–73.13 | 62.97–75.45 |
|            |              | Dmean [Gy]         | 66.95 ± 3.10 | 68.42 ± 3.50 | 61.50–72.24 | 62.09–72.78 |
| PGTVnd(R)  | 17.20 ± 19.32| D90% [Gy]          | 65.56 ± 2.78 | 65.68 ± 2.64 | 60.24–71.04 | 61.42–71.32 |
|            |              | D2% [Gy]           | 68.23 ± 2.92 | 68.27 ± 2.94 | 61.99–73.19 | 63.25–74.39 |
|            |              | Dmean [Gy]         | 67.02 ± 2.80 | 67.31 ± 2.77 | 61.31–72.27 | 62.60–72.94 |
| PCTV1      | 163.16 ± 112.28| D90% [Gy]         | 62.09 ± 1.34 | 62.42 ± 1.60 | 59.56–65.15 | 58.38–65.56 |
|            |              | D2% [Gy]           | 75.08 ± 0.97 | 74.60 ± 0.95 | 71.85–77.82 | 72.25–77.02 |
|            |              | Dmean [Gy]         | 70.00 ± 1.54 | 70.29 ± 1.38 | 65.02–72.31 | 65.15–72.95 |
| PCTV2      | 625.98 ± 153.03| D90% [Gy]         | 54.50 ± 1.58 | 54.58 ± 2.03 | 49.85–58.91 | 50.06–62.25 |
|            |              | D2% [Gy]           | 74.44 ± 0.97 | 74.07 ± 0.93 | 71.28–77.04 | 71.66–76.28 |
|            |              | Dmean [Gy]         | 62.07 ± 1.68 | 63.61 ± 2.21 | 58.31–66.29 | 59.69–70.38 |
|            |              | CI                 | 0.91 ± 0.04 | 0.90 ± 0.04 | 0.80–0.98 | 0.83–0.98 |
maximum doses of the brain stem, lens, and right optic nerve were slightly increased in the autocrop plans, and the spinal cord maximum dose, parotid mean dose, and V30 were more increasing, while the increase was all within 3%. The average maximum doses of the optic chiasm and left optic nerve were insignificant decreased in the autocrop plans (p = 0.03).

Table 5 summarizes the results in terms of the number of MUs for fraction and γ passing rate (3%, 3 mm) averaged for the 66 cases. Compared to the manual cropping plans, the autocrop plans achieved a 12.9% relative decrease in the mean number of MUs (1412 MU vs. 1230 MU). Compared to the manual cropping plans, the mean integral MU of the autocrop plans decreased by 6006 MU (46596 MU vs. 40590 MU) for 33 fractions delivery. Additionally, reducing the integral MU by that much could reduce the risk of associated second malignancy, which could be determined through long-term follow-up. All 132 plans passed our institutional IMRT QA standard (γ passing rate ≥ 90%). A comparable agreement between the planned and delivered doses (insignificant difference γ passing rate) was found for the two methods. The average γ passing rate of the manual cropping plans was 97.7 ± 2.2% (range: 91.6–99.8%) compared to the autocrop plans 98.2 ± 1.9% (range: 92.2–99.3%).

The biological parameters NTCP estimates for the critical organs at risk and the expected TCP values for the PGTVnx are quantified, as depicted in Table 6. The average EUD and TCP of the PGTVnx were 64.28 ± 2.22 Gy, 87.36 ± 3.36% for the manual cropping plans, while 64.00 ± 2.09 Gy, 86.97 ± 3.21% for the autocrop plans. The average EUD for OARs in the autocrop plans was a slight increase compared to the manual cropping plans. The average NTCP for the Optic chiasm slight decreased: the manual cropping plan was 1.14 ± 2.17%, and the autocrop plan was 1.08 ± 2.14%. The average NTCP for left and right lens remained the same: 0.02 ± 0.05%, 0.02 ± 0.08% in the manual cropping plans, while 0.02 ± 0.06%, 0.02 ± 0.08% in the autocrop plan, separately. The average NTCP for the brain stem (1.85 ± 2.28% to 2.00 ± 2.37%), spinal cord ((1.42 ± 2.85) × 10−3% to (2.07 ± 4.13) × 10−3%), left parotid (0.65 ± 1.70% to 0.94 ± 2.21%) and right parotid (0.57 ± 1.23% to 0.92 ± 1.84%) were slightly increase compared to the manual cropping plans (p < 0.05).
Discussion

The SIB IMRT allows for concurrent dose escalation to the primary tumor with complex multiple level prescription doses during optimization. However, it makes treatment planning more difficult and complex. The traditional manual cropping target is a tedious job in the Eclipse TPS. A simple autocrop target method is suggested in this study to take some of the clinical load off.

Planning target quality indices indicated that there was a slight difference with different target crop methods in the EUD, TCP, NTCP, $D_{\text{min}}$, $D_{\text{max}}$, $D_{\text{mean}}$, HI, CI for SIB IMRT plans. Planning studies are often subjected to uncertainties from the different treatment planning conditions (optimization parameters and objectives), so an effort is made to minimize these effects by selecting the same parameters. We expected the minuscule decreased plan quality for the autocrop method because the new autocrop plan was just a re-optimization based on the approved manual cropping plan clinically and without more optimization and calculation to keep the optimization conditions consistent. However, the autocrop plans also were considered clinically acceptable and excellent by an experienced oncologist.

Table 4 OAR sparing comparison between the autocrop and manual-crop plans for all patients

| OARs       | Parameters | Avg. ± SD | Range     |
|------------|------------|-----------|-----------|
|            | $D_{\text{M}}$ | $D_{\text{A}}$ | $D_{\text{M}}$ | $D_{\text{A}}$ |
| Brain stem | $D_{\text{max}}$ [Gy] | 56.14 ± 7.60 | 56.29 ± 7.04 | 37.16–68.06 | 39.18–68.75 |
|            | $D_{1}$ [Gy] | 50.99 ± 7.04 | 51.66 ± 6.42 | 36.03–62.38 | 36.60–62.51 |
| Spinal cord | $D_{\text{max}}$ [Gy] | 34.58 ± 2.88 | 35.60 ± 2.81 | 31.25–44.90 | 31.87–45.09 |
|            | $D_{1}$ [Gy] | 32.40 ± 2.33 | 33.13 ± 2.52 | 29.78–42.59 | 28.24–42.39 |
| Optic chiasm | $D_{\text{max}}$ [Gy] | 43.81 ± 17.05 | 43.13 ± 17.19 | 6.28–70.18 | 6.24–70.94 |
|            | $D_{1}$ [Gy] | 41.88 ± 17.47 | 41.63 ± 17.26 | 5.79–67.39 | 5.84–68.28 |
| Optic nerve L | $D_{\text{max}}$ [Gy] | 42.00 ± 18.01 | 41.74 ± 17.65 | 7.85–75.36 | 7.49–74.78 |
|            | $D_{1}$ [Gy] | 40.01 ± 18.15 | 40.14 ± 17.68 | 7.15–74.91 | 6.78–74.57 |
| Optic nerve R | $D_{\text{max}}$ [Gy] | 43.63 ± 17.36 | 43.17 ± 17.35 | 6.78–72.14 | 6.75–70.18 |
|            | $D_{1}$ [Gy] | 41.60 ± 17.43 | 41.49 ± 17.34 | 6.20–70.44 | 6.18–68.69 |
| Len L      | $D_{\text{max}}$ [Gy] | 6.89 ± 2.59 | 7.01 ± 2.53 | 2.00–14.88 | 2.00–14.88 |
|            | $D_{1}$ [Gy] | 6.69 ± 2.58 | 6.74 ± 2.45 | 1.97–14.78 | 1.98–14.41 |
| Len R      | $D_{\text{max}}$ [Gy] | 7.22 ± 2.78 | 7.30 ± 2.93 | 2.02–19.06 | 2.04–21.19 |
|            | $D_{1}$ [Gy] | 7.00 ± 2.78 | 7.07 ± 2.84 | 2.01–18.93 | 2.02–20.51 |
| Parotid L  | $D_{\text{mean}}$ [Gy] | 25.16 ± 2.71 | 26.32 ± 2.67 | 18.73–31.24 | 19.76–31.85 |
|            | $V_{30}$ [%] | 19.46 ± 12.28 | 20.15 ± 12.66 | 2.71–31.24 | 2.76–31.87 |
| Parotid R  | $D_{\text{mean}}$ [Gy] | 25.34 ± 2.56 | 26.58 ± 2.72 | 17.59–30.18 | 18.10–31.87 |
|            | $V_{30}$ [%] | 18.92 ± 12.07 | 19.82 ± 12.73 | 2.56–30.18 | 2.72–31.87 |

$D_{\text{max}}$ is the maximum dose, $D_{1}$ is minimal dose to 1% of structure, $V_{30}$ is the volume that received 30 Gy dose. “rel.” represents relative value. “M” and “A” represent the manual-crop and the autocrop plans, respectively.

Fig. 2 HI distribution for these NPC patients whose lymph nodes are the low-risk region

Fig. 3 HI distribution for these NPC patients whose lymph nodes are the low-risk region
What is surprising is the magnitude of the improvement in delivery efficiency of the autocrop plans compared to the manual cropping plans. A previous article [22] on SIB NPC focused on Eclipse TPS (version 8.6) slide-window IMRT techniques, which mean MU of the ten cases enrolled was 1537MU. The other two articles [23, 24] referred to the mean MU of SIB IMRT for NPC were 1288 and 1379, respectively. Dose prescriptions of that articles were set to 54 Gy with 1.63 Gy/fraction to PTV54, at 60 Gy with 1.81 Gy/fraction to PTV60, at 66 Gy with 2.00 Gy/fraction to PTV66, and at 70 Gy with 2.12 Gy/fraction to PTV70. These results were similar to the comparative study of these in the current article. In the study, the mean MUs for the two target crop methods were 1412 MU and 1230 MU, severally. The reduced MU of about an average of 182MU (12.9%) could potentially lead to less radiation dose transmitted through the MLC and a meaningful decrease in linac burden. Besides, the shorter delivery time increases machine throughput and is also favorable for patients for yielding reduced intrafraction motion, increased patient comfort, especially for patients who cannot remain stable on the treatment couch for a long time.
The in-depth reason the autocrop plans give lower MU may be explained as follows: The structures of the radiotherapy target volume in nasopharyngeal carcinoma are complex, and there are at least two to three overlapping areas. The width of the manual-crop buffer ring, given optimization objectives, and personal expertise and experiences influence the quality of plans. If the width of the manual-crop buffer ring is judged improperly or/and the given optimization objectives are not good, it will increase the optimization difficulty of the radiotherapy plan. The treatment planning system solves this "problem" by increasing the number of small area segments to increase the number of MU as a whole. If the new target autocrop function is adopted, the above problem may not be encountered.

To the best of our knowledge, it is the first article on the dosimetric and radiation biological comparison between the target autocrop and manual cropping methods for radiotherapy treatment of SIB NPC in the Eclipse TPS. The comparison and evaluation of the radiotherapy plan are commonly based on the three-dimensional dose distribution and DVH indices [25–28]. Besides, the radiobiological ranking by calculating indices EUD, TCP, and NTCP is also applied widely [29–32]. A previous paper [11] proposed a composite plan quality index integrated dosimetric and radiobiological quality indices. In our study, both dosimetric and radiobiological quality indices were considered, respectively. The differences in all the indices between the two crop methods were small. Kim et al. [33] investigated out that the mean TCP of the tumor GTV for head and neck IMRT was about 89.5%, which was a similar result in our study.

In brief, each plan was evaluated rigorously using the dosimetric parameters, radiobiological parameters, and gamma passing rate. All parameters results were deemed acceptable for the manual cropping and autocrop plans suggesting that the autocrop plans can be dosimetrically and radiobiologically equivalent to the manual cropping plans and a faster and equally effective treatment delivery offered to patients. Our study had a potential limitation: all the autocrop plans were re-optimized only once to keep the optimization objectives constant. According to our previous experience in making plans, it is not easy to optimize the plan only once to achieve the best results, especially for nasopharyngeal carcinoma. A slight adjustment of the optimization objectives can make the plan more perfect. In the future, the target autocrop function will be used for the radiotherapy plan directly and investigated the plan quality compared to the manual cropping one.

### Conclusion

A new target autocrop function was evaluated in this study to facilitate the SIB IMRT plans for nasopharyngeal cancer patients. The introduction of the tip can not only guarantee the quality and delivery accuracy of the radiotherapy plan but also make the operation simpler, improve the treatment efficiency, reduce the dosimetrist's intervention, and machine wear and tear. It will be a promising tool for optimal plan selection for NPC SIB IMRT.

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### Declarations

**Conflict of interest**  Author xiaojuan duan declares that she has no conflict of interest. Author lu chen declares that she has no conflict of interest. Author yibing zhou declares that he has no conflict of interest.

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**Table 6** The EUD values, NTCP estimates for OAR, and the expected TCP values for target volume concerning two crop methods

| Target | EUD [%] | TCP [%] or NTCP [%] |
|--------|---------|---------------------|
|        | Manual-crop plans | Autocrop plans | Manual-crop plans | Autocrop plans |
| PGTVnx | 64.28 ± 2.22 | 64.00 ± 2.09 | 87.36 ± 3.36 | 86.97 ± 3.21 |
| Brainstem | 43.38 ± 6.01 | 44.23 ± 5.71 | 1.85 ± 2.28 | 2.00 ± 2.37 |
| Spinal cord | 31.75 ± 2.18 | 33.43 ± 2.42 | (1.42 ± 2.85) × 10^-3 | (2.07 ± 4.13) × 10^-3 |
| Optic chiasm | 33.38 ± 14.44 | 33.43 ± 14.23 | 1.14 ± 2.17 | 1.08 ± 2.14 |
| Optic nerve L | 29.99 ± 14.41 | 30.99 ± 13.93 | 0.64 ± 1.59 | 0.74 ± 1.95 |
| Optic nerve R | 31.54 ± 13.78 | 31.85 ± 13.71 | 0.65 ± 1.52 | 0.79 ± 2.11 |
| Len L | 1.53 ± 0.76 | 1.55 ± 0.74 | 0.02 ± 0.05 | 0.02 ± 0.06 |
| Len R | 1.59 ± 0.77 | 1.59 ± 0.75 | 0.02 ± 0.08 | 0.02 ± 0.08 |
| Parotid L | 33.47 ± 4.58 | 34.08 ± 5.05 | 0.65 ± 1.70 | 0.94 ± 2.21 |
| Parotid R | 33.95 ± 4.11 | 34.71 ± 4.21 | 0.57 ± 1.23 | 0.92 ± 1.84 |
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Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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